Transition to Solar Energy Using Rooftop of Public Buildings in Palestine

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Abstract. This paper presents a study for (20 kWp) grid-connected solar PV systems installed on the roof top of municipalities in different cities in Palestine, using actual monitored data that extracted from project portal and compare the result with PV-syst software result which provide a comprehensive study of the system design and detailed analysis for performance of systems under a local climate conditions. The supplied grid energy and main performances are described, and the effects of losses of the inverter to the grid have been studied. The performance, CUF and yield parameters were studied using the monitored data of year 2018 in different location at west bank. The PV system generated 36.2 MWh in average during the year 2018. The average final yield ranged from 5.35-5.5 kWh/kWp-day, PR ranged from 74-89% and annual CUF varies between 16 - 20%. The findings from this study are useful in identifying solar performance and provide useful information to policy makers and individuals about the performance of grid-tied PV system in different cities in Palestine.

Key words. Grid connected PV system, Performance indicators; Techno – economic feasibility, Municipalities, Palestine.

1. Introduction

Currently, Palestine suffering a lot at lack of conventional supply, this problem have forced government to think more deeply about the alternative sources of energy to substitute the conventional sources of supply. Solar PV now is a popular source of energy in Palestine, both on the utility's side and for roof top governmental, commercial and residential home use [1, 2]. Solar Photovoltaic (PV) systems is a good alternative and feasible solution for generating electricity in Palestine, especially for grid connected systems. The potential of solar radiation is about 5.4 kWh/m²/day with about 3000 sunshine hours a year [3]-[6]. PV-grid connected systems are worldwide installed because it allows consumer to reduce energy consumption from the electricity grid and to feed the excess energy back into the grid. The system does not contain battery; therefore the overall system cost and maintenance are very cheap comparing to other PV systems types [7].When planning to implement a new solar project , the requirements and the specifications of the photovoltaic panel are usually unclear, incomplete and not integrated with design process and if the project was implemented and errors are detected at this point is already too late, and in that case we have to re-design or make a very expensive tests in order to reduce negative results, so the performance evaluation of PV systems is an important measure to help identify the future needs of research , development and test the system before implementation to get an estimated results for operation and output. Using appropriate performance parameters facilitates the assessment of energy efficiency of PV systems connected to the grid which can be affected by design, technology used or geographic location. However, in order to ensure the safety of PV installer and reliability of the utility grid, the technical requirement for the grid and the PV system must be achieved to prevent any problems, such as harmonic distortion and electromagnetic interference [1].The need to choose PV modules and inverters have become necessary due to the diversity of technology and in order to determine the system behaviour, but knowing the extent of efficiency of the system is a very difficult, therefore, PV system can be evaluated by investigating the performance ratio (PR) which defined by ratio of the system efficiency and nominal efficiency of PV module under STC [8].In fact, growing the electricity generation by PV units is one of the highest in the field of renewable energies and this tendency is expected to continue in the next years. As obvious, an increasing number of new PV components and devices, mainly arrays and inverters are coming onto the PV markets. This paper aims to investigate the performance of 20 kWp that located in different location on rooftop of 7 municipalities buildings in different cities at West Bank - Palestine. The performance is studied during the monitored period of one year 2018. The PV system performance is characterized using different parameters: reference yield, final yield, capacity utilization factor, and system efficiency and performance ratio. Then the paper present a comparison between actual measured and predicted performance using PV simulation software as PVsyst, this study offers a baseline information to enhance Mono-crystalline PV performance and reduced cost.

2. Description of Solar PV Grid System

The seven 20 kWp grid-connected PV systems under investigation were installed on roof-top of seven

municipalities at West Bank - Palestine. Each system has 64 Mono-crystalline modules of 320 Wp to get overall installed capacity of 20.48 kWp, covering a total surface area in each building of 120 m2, and inclined at 32 degree toward the south. The PV modules are arranged to 4 parallel strings with 16 modules in each string and connected to two 3-phase inverters (Sunny Tripower 10000TL) to convert DC energy generated by PV array to AC energy as shown in Fig.1, 2. The inverter enclosure is IP65 which offer complete protection from particles and a good level of protection against water, so practically, it can install indoor and outdoor without affect the inverter operation. The installed inverter has maximum efficiency of 98%, with rated power 10 kW for 230V, 50Hz on AC grid side, Tables.1 and 2 show the specification of power plant.

Table 1. PV module specification

Number of panel	64
PV Brand	Amerisolar
model No.	AS-6M 320
Wp/panel	320 Wp
System capacity	20.48 kWp
Voltage at Maximum Power (Vmpp)	37.1
Current at Maximum Power (Impp)	8.63
Open Circuit Voltage (Voc)	45.7
Short Circuit Current (Isc)	9.00
Panel Efficiency (%)	16.49
Cell Type	Mono-crystalline
Panel dimension (m)	1.956×0.992×0.05m
Panel area (m2)	1.94
Panel weight (Kg)	27

Table 2. Inverter specification

System capacity	20 kW
Brand	SMA
Model No.	Sunny Tripower 10000TL
NO. of independent MPP inputs	2
DC MPPT Range/Input voltage range	370-800 V
Max input current (DC) / string	18 A/10 A
Rated AC power (W)	10,000
AC voltage range	160-280 V
Max output current	14.5 A
Efficiency (%)	97.6%
Weight	37 kg
No. of inverter per project site	2

Fig.1. PV system in Hebron municipality

Fig.2. Out-door Sunny Tripower Inverter

3. Performance Analysis of PV Systems in Different Cities

The performance of grid connected solar PV power plant was displayed in this paper in 2 stages:
(1) Manually extract the monitored data of power generation through remote monitoring system using online portal , (2) Compare the performance with PVsyst software result This performance parameters are developed by International Energy Agency (IEA) [9, 10], for analyzing the performance of solar PV grid interconnected system.

Array yield (YA)

Array yield of the system is the ratio of annual/monthly/daily energy output to the installed capacity of PV system.

$$Y_A = \frac{E_A}{P_\circ} \tag{1}$$

EA: Array DC energy yield per day
P°: Nominal power at STC

This parameter shows the time which operated by PV array per day

Reference yield (YR)

$$Y_R = \frac{H_t}{G\circ} \qquad (2)$$

Ht: total horizontal irradiance on array plane (Wh/m^2)
G°: Global irradiance at STC (W/m^2)

This parameter refers to number of peak sun hours

Final yield (YF)

The final yield or called yield factor (YF) is the ratio of the net AC energy of the system, at standard testing conditions, and the peak power of PV system installed [11], the net energy can be annual, monthly or daily and it is calculated as in Eq (3).

$$Y_F = \frac{E_{AC}}{P_{MAX,STC}} \qquad (3)$$

E_{AC}: AC Enegy yield of PV system
$P_{MAX,STC}$: Peak power of installed PV systrm at STC

Performance Ratio (PR)

Concerning the performance ratio (PR), it represents the ratio of energy fed to the grid (final yield) to the energy that the system could have produced when it operated at its rated conditions (STC) of $1KW/$ m2 (reference yield) [12]. PR represents the fraction of energy actually available after deducting energy losses. PR is given by Eq (4).

$$PR = \frac{Y_f}{Y_R} * 100\% \qquad (4)$$

Capacity utilization factor (CUF)

CUF is annual factor comparison between actual output and PV energy output if it is operated at full rated power for 24 hours all year [13]. This factor is used in assessing the PV array usage. The equation of capacity factor is shown in Eq (5).

$$CUF = \frac{Energy\ measured\ (kwh)}{365 * 24 * installed\ capacity\ of\ PV} \qquad (5)$$

Inverter efficiency (η inverter)

Inverter efficiency can be defined based on the amount of electrical DC power delivered to the inverter from the PV generator (PDC) and the AC power obtained from the inverter (PAC) [14]. The instantaneous inverter efficiency (η inv) is defined as the ratio of output to input power and calculated as in Eq (6).

$$\eta_{inverter} = \frac{P_{AC}}{P_{DC}} \qquad 6)$$

System efficiency (η (sys))

The system efficiency is calculated as in Eq(7).

$$\eta_{sys\ total} = \eta_{PV} * \eta_{inverter} \qquad (7)$$

This factor measures the conversion efficiency of inverter under operation condition.

Solar Fraction (SF)

The solar fraction is calculated as in Eq (8).

$$SF = \frac{Energy\ measured\ (kwh)}{site\ energy\ load\ (Kwh)} \qquad (8)$$

This factor measures how much energy the PV system will cover of load-penetration factor.

4. Results and discussion

The results of performance analysis of measured data for the seven PV systems are discussed in this section.
The monthly energy outputs result shows as indicated in Table.3 that the maximum energy output was in Baqa Alsharqia in April 2018 (3514 kWh/month) and minimum in February 2018 (1800 kWh/month) in Alittiharq municipality as shown in Fig.3. The annual overall system efficiency varies from 7- 23% as indicated in Fig.8.

Table 3. AC monitored energy yield at seven project location

|	Energy AC (kWh/month)						
M	Hebron	Nablus	Thaheriya	Qabalan	Baqa Alsharqia	Anata	Alittihad
1	2354.89	1983.509	2036.85	2268.81	2404.87	2484.87	2136.8
2	2688.55	2359.86	2626.94	2451.58	2680.92	2600.96	1800.23
3	2740.73	2499.309	2784.56	2689.80	3011.28	2961.7	2587.556
4	2557.56	2996.669	2690.31	3173.74	3513.87	3330.89	3145.714
5	2647.95	2905.519	3158.03	3164.97	3321.32	3376.44	3240.054
6	2427.17	3068.757	2809.26	3080.08	3074.47	3246.21	3140.4
7	2441.95	2990.89	2673.05	2965.95	3283.28	3165.98	2894.212
8	2376.33	2972.006	2525.10	3070.15	3212.79	3255.46	2415.592
9	3006.81	2835.877	3183.59	2632.75	2940.28	2895.57	2411.702
10	2845.13	2637.027	2963.41	2647.94	2768.04	3003.18	2840.128
11	2517.33	2124.988	2289.15	2344.67	2311.88	2445.79	2303.782
12	2443.48	1975.391	1850	2164.53	2638.43	2332.46	1817.79
Tot	31047.9	31349.8	31590.2	32655.0	35161.4	35099.5	30733.96
Max	3006.82	3068.757	3183.59	3173.74	3513.87	3376.44	3240.054
Min	2354.89	1975.391	1850.00	2164.53	2311.88	2332.46	1800.230
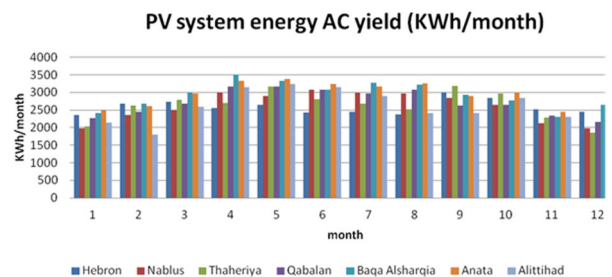
Fig. 3. PV system AC energy production

The annual average monthly performance ratio varies between 74%-89%, and CUF factor has minimum annual average monthly in Hebron (16.3%) and maximum value in Baqa alsharqia of 20.1% as shown in Fig.8.Regarding final yield and solar fraction, the result shows as in Fig.5 and Fig.7 that the highest final yield in all site were observed in summer due to clear sky in most of monthly day and the overall highest value of 5.719 kWh/kW was observed during April in Baqa Alsharqia, but the minimum PV system operated hours were mostly in December (winter season), and thus the penetration/solar factor of PV system is higher in summer in comparative to winter season because it depends on number of operated

PV system hours per day.The system performance changed due to weather, in cold weather the PR and system efficiency was observed and its value varies 85-92% due to lowest final yield and the maximum system efficiency was 16.3% and this due to low ambient temperature which prevent module to reach high temperature. But in summer, the operated hours of system has increased which cause the performance ratio to be low and reach 72-77%.Fig.4 shows the average system production versus solar irradiance.
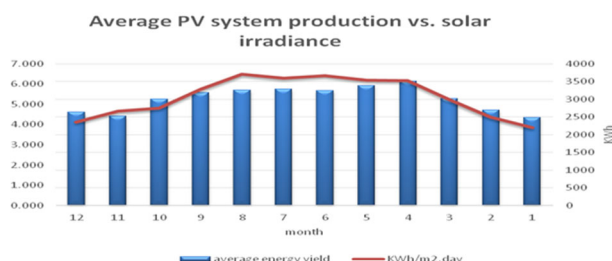

Fig. 4. Average PV system production vs. solar irradiance
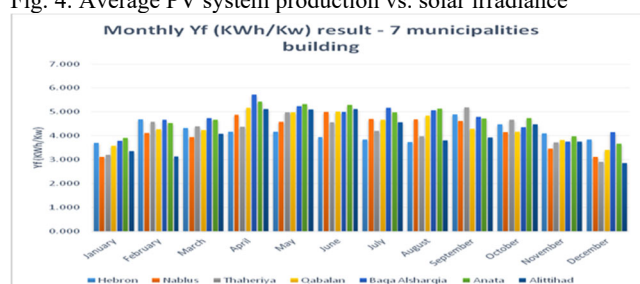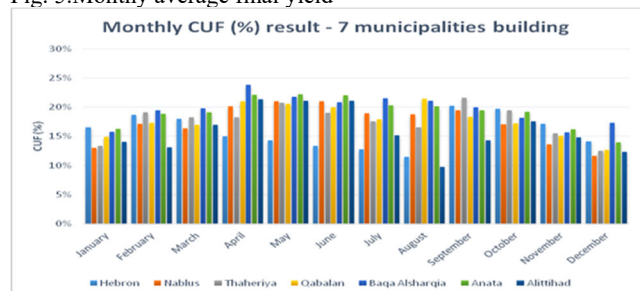

Fig. 5.Monthy average final yield

Fig.6. Monthly average capacity utilization factor

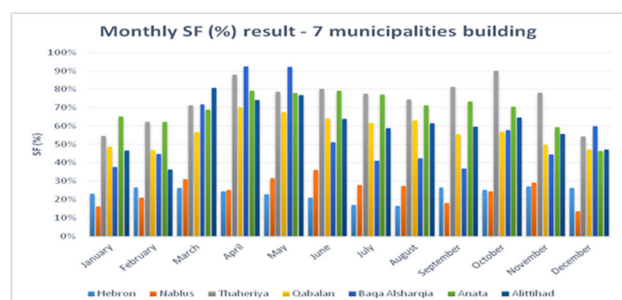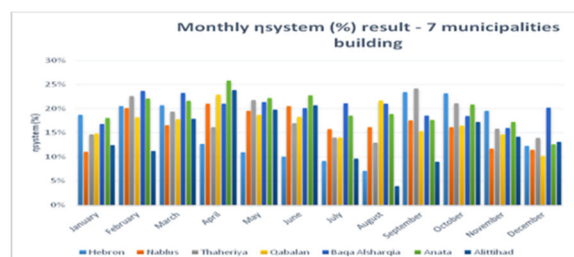
Fig. 7.Monthly average solar fraction

Fig.8.The annual overall monthly system efficiency

5. Simulation Results vs. Actual Output

A number of simulation software are developed to predict the performance of a solar power plant and easily to assist designers and installers [15]. In this study, PVsyst software is used to predict the performance parameters and energy output of 20 kWp grid-connected power plants. PVsyst was design for studying, sizing and data analyzing of photovoltaic grid-connected, stand-alone and water pumping systems. The PVsyst simulations inputs involve meteorological data, modules and inverters specifications. The system was simulated to estimate the performance of solar power plant and predicts the system output using meteo data from many resource as well as a personal data. The total amount of energy that injected to grid for a year is 39.126 MWh. the maximum energy output is 3868 kWh of October and minimum energy output in January is 3022 kWh.as indicated in Fig.9. The actual energy generated by the array is 40879 kWh /year before losses about 1753 kWh /year.

Table 4. Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
January	114.0	7.90	175.6	171.0	3156	3022	17.22	16.49
February	124.0	8.40	166.5	162.4	2974	2848	17.11	16.39
March	166.0	10.70	194.0	188.6	3426	3278	16.92	16.19
April	184.0	15.10	186.1	180.5	3221	3081	16.58	15.86
May	210.0	19.00	191.2	185.1	3254	3113	16.30	15.60
June	219.0	21.20	188.6	182.2	3167	3029	16.09	15.39
July	223.0	22.90	196.7	189.9	3282	3140	15.99	15.29
August	221.0	23.40	214.6	207.9	3577	3422	15.97	15.28
September	202.0	22.30	227.1	221.0	3818	3656	16.11	15.42
October	177.0	19.00	236.4	230.5	4039	3868	16.37	15.68
November	136.0	14.50	209.7	204.6	3638	3483	16.62	15.92
December	114.0	9.50	186.5	182.0	3328	3188	17.09	16.38
Year	2090.0	16.20	2372.9	2305.7	40879	39126	16.51	15.80

According to Table 4. The annual global horizontal irradiation is 2090 kWh/m2, the global incident energy on the collector plane annually is 2372.9 kWh/m2. The total energy obtained from output of PV array is 40.879 MWh.
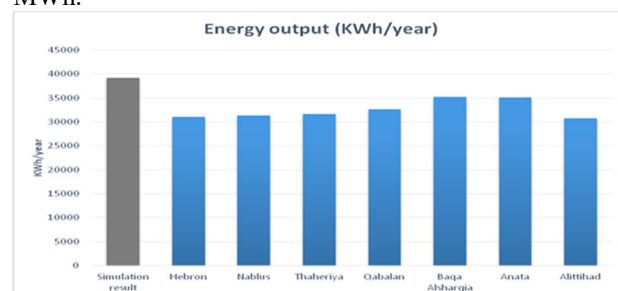

Fig.9.Simulated energy output results compared with real results

The annual average performance ratio is 82%, this value has not much difference with actual performance ratio.
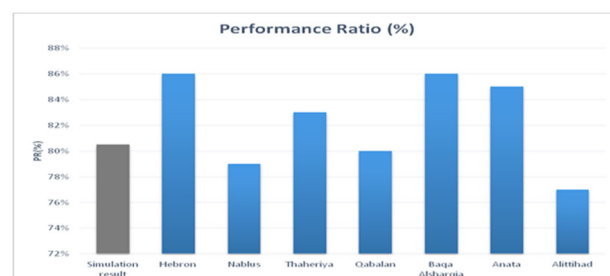

Fig.10.Simulated performance ratio results compared with real results

For the loss diagram over the whole year, the results shown the largest losses were because of the temperature around 5.6%, the horizontal global irradiance is 2090 kWh/m2 and the effective irradiance on collectors is 2306 kWh/m2 which means the total energy for the area of 104 m2 is 239.8 MWh, the efficiency of the system equal to 19.7%, and the array nominal energy at STC is 47.3 MWh.

The measured average result from SMA portal from 7 locations in WestBank-Palestine is compared with PVSyst software result, are presented in Fig.11.
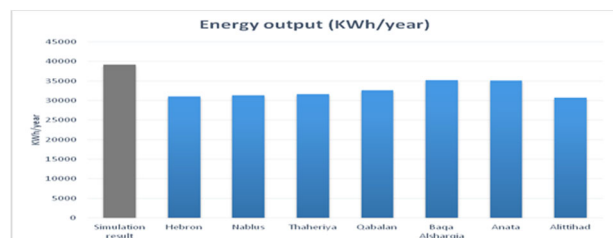

Fig.11. Simulated energy eutput results compared with SMA monitored results

6. Economic analysis

After investigating the technical performance, it is necessary to pursue an economic analysis. The feasibility of system must be also determined. The aim of the financial analysis is to determine and compare the profitability of the construction of the PV plant. The financial analysis of the PV plant gives an evaluation of potential additional or rising income and costs. To identify the effect of installing PV solar system, we calculate the payback time, capital cost, financial saving [2].

A. Simple Payback Period

The payback time depends on the price of equipment cost which includes Photovoltaic panel, inverters, cabling, connectors, frame price and labour cost which includes planning cost, assembly, commissioning cost, permit cost as well as interest rate. SPBP is simple calculated as in Eq (9).

$$S.P.B.P = \frac{Investment\ cost}{saving\ cost\ per\ year} \qquad (9)$$
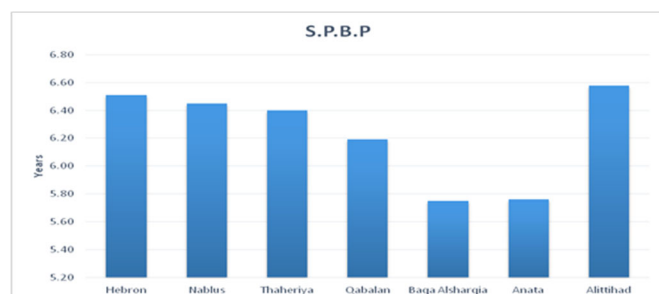
The SPBP for each municipality is shown in Fig.14.

Fig.12.Simple payback period for each municipality

Annual AC energy production of 20 kW system = 36,202.52 kWh/year and the saving cost ($) = 3,982.3 US$/year as shown in Table 5.

Table 5. Financial saving

System capacity = 20 kWp		Saving ($)
Month	E out (kWh)	
January	2484.872	273.33592
February	2688.557	295.74127
March	3011.28	331.2408
April	3513.876	386.52636
May	3376.442	371.40862
June	3246.21	357.0831
July	3283.282	361.16102
August	3255.46	358.1006
September	3183.592	350.19512
October	3003.18	330.3498
November	2517.334	276.90674
December	2638.434	290.22774
	36202.52	3982.27709

- *PV Investment cost = 22,240 US$*
- *Average S.P.B.P = 5 years & 7 month.*

B.   NET Present Value/ Cash Flow
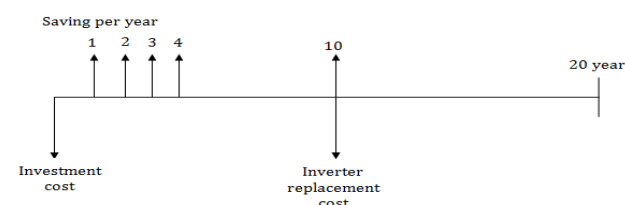
The cash flow diagram is shown in Fig.13.

Fig. 13. Cash flow diagram

To find equivalent present value as in Eq (10) , when i = 10 % and n= 20 years.
NPV=Income cash flow – Outcome cash flow   (10)

The average NPV value is 11,053.52 (> 0), so the project is feasible, Fig.14 shows the NPV foe each municipality.

C.   Internal Rate of Return (IRR)

The IRR is calculated as in Eq (11)

$0=NPV=P0 + P1/(1+IRR) + P2/(1+IRR)2 + P3/(1+IRR)3 + .. +Pn/(1+IRR)n$ (11)

Where P0, P1, . . . Pn equals the cash flows in periods 1, 2, . . . n, year respectively; and IRR equals the project's internal rate of return and NPV = Zero.
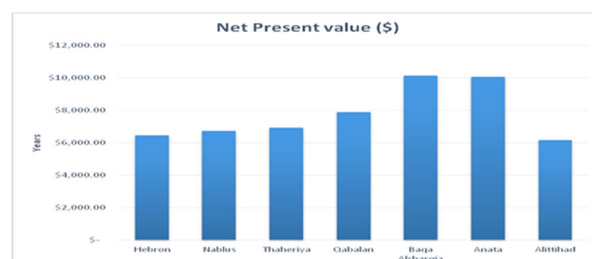
Internal Rate of Return (IRR) is 16.8 %.

Fig.14.Net present value for each municipality.

7. Conclusion

Comparative Analysis of Measured and Simulated Performance of grid-connected solar photovoltaic (PV) system in the Rooftops of different cities in Palestine, for this research study we used a convenience sample of seven systems for simulation and analysis the impact of installing a rooftop solar PV technology. The 20 kWp grid-connected PV power plants was monitored during the year of 2018 and its monthly and annual performance parameters were evaluated and compared with simulated parameters. The simulation results gave a good approximation to measured energy output and irradiation; however, the simulation is less accurate when it comes to the ambient air temperature particularly in April, May and July when temperature increases in the region. The results show a rooftop solar photovoltaic potential and the impact of installing 20 kW on the roof top of public buildings.

The following conclusion was obtained from the study:

• The systems are operated with losses of 7% from predicted generation of PVSyst software

• The annual average penetration factor is found to be 24-74% of building load

• The average final yield per year is 1817 kWh/KW of 20kWp system in West bank-Palestine

• The average annual performance ratio was found 82%

• The average annual capacity factor was found 18%.

• In the analysis, we used 5 performance indicator to study the PV system efficiency

• The indicators were grouped into two groups:

- 1st group: include the factors which depends on studying the system output to ideal/load condition (SF, CUF, Final yield) and this show that the maximum performance occurs in summer

- 2nd group: include (PR, System efficiency) which taking into consideration system component efficient and irradiance changed and the comparison show that the maximum performance was in winter due to reduction of thermal losses.

• The result show the average of reduction CO_2 emission about 27,151 kg per year

• Financial performance indicators (payback period, internal rate of return (IRR), and net present value (NPV) were analyzed for the PV system. The main income of the project is provided by selling the generated electricity to the distribution company. Fig.15 explains the cumulative cash flow of the project during the lifetime of the project which is expected to be around 20 years. The payback period is expected to be ranged from 5-6 years and the Net Present Value (NPV) is about $11,053.52. The Internal Rate of Return (IRR) for the project during a 20-year lifespan is about 16.8%.In this paper we aim to encourage the decision makers to install solar PV on the roof top of any public buildings and schools in Palestine to collect the solar energy as the alternative source of electricity for covering their electricity demand.

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