Electrification of a Rural Home by Solar Photovoltaic System in Haur Al-Hammar of Iraq

Samah Shyaa Oudah[1], Raed Kadhum Fakher Alfahed[2,*] and Kareem K. Mohammad[2]

[1]Iraqi Engineers Association
[2] AL-Nahrain Nano -renewable Energy Research Centre, Al-Nahrain University
**Corresponding author: rrr80kkk@yahoo.com*

Manuscript Received 6 July, 2018; Revised 28 September, 2018; Accepted 30 October, 2018. Paper no. JEMT-1806-1102.

The need for electricity plays a vital role in the development nature life of communities who live in marshes, which is far from any other electricity sources. For this regard, a stand-alone solar power system was proposed for electrification as sample solar photovoltaic system for daily used in Haur Al-Hammar at Al-Nasiriya Governorate. The assessment of 4kW peak capacity Stand-alone Solar PV system was showed to be acceptable for providing electricity for all home appliances with an access energy that could be used for future extended. This procedure can be used as a guideline design of solar power systems for electrification of many homes which close to each other. The solar photovoltaic home system could provide electricity at daylight for operation all the assumed appliances at full load with a current for appliances about 7 A for continuous 10 hours during night time at 50% depth of discharge. However, the performance ratio varies from month to month throughout the year with an average value of 50.3%.

Keywords: *Rural electrification, Renewable Energy, Stand-alone PV Systems, solar home systems, PVsys6 software.*

http://dx.doi.org/10.22109/ jemt.2018.134845.1102

Nomenclature

δ	Declination angle (degrees)
θ	Angle of solar incidence (degrees)
ω	Hour angle (degrees)
ωss	Sun set time
ωsr	Sunrise time
β	Tilt angle (degrees)
γ	Surface azimuth angle (degrees)
φ	Latitude angle (degrees)
$\bar{H}t$	Total solar radiation on an inclined surface.
$\bar{H}B$	Beam component of solar radiation on an inclined surface
$\bar{H}D$	Diffuse component of solar radiation on an inclined surface
$\bar{H}R$	Reflected component of solar radiation on an inclined surface
$\bar{H}g$	Global solar radiation on a horizontal surface
$\bar{H}d$	Diffuse solar radiation on a horizontal surface
YA	Array yield
YF	Final System Yield
PR	Performance Ratio
YR	Reference Yield
CF	Capacity Factor

1. Introduction

The global challenge to obtain renewable energy from trustworthy and low-cost services still one of the main challenges facing the countries of world in this recent time. The application of renewable energy solutions importantly impacts on the air natures as well. Moreover, there are 85% of mercury emissions produced by coal combustion to generate power and manufacturing processes [1]. For example, the last studies have demonstrated that concentrations of most air pollutants in Iraq oscillated among high and below limits which documented by Iraqi and international standards [2]. However, due to the difficulties of the land nature and economic considerations for some governments ignore electrification of rural villages. These considerations are geographical limitations, far from electrical grid lines and rapid population growth. So, this situation is expected to continue till to 2030 [3-5]. in the Recent years, the PV energy systems collected high attention because of such as these systems can get the better of the intermittent nature of renewable energy sources, the over-sizing issue and build up the precision of supply. Several authors have been used the PV systems as a case study. For example; Givler and Lilienthal [6] managed a case study of Sri Lanka in which they specified that a PV/diesel hybrid has a low cost compared to a stand-alone small solar home system (50 W PV with battery). Qusay Hassan and et al. [1] studied and analyzed the off-grid photovoltaic (PV) system to provide the required power for a house located in Diyala city/ Iraq as well as the CO2 emissions and life cycle (LCC) and economical aspect was studied. O. Adeoti and et al. [7] have estimated the home load required of rural locations in Nigeria which will be carried out as input data in the design of photovoltaic-based rural home electrification systems. The result was showed that rural households in Nigeria will require 2324.5 Wh/day or 850.8 kWh/yr to meet their basic power requirements for example of these loads are lighting, electronic appliances, radios, and televisions.

Marshes are a wetland zone located in southern Iraq, some regions of southwestern of Iran and north of Kuwait [8]. The marshes look like a triangular region bounded by three major southern cities; Nasiriya of the west, Amara of the northeast and Basra of the south. The marches are formed by the confluence of the Tigris and Euphrates Rivers [9]. The extension of national electricity grid could not cover and serving the marshland. Therefore, it is necessary to provide these marshlands by renewable energy. For example, Photovoltaic systems for home lighting, operation of their electric devices and irrigation purposes of the plants and animals.

In this study, the Photovoltaic (PV) electricity which transforms sunlight into electricity, storing it in batteries to use at any time was received. A PV system is made up of a module, at least one battery, a charge controller, and an inverter, plus the electrical end-use equipment. Moreover, optimum sizing of 4.0kW off – grid Solar PV system has been investigated for providing electricity to a sample home in the Haur Al-Hammar region. The estimation and analysis were performed using mathematical equations with Excel worksheet and PVsys6.68 software simulation package.

2. Methodology and calculations

2.1. Data Collection and selected site

The proposed sample of 4 kW off-grid solar PV system was adopted for electrification a rural home at the southern boundaries of Haur Al-Hammar region, close to Al-Fuhood town, in Nasiriya Governorate, as shown in the Fig. 1. The geographical location of the selected site at 30.5811 N (Latitude), 46.4335E (Longitude).

The monthly average value of solar radiation which incident on a horizontal surface (kWh/m2/day) was obtained from surface meteorology and solar energy of atmospheric science data center of NASA, over 22 years [10], as shown in the fig. 2. The annual average of solar radiation 5.22 kWh/m2 /day which is enough for installing an efficient off-grid PV system.

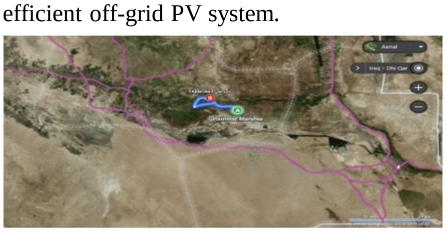

Fig. 1. Location of selected sampling home site at Hawer AL-Hammar region.

Fig. 2. Monthly averaged insolation incident on a horizontal surface (kWh/m2/day) at Haur Al-Hammar.

2.2. Modeling of solar radiation

The solar radiation on an inclined surface can be described by the parameters of declination (δ), latitude (φ), angle of incidence (θ), surface azimuth angle (γ), hour angle (ω), day of the year (n), global, beam, diffuse and reflected solar radiation, orientation towards equator, tilt angle (β), sky-clearness (k_t) and cloudiness index (k_d). So, the ratio of normal beam radiation on tilted surface (H_{Bt}) to radiation on horizontal surface (H_B) is given in terms of θ_z (the angle between the direction of solar radiation, H_n, and a line perpendicular to a horizontal plane through the point) and θ_T as shown in the Fig. 3.[11]. The total solar radiation received on an inclined surface ($\bar{H}_t$) is the sum of the monthly average daily of (beam radiation $\bar{H}_B$, diffuse radiation directly incident on a surface $\bar{H}_D$, and reflected by the surroundings radiations $\bar{H}_R$). Thus, the monthly average total solar radiation in *kWh/m²/day* on an inclined surface is expressed as [12]:

$$\bar{H}_t = \bar{H}_B + \bar{H}_D + \bar{H}_R \quad (1)$$

The monthly average daily of beam radiation, $\bar{H}_B$, falling on a tilted surface is given as [13]:

$$\bar{H}_B = (\bar{H}_g - \bar{H}_d)\bar{H}_b \quad (2)$$

Where, $\bar{H}_g$ and $\bar{H}_d$ are the monthly average daily global and diffuse radiation on a horizontal surface. The mean beam radiation tilt factor can be written in the form of [14]:

$$\bar{R}_b = \frac{\cos(\emptyset-\beta)\cos\delta\sin\omega_x + \left[\frac{\pi}{180}\right]\omega_x\,\sin(\emptyset-\beta)\sin\delta}{\cos\emptyset\cos\delta\sin\omega_x + \left[\frac{\pi}{180}\right]\omega_x\,\sin\emptyset\sin\delta} \quad (3)$$

The monthly average daily reflected radiation $\bar{H}_R$ reflected by the surrounding falling on tilted surface is given by [14]:

$$\bar{H}_R = \bar{H}_g\bar{H}_r \quad (4)$$

Where, ρ_g is ground reflectivity assumed as 0.2 for hot and humid tropical location as suggested by [14] and ($\bar{R}_r$) the mean reflected conversion factor:

$$\bar{R}_r = \rho_g\left(\frac{1-\cos\beta}{2}\right) \quad (5)$$

The monthly average daily diffuse radiation falling on a tilted surface is given by [15]:

$$\bar{H}_D = \bar{H}_d\bar{R}_d = \bar{H}_d\left(\frac{1-\cos\beta}{2}\right) \quad (6)$$

2.3. Tilt, Mounting Angle

The tilt plane angle (β) of the solar module (as shown in the Fig. 4) can be expressed in the following equation [16]:

$$\tan\beta = \frac{(-\sin\delta\cos\emptyset\cos\gamma + \cos\delta\sin\emptyset\cos\gamma\cos\omega_s + \cos\delta\sin\gamma\sin\omega_s)}{\sin\delta\sin\emptyset + \cos\delta\cos\emptyset\cos\omega_s} \quad (7)$$

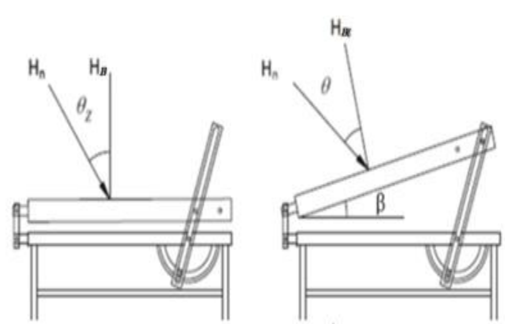

Fig. 3. Beam radiation on horizontal surface and tilted surface.

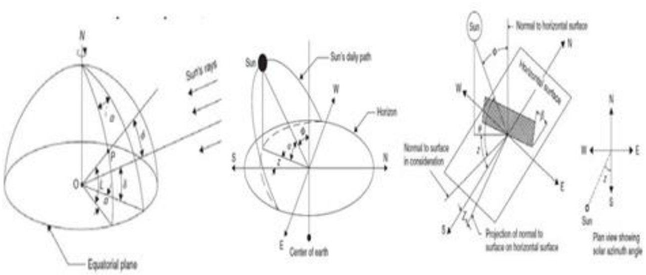

Fig. 4. Apparent daily path of the sun across the sky and latitude, hour angle, solar declination, altitude, azimuth and tilt plane angle.

2.4. Performance Analysis of Solar PV Power System

The performance of 5 kw system is analyzed using the following performance parameters [17-19].

2.4.1. Array yield (YA)

The array yield (Y_A) is known as DC amount of energy that output from the PV array over a given period of time normalized by the PV rated power. It represents the time measured in kWh/kWps [20,21].

$$Y_A = \frac{E_{DC}}{P_{PV,rated}} (kWh/kW_P) \tag{8}$$

Where E_{DC} is the DC energy output (kWh) from the PV array.

2.4.2. Final System Yield (Y_F)

The Final yield (Y_F) of PV solar power plant is the ratio of the total annual, monthly or daily net AC energy output (E) divided by the peak power of the installed photovoltaic array at the standard test conditions; 1KW/m^2 irradiance, 25˚C ambient temperature and (A.M 1.5) [22,23] It is given by the expression:

$$Y_{F,a} = \frac{E_{AC,a}}{P_{PV,rated}} (kWh/kW_P) \tag{9}$$

Where E_{AC} is the total net energy output of the system kWh AC, $P_{PV,\ rated}$ is the peak power of the installed PV array kW DC.

2.4.3. Reference Yield (Y_R)

Reference yield is known as the total global in -plane solar insulation (H_t) (kW h/m^2) divided by the array reference irradiance (G_o) at STC which is (1kW/m^2) [24, 25]. at a specified time and a specific location, the theoretical energy can be measured which known as Reference yield according to the following express:

$$Y_R = \frac{E_t}{G_0} (kWh/kW_P) \tag{10}$$

Where H_t is the total in-plan solar irradiation KWh/m^2, and G_o is the array reference irradiance (1KW/m^2).

2.4.4. Performance Ratio (P_R)

Performance ratio (P_R) is known as the ratio of the of energy fed to the grid (final yield, Y_F) to the reference yield (Y_R) by comparing the photovoltaic system efficiency with the nominal efficiency under standard test conditions.PR values are typically reported on a daily or monthly or yearly basis and expressed as [26]:

$$P_R = \frac{Y_F}{Y_R} \tag{11}$$

2.4.5. Capacity Factor (CF)

The annual capacity factor (CF) is the proportion of the real annual enegy output of the photovoltaic system to a given timeframe (as a matter of fact one year) to the energy output that would have been created if the system were worked at the full limit with respect to the whole-time frame. It's given by the following equation [27,28]:

$$C_F(100\%) = \frac{E_{generated}(Wh/year)}{P_{module\ peak\ power}(W) \times 8760h} \tag{12}$$

2.4.6. Solar Fraction

The ratio of the energy demand (E_{load}) that is insured by the generated energy (E_H) from the solar photovoltaic system, which gives indication of how much the installed PV system will provide energy to the customers. [29]:

$$Solar\ Fraction(100\%) = E_H(Wh)/E_{load}(Wh) \tag{13}$$

3. Results and discussions

The total daily of energy demands for the sample home load consumption will be differ from month to month according to the variation of seasonal load. The energy required from the photovoltaic system decides the daily energy demand that be must accommodate the distinctive apparatuses, multiplied with the number of units and the total daily hours of consumption, then adding installation is then the whole of each heap working inside consistently.

3.1. Mounting Tilt and Solar Angels

For the system design, selecting 21 December, at 12:00 midday to calculate the tilt angle of constructing the modules as following:

$\emptyset = 30°.5811$, Where maximum value of δ =+23˚.25 at summer solstice and minimum value of our case design is δ= -23˚.25 at winter solstice. Based on the Excel worksheet we obtain (h =1˚.8515).

Zenith angle (θz):

$$\theta_z = \cos^{-1}(\sin\delta.\sin\phi + \cos\delta.\cosh.\cos\phi) = 54^\circ \tag{14}$$

The angle of solar elevation at noon is either $\alpha = 90° - \theta_z$ =90˚-54˚=35˚, or from equation $\alpha = 90° - \emptyset \pm \delta$=90-30.58-23.45=35˚.97 for the design month of winter solstice.

The solar azimuth angle:

$$\gamma = \sin^{-1}\left[\frac{\cos\delta \sinh}{\cos\alpha}\right] = cos\ (-23.45 * sin(1.86)/cos35 = 2^\circ$$
$$= -180^\circ + 2^\circ = -178^\circ \tag{15}$$

Where the negative sign refers to morning time only.

Sunset hour angle h_{ss}: The sun is said to rise and set when the solar altitude angle α=0˚, for the tilted surface for the mean day of the month which is given by the smaller value of the two terms in the bracket, the hour angle at sunset can be found from which is positive at sunset and negative at sunrise h_{sr} [30].

$$h_{ss} = \min\begin{bmatrix} \cos^{-1}(-\tan\phi\tan\delta) \\ \cos^{-1}(-\tan(\phi-\beta)\tan\delta \end{bmatrix} =$$
$$75.1471098,\ 101^\circ.8965231 \tag{16}$$

using minimum value of 75˚.1471098 (Excel work sheet).

Sun set and sunrise time in hours are equal in value but differs in sign from local solar time when the hour angle is 0˚ so;

$$H_{ss} = -H_{sr} = \frac{1}{15}\cos^{-1}\left[-\tan\phi \times \tan\delta\right](Hours) \quad \textbf{(17)}$$

$$=1/15 \times cos^{(-1)}[(-tan30.5811)tan(-23.45)] = 5\ hours$$

$$Day.length = \frac{2}{15}\cos^{-1}\left[-\tan\phi \times \tan\delta\right](Hours) \quad \textbf{(18)}$$

$$2/15cos^{(-1)}[(-tan30.5811)tan(-23.45)] = 10\ hours$$

The optimal tilt angle of a surface was calculated using excel worksheet:

$$\tan\beta = \frac{(-\sin\delta\cos\emptyset\cos\gamma + \cos\delta\sin\emptyset\cos\gamma\cos h + \cos\delta\sin\gamma}{\sin\delta\sin\emptyset + \cos\delta\cos\emptyset\cos h} \quad \textbf{(18)}$$

=1.25, and then β=51˚

The optimal tilt angle of solar panels was found (51˚) during winter months and (13˚) at summer months in both of mathematical and PVsys6.8 simulation.

3.2. Site Assessment

The average monthly values of global solar radiation on tilted surfaces of the panels were found more than 100 kWh/m^2 in all the months and reach its maximum values throughout summer months. Thus, in summer months are also found that the load would be more than the other months throughout the year as shown in Fig. 5. The diffuse radiation on both horizontal and inclined surfaces seem to be as little differences in values. The average monthly of global solar radiation on horizontal and inclined surfaces give a good indication for the encouragement of solar photovoltaic system in the selected site.

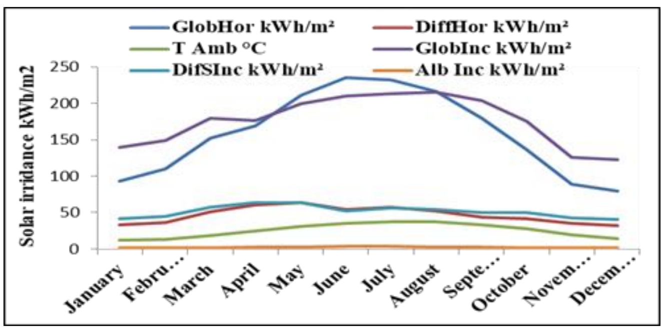

Fig. 5. Metrological and incident energy

The Transposition Factor (FT) which is the ratio of the incident irradiation on the plane, (GlobInc kWh/m²) to the horizontal irradiation (GlobHor kWh/m²) as shown in the Table 1, stated that how gain (or loose) solar irradiance with respect to optimum tilt angle of the solar modules. When tilting the collector's plane at 51˚ in winter months, FT is larger than 1 which indicate gain more solar irradiance whereas at installing the solar modules at 13˚ at summer months increased FT values more than in winter months. So, it is advised to change the tilting plane angle between summer and winter season to the maximization of gain solar energy.

3.3. Determination of Daily Power and Energy Consumption

Important issues must take into consideration when designing solar system, the load of the system is not constant over the period of the day and the energy available varies from time to time during the day. The determination of power and energy consumption demands for all appliances represents the first step in designing of solar PV system. The supposed appliances of the sample home at Haur AL- Hammar as following in the Table 2. All appliances should be chosen for the lowest possible energy consumption (High efficiency lighting and Energy efficient refrigeration).

Table 1. Optical factors (Transpos.,IAM,Shadings)

	Optimal tilt plane angle 51˚ at winter			Optimal tilt plane angle 13˚ at summer		
	GlobHor kWh/m²	GlobInc kWh/m²	FTransp	GlobHor kWh/m²	GlobInc kWh/m²	FTransp
January	93.3	152.6	1.635	93.3	116.5	1.248
February	110.3	156.4	1.418	110.3	130.9	1.187
March	151.9	175.1	1.153	151.9	168.7	1.111
April	169.5	157.5	0.929	169.5	177.3	1.046
May	211.1	164.7	0.780	211.1	211.7	1.003
June	235.8	165.3	0.701	235.8	230.7	0.978
July	232.5	170.7	0.734	232.5	230.1	0.990
August	216.1	185.7	0.859	216.1	222.2	1.028
September	179.7	192.8	1.073	179.7	196.0	1.090
October	136.1	179.8	1.321	136.1	157.9	1.160
November	89.1	135.7	1.523	89.1	108.2	1.214
December	80.0	135.7	1.697	80.0	101.1	1.265
Year	1905.4	1971.9	1.035	1905.4	2051.3	1.077

7.3.1. Load calculation

1. Total AC load was found to be 2860Watts and the AC daily energy for all the appliances was 10860 Wh/day. The input parameters of:

- The Inverter/charger efficiency is 98.5 %. (TriStar TS MPPT 60-48Vdatasheet).
- Charge Controller Efficiency (Nom. 48 V) 98.5 %. (TriStar TS MPPT 60-48Vdatasheet).
- PV Array Efficiency 15.52 %, (BenQ Solar_PM250M01_250.PAN).
- Cable Loss 3 %, [26].
- Battery Rolls_12_CS-11PS.BTR Approximately Battery Efficiency 90 % [26].

The efficiency of subsystem η_{out} will be:

$$\eta_{out} = Charge\ Controller\ Efficiency \times Battery\ Efficiency \times Inverter\ Efficiency \times Cable\ Loss \quad \textbf{(20)}$$

= (0.985×0.985×0.9×0.97) = 0.847.

2. The photovoltaic array energy demand is evaluated, with respect to the sub system efficiencies as following [29]:

$$E_{PV,array}(Wh/day) = \frac{Daily\ energy\ demand}{Sub.\ Syst.\ Efficiency} \quad \textbf{(21)}$$

= 10860 Wh/day / 0.847=12822 Wh/day.

Fig. 6. illustrated the average daily demand of energy for appliances consumption wherein the losses were taken in the consideration of system design. The solar PV system will provide the recommended energy at an average12822 Wh/day during all the time through the entire year and there will be an access generated solar energy throughout all the months which named as unused energy as shown in the Fig. 7. The unused energy could be used for future oversizing of home load or any demands of agricultural purposes.

3. The daily peak sun hours were computed from dividing the average daily of the solar irradiance for the worst month, December (4.0 kWh/m^2) by the peak solar radiation is 1 kW/m^2, so (PSH=4.0 hours/day) for the studied site [31].

4. The specified PV array output is calculated by using dividing the electricity demand from the PV array, over the Peak Sun Hours

(PSH) at the site [29].

$$Required\ PV\ array\ output\ (W) = \frac{E_{PV,array}(Wh/day)}{PSH} \quad \textbf{(22)}$$

=12822 Wh/day.÷ 4 hours =3205 Watts.

This represents the critical output power that recommended from the solar system.

Table 2. Daily load and energy consumption of appliances for Proposed sample home electrification.

No.	Appliance	Nos.	Watts AC	Total Watts AC	hr. /day	hr. /Week	Total wattage (Wh) AC/day
1	Ceiling fans	4	80	320	12	-	3840
2	Television 36″	1	150	150	10	-	1500
3	Receiver	1	50	50	10	-	500
4	Refrigerator	1	150	150	24	-	1200
5	LED Bulb - 40 Watt	6	40	240	8	-	1920
6	Freezer	1	150	150	24	-	1200
7	Clothing Washer	1	400	400	-	3/7	160
8	Iron	1	1000	1000	-	1/7	140
9	Others			400			400
	Sum			2860 Watts			10860 Wh/day

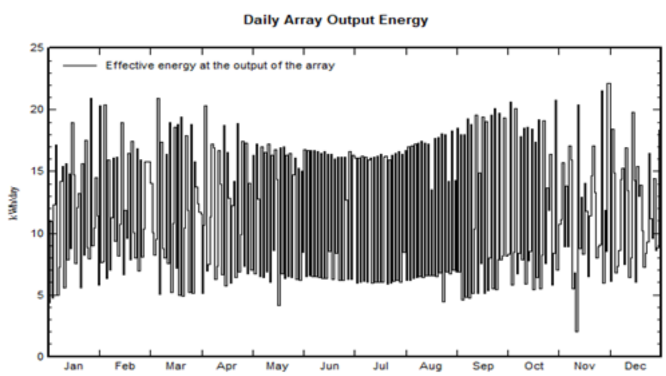

Fig. 6. Daily array output energy.

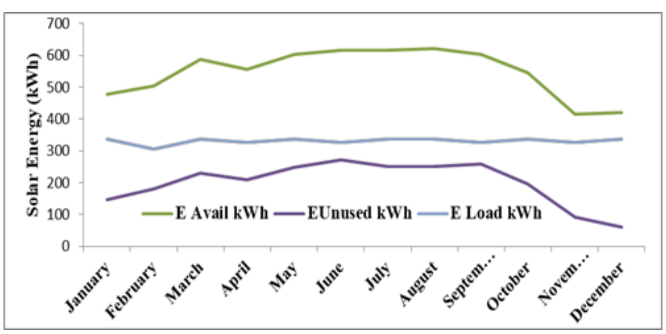

Fig. 7. Available, Used Solar energy and excess generated solar energy home consumption

3.4. Sizing of PV System

3.4.1. Oversizing the PV Array

Operating conditions can vary throughout the day and temperature can greatly impact the output power of a PV array. Oversizing the PV Array it's rated power within a ratio ranging between 1:10-1:25 to maximize energy production [29]. The oversizing depends on the location of project and design specific DC loss factors for example, tilt angle, orientation, mounting method, DC wiring losses, mismatch and soiling [29]. Oversizing offers extra charging to the batteries, and to cover the required energy to charge the battery bank [32]. The adopted oversizing ratio in this research paper is10%.

PV Array Output Power =3205 Watts ×1.1=3526 W

3.4.2. Derating of the Module Performance

The performance of the module decreases as a result of several influential factors such as surrounding temperature, manufacturers derating tolerance (which either given as a ± value in percent or watts), dirt, debris, and precipitated salts up at the array. Dirt value will vary from site to each other and the value of 4% dirt was adopted for this site. Solar module type BenQ Solar_PM250M01_250 module, 60Cells, Poly-Si was taken in this study and inverter type Tristar TS MPPT 60 - 48V as in Table 3.

The average of surrounding temperature of the selected site at Haur AL-Hammar was record as 25.3˚from NASA SEE. Then,

$$T_{cell-eff.}(℃) = T_{ave.day}(℃) + 25℃ = 25.3 + 25 = 50.3℃ \quad \textbf{(23)}$$

The temperature coefficient of the used module is -0.43 %/˚C. So that,

$$Temp.Loss = T_{ave.day}(℃) \times Temp.Coeff. \quad \textbf{(24)}$$

$$= 25.3 \times (-0.43\%/℃) = -10.879\%$$

Then,

$$Temp.Derating\ Factor = \frac{100\% - Temp.Loss\%}{100}$$

=1-10.879%=0.89121 **(25)**

To adjust the module power, by considering the temperature derating factor and the dirt correction factor as following:

$$Adjusted\ module\ power = P_{peak\ power\ module}(W) \times Temp.derating\ factor \times\ dirt\ correction\ factor$$

=250W×0.89121×0.94=214W **(26)**

Table 3. Characteristics of used solar module and inverter.

of BenQ Solar_PM250M01_250.Watts		Inverter type Tristar TS MPPT 60 - 48V.	
Maximum Power (Pmax)	250 W	Maximum Power	3200 W
Power Tolerance	-0%, +3%	Maximum charging current	66.7 A
Open Circuit Voltage (V_{oc})	37.86V	Max. discharging current	60 A
Short Circuit Current (I_{sc})	8.660A	DC voltage range	50-120 V
Voltage at Max. Power (V_{mp})	30.82V	Max. DC voltage	150 V
Current at Max. Power (I_{mp})	8.112A	Nominal output DC Voltage for battery	48 V
Module Efficiency	15.52%	Max. efficiency	98.5%
Temperature derating factor	-0.43 %/ ˚C		

3.4.3. The Number of PV Array Modules

The number of PV modules that are needed to cover the energy demand of the installation was determined from peak output power divided with the adjusted module power.

$$Number\ of\ PV\ modules = \frac{Peak\ PV\ array\ output\ (W)}{Adjusted\ module\ output\ power\ (W)/Module}$$

=3526W / 214W=16 modules **(27)**

a. The maximum power voltage at STC of the module (V_{mp})=30.82V.

b. The design operating voltage for the solar module comes from numerical multiplication of voltage at maximum power, temperature derating factor and the dirt derating factor (30.82V×0.89121×(1-0.04)) which will be 26.37V.

c. $$Number\ of\ series\ module/string = \frac{Battery\ Bus\ Voltage\ (V)}{V_{mp}(V)/module} \quad \textbf{(28)}$$

=48V / 26.37 V/module=2 modules in series/string.

d. $$Number\ of\ string\ in\ parallel = \frac{Total\ PV\ module}{Number\ of\ series\ module\ /\ string} \quad \textbf{(29)}$$

=16 modules / 2 modules in series/string

=8 parallel strings of modules.

The number or modules are also dependent on the limitations of the chosen charge controller and its MPPT limits. The total power of the new number of modules will be equal to (16 ×250 W =4000 kW_P). While, the total Effective cells area of the selected modules calculated from numerical multiplication of module area and number of PV modules which will be (1.611m^2×16=25m^2). Also, the number or modules are related to the limitations of voltage limits (MPPT) of the inverter. The layout of solar PV Home system included 8 strings and each string consists of two series modules. It is important to see how the array will covers any peak power consumptions by checking the relation between the generated energy with peak power consumption must satisfy the condition, $E_{generated}$ (Wh)≥$E_{peak\ power\ consumption}$ (Wh). The effective solar cells area of the panels is 25 m^2 which provides a maximum power from solar irradiance values in worst month (December) as:

$$E_{max} = Solar\ irradiance\ (kWh/m^2) \times Area_{PV\ array}(m^2) \times \eta_{PV} \times T_{cell-eff} \times \eta_{out} \quad \textbf{(30)}$$

=4.0kWh/m^2.day×25m^2×15.52%×0.89121×0.837

=11.577kWh/day

So, generated Power can be evaluated through dividing the maximum power over the PSH (11.577kWh/day / 4.0kW/m^2=2894Watts). This is result was agreed with the condition, $E_{generated}$(Wh)≥E_{peak} power consumption(Wh) (2894 Watts ≥ 2860Watts). The size of the peak power determines the system sizing that should be evaluated to give the peak power consumption. The Fig. 8. stating that there is 25.2% unused energy as storing in battery bank and the overall losses of PV array, system loss and battery charging loss about 24.6% of the net generating solar energy. Thus, the useful of solar energy represents 50.3%.

3.5. Determination of the battery storage required

The batteries are composed a high percentage of the total cost of the solar system. The battery sizing depends on the number of days you anticipate that your system will give power without accepting an input charge from the solar PV array. It depends on the days of autonomy, load consumption pattern and the appliances that should be considered. The working temperature of the battery more than (20˚C) will experience a critically decreased lifetime and capacity [33].

3.5.1. System Voltage

The size solar power system is 12 V, 24 V or 48 V depending on the providing energy from the battery bank. Whoever, if the batteries and inverter are not adjacent as close to each other, a higher system voltage should be used to indemnity power loss in the cables [29] as seen in the Fig. 9. The PV array energy demand with consideration of the sub system efficiencies was found14384 Wh/day and the suitable battery system voltage is 48 V. The battery bank capacity is determined by the following equation [29]:

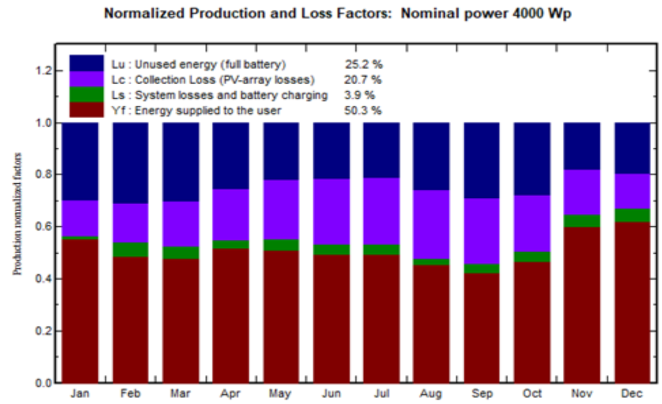

Fig. 8. Normalized production solar energy

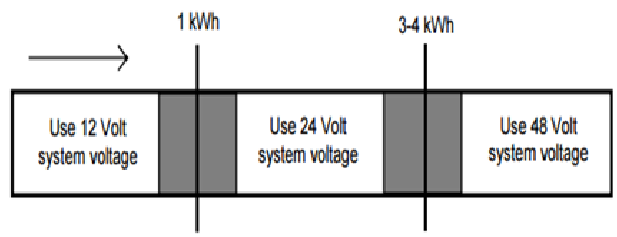

Fig. 9. System Voltage Based on the Daily Energy Consumption

The battery bank capacity is determined by the following equation [29]:

$$Battery\ Bank\ Capacity(Ah) = \frac{Total\ Daily\ Energy\ Need\ (Wh) \times Days\ of\ Autonomy}{Battery_{round-trip\ efficiency} \times Battery\ System\ Voltage\ (V) \times DOD} \quad \textbf{(31)}$$

Where DOD is the maximum depth of discharge. The recommended DOD for an off-grid solar power system is between 20-50% [33]. DOD of 50 % was used in the calculation and days of Autonomy were chosen as 1 day. So,

Battery Bank Capacity (Ah) = (12975 Wh/day × 1 Days) / (48V×50%×90%) =600Ah.

And,

$$Required\ number\ of\ batteries\ wired\ in\ parallel = \frac{Battery\ Bank\ Capacity(Ah)}{Battery\ rating(Ah)/Battery} \quad \textbf{(32)}$$

=600Ah/296 Ah= 2 parallel rows of batteries

And also,

$$Number\ of\ Batteries\ in\ series = \frac{Nominal\ system\ voltage(V)}{Battery\ voltage(V)/Battery} \quad \textbf{(33)}$$

=48V /12 V/Battery=4 Batteries

So that,

$$Total\ number\ of\ batteries = Number\ of\ batteries\ in\ series \times Number\ of\ batteries\ in\ parallel$$

=2×4=8 Batteries **(34)**

3.5.2. Battery Temperature Derating

Battery capacity is affected by temperature so that the lower the temperature leads to reduce the battery capacity. The battery correction factor at a low-temperature operation (at 25°C) is 1 as shown in the Fig. 10. For the design problem, assuming that temperature operation will be kept at 25°C and the correction factor value is 1[33].

3.5.3. Maximum Charging Current

For a given capacity, C-rate is a scale that used to determine a charged and discharged size of the battery current until reaching its defined capacity. The maximum charging current is typically (C10 or C/10) of the battery capacity. The C10 rating refers to a specific size load to a battery over a period of 10 hours and was applied in this study. [33]. For this study the capacity of the battery bank is 592Ah. So, the maximum charging current will be calculated by numerical division of battery capacity rating over to C-rate (592Ah / 10 h= 60 A). The Fig. 11. shows the average state of battery bank charging of 0.1C, and this compatible within the above result of time charging 10.9 hours for each cycle of discharge.

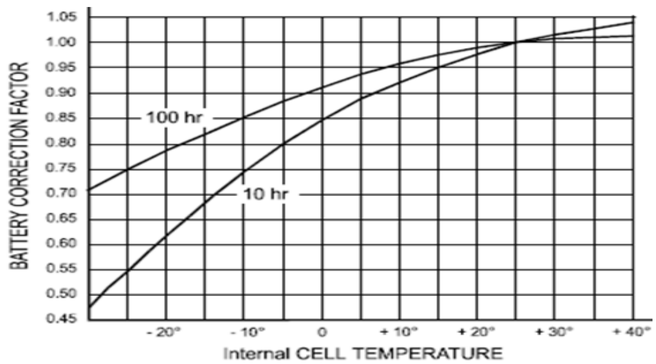

Fig. 10. Battery correction factor due to temperature [33].

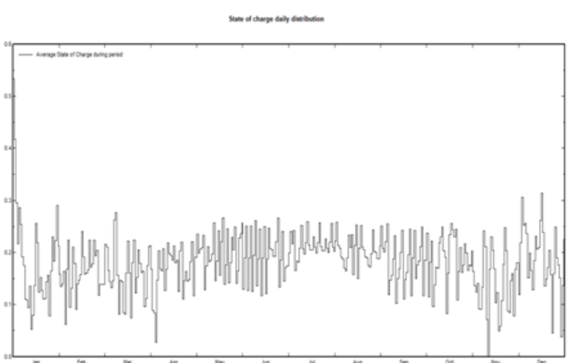

Fig. 11. State of batteries charging daily distribution

The Fig. 12. showing the continuously state of charging and discharging of battery bank, for the worst day of 21 December where it is short peak sun hours, the user can draw the current for appliances about (7.421A) until 10 hours continuously at night time with 50% depth of discharge. However, the drawn current for appliances will be (143.6Ah/10= 14.36A). For verification within AC load of appliances which is 2860Watts, the AC Current (2860W / 220V=13 A). The duration of stored energy in a battery can be able to run the total appliances load of 2860 Watts for 5 Hours as a result of the following details:

1. The Stored energy of Battery bank capacity =600Ah×48V×50%=14400Wh.

2. Inverter Efficiency =Load energy (Wh)AC ÷ Battery bank stored energy DC (Wh).

3. The running time of total load was estimated by dividing the numerical multiplication of stored energy of battery bank, DC Cable losses (3%), and inverter efficiency over to the numerical multiplication of appliances load and AC Cable loss (2%) ((14400Wh×0.97×0.98) / (2860Watts×0.98) =5 Hours).

4. It's important for the homeowner to disconnect 50% of the full load through the night time will be duplicate to 10 hours.

5. The system is good for partially loading (50%) throughout night time.

The battery bank efficiency of the charging and discharging for both energy and current drawn was varied in the range of more than 95% as efficiencies. thus, this gives an excellent indicator for optimum design of solar home system in the selected site as showing in the Fig. 13.

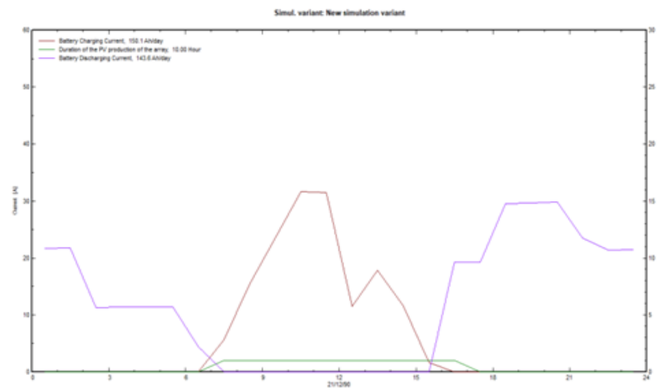

Fig. 12. State of charge and discharge daily distribution

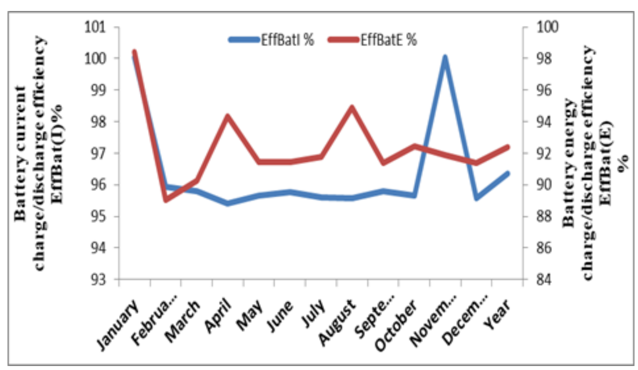

Fig. 13. Battery energy and current charge/discharge efficiencies

3.6. Determining inverter rating

The inverter has to be successful to deliver energy to all AC loads, must have sufficient surge capacity to handle it whereas running any other loads that perhaps on. It is important to size an inverter sufficiently, especially to handle the starting surge [29]. ability or rating of the inverter should be 20–25 % bigger than "general power of AC appliances". capability or rating of inverter ≥ 1. 2 X total electricity of AC home equipment. The inverter power sizing in this study was estimated to be (1.2×AC load =1.2×2860Watts =3432Watts).

3.7. Charge Controller sizing

The charge controller size should be 25% more than the short circuit current (I_{SC}) of the array, and its voltage 20% more than the open circuit voltage (V_{OC}) of the array [29]. Thus, the charge controller current ($I_{C.C}$) estimated through numerical multiplication of 1.25, number of parallel stings and short circuit current (I_{SC}) to be

(1.25×8 strings× 8.660A/string=86.6 A). While, the voltage of charge controller ($V_{C.C}$) by the numerical multiplication of panel value of the open circuit voltage (V_{OC}), 1.2 and number of series modules to be (1.2× 37.86V×2=90.864V).

3.8. Carrying Capacity of DC current &Voltages

Calculation the Maximum Carrying Capacity of DC current and Voltages as following [29]:

a. Maximum DC current/ string = I_{SC}= 8.660A.

b. Maximum DC Voltage/string= VOC×NS =37.86V×2 =75.72V.

c. Maximum continuous current to be carried by the conductor = 1.25 ×1.25×Isc=1.25 ×1.25×8.660A =13.53 A.

d. Maximum DC current of Combiner Box =1.25×No.of strings× Isc =1.25×8 string × 8.660A / string=86.6 A.

e. Maximum DC Voltage of Combiner =1.2×Voc×NS =37.86V×2 = 90.86V

The current generated from the solar System can be expressed in the following equation [34]:

$$Current_{PV\ array\ output} = E_{PV,array}/(PSH \times battery\ system\ voltage)$$

= 12822 Wh/day / (4h×48V) =67A. **(35)**

The Current $_{pv,array}$ 67 A ≤86.6 A this result was agreed with the condition Current $_{pv\ array\ output}$ (I) ≤ Max.Current ($I_{C.C}$). An inverter of 3200Watts (Tristar MPPT 60-48V) was chosen in this design of sample solar home system. The maximum current from battery at full load supply ($I_{L\ max}$) is given by the following equation [34]:

$$I_{L\,Max} = Total\ power(W)/battery\ voltage(V) \quad (36)$$

= 2860Watts / 48 (Volt) =59.58A=60 A.

3.9. PV Array Performance

3.9.1. Solar Fraction

The solar fraction is known as the percentage of the generated energy ($E_{generated}$) from solar PV system to energy demand (E_{load}) which must be as high as possible. The calculated solar fraction in the worst month of lowest irradiance was found as:

$$Solar\ Fraction\ (100\%) = \frac{E_{generatted}}{E_{load}} \quad (37)$$

= (11577 Wh/day) / (10860 Wh/day) =100%.

This result stated that the net generated solar energy is sufficient for the home appliances operation at percentage of 100% and there is an access of energy throughout all the months as showing in the Table 4. There is no loss of load (Pr_{LOL}) i.e. 0% and no loss of production time (T_{LOL}) i.e. (0.0 hours) also. This is important indication of balancing between solar PV system sizing and the recommended energy for the sample home load in selected site.

Table 4. Energy of array, load, user, SF, T_{LOL} and Pr $_{LOL}$.

	EArray	E Load	E User	SolFrac	T LOL	Pr LOL
	kWh	kWh	kWh		Hour	%
January	335.6	336.7	336.7	1.000	0	0.00
February	328.0	304.1	304.1	1.000	0	0.00
March	362.8	336.7	336.7	1.000	0	0.00
April	352.9	325.8	325.8	1.000	0	0.00
May	360.5	336.7	336.7	1.000	0	0.00
June	348.7	325.8	325.8	1.000	0	0.00
July	369.6	336.7	336.7	1.000	0	0.00
August	377.5	336.7	336.7	1.000	0	0.00
September	349.9	325.8	325.8	1.000	0	0.00
October	355.8	336.7	336.7	1.000	0	0.00
November	328.1	325.8	325.8	1.000	0	0.00
December	364.1	336.7	336.7	1.000	0	0.00
Year	4233.5	3964.0	3964.0	1.000	0	0.00

3.9.2. Capacity Factor (CF)

Usually, the capacity factor for solar power systems variety from 10 % to 25 % with a fixed mounting and tilt. the yearly capacity factor (CF) is the ratio of the actual annual power output of the photovoltaic system over a given time frame (typically twelve months) to the energy output that might have been generated if the device had been operated at full capacity for the complete duration [27,28].

$$CF(100\%) = \frac{E_{generated}(Wh/year)}{P_{adjusted,peak} \times N_{modul} \times 8760(h/year)} \quad (38)$$

= (11577 Wh/day ×365day/year)/(214W/module×16module ×8760 h/year) =14%.

The disadvantages of CF does now, don't forget any environmental element like a variation on irradiance from 365 days to another nor does it consider the de-rating or degradation of the panels. Therefore, we aren't convinced that it is a great tool to provide insights into a solar photovoltaic system. The solar strength machine primarily based at the simulation results had an efficiency of 14 % because of the situations the device is actually operating [35].

3.9.3. Performance Ratio (PR)

Performance ratio (PR) is known as the ratio of the of strength output (latest yield, YF) to the reference yield (YR) by using comparing the photovoltaic system efficiency with the nominal performance underneath general check situations [24]. It indicates the percentage of the energy this is truly available for load after deduction of energy losses (e.g. thermal losses, soiling, and so on.) and power consumption for operation. It takes into consideration environmental factors (temperature, irradiation, etc.). PR values are normally suggested on every day or month-to-month or yearly basis and expressed as [26]

$$Performance\ Ratio\ (PR)\% = \frac{Energy\ measured\ (kWh)}{(Irradiance\ (kWh/m^2)\ other\ panel \times Aactive\ area\ of\ PVmodul(m^2) \times PVmodule\ efficiency)} \quad (39)$$

=11577 Wh/day / (5400Wh/day×26m2×0.1552) =53%

The Fig.16. shows that PR varies from month to month throughout the year with an average value of 50.3%. The value of PR in PVsys6.8 was found 50.3% and there is a difference in mathematical calculation (1.9%), this is caused due to deference of the methodology that applied in the software. An outsized system faces common partial or whole array disconnections to shield the batteries in opposition to overcharge, which reduces the PR value. Disconnections to protect the batteries against overcharge.

3.9.4. Array yield YA

The array yield (YA) which represents the (DC) energy output from the PV array throughout the months with respect to normalized PV rated power. It interprets how could generate kWh from PV system per each of peak power of the installed capacity [20, 21]. As seen in the Fig. 14., the average value of about 2.87 kWh/kWp/day during all the months, which reveal this site is very promising in solar energy production over the whole year.

3.9.5. Final System Yield (Y_F)

The Final yield (Y_F) of PV solar power plant is the ratio of the total annual, monthly or daily net AC energy output (E) divided by the peak power of the installed PV array at the standard test conditions 1 kW/m2 irradiance, 25˚C ambient temperature and (A.M 1.5) [22,23]. Figure 15. states that the average of the final system yield is 2.72 kWh/kWp/day ,which means every kW of installed peak power would be generate an average of 2.72 kWh/day throughout all the months which will be covering the demand energy for appliances consumption.

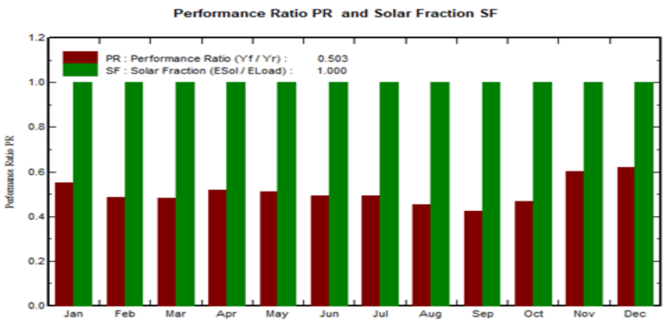

Fig. 14. Performance value of the solar PV system

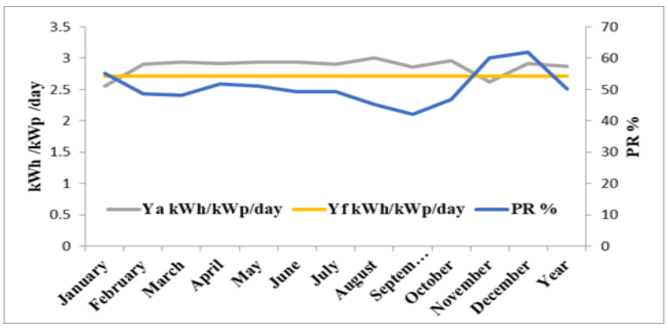

Fig. 15. Performance parameters of solar PV system

3.9.6. Reference Yield (Y_R)

Reference yield is defined as the ratio of total (global) in -plane solar insulation (H_t) (kW h/m^2) divided by the array reference irradiance (G_o) at STC which is (1kW/m^2) [24, 25]. It is a measure of the theoretical electricity to be had at a particular place over a particular time period and may be calculated by [35,36]. The Fig. 16. showing the availability of in-plane solar irradiance over the entire period of the year for generating solar electrical energy that recommended for electrification of the sample home in Haur AL-Hammar. The maximum values through the summer months where maximum energy needed for high electric consumption.

3.9.7. Production factor

Production coefficient is the array production at STC by the manufacturer of the systems. Therefore, the production factor (PF) was calculated as following:

$$PF = E_A/(P_0.H_i/G_{STC}) = Y_A/Y_R \quad \textbf{(40)}$$

Then, the system efficiency (η_{sys}) was determined (as illustrated in fig. 17) according to the following equation:

$$\eta_{sys} = PR/PF = Y_f/Y_A \quad \textbf{(41)}$$

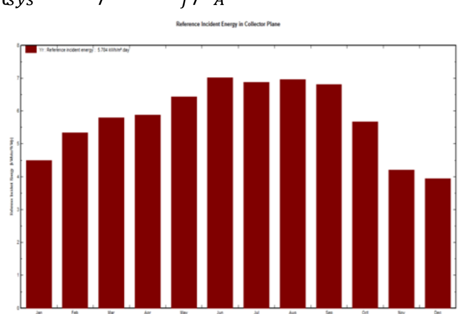

Fig. 16. Reference incident energy in collector plane

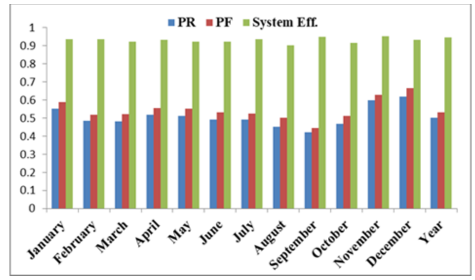

Fig. 17. System efficiency

3.10. Losses of the solar PV system

The loss diagram as shown in the Fig. 18. is available for the complete 12 months or for each month to be able to compare seasonal effects of specific losses. The loss diagram provides insight look into the quality of a PV system design, by identifying the main sources of losses which are include (Shading losses, Incidence angle modifier (IAM), Irradiance Loss, Thermal losses, one-diode model, Real module performances, Mismatch losses, Dirt on the PV-modules, Partial shading electrical effects, MPP loss, Ohmic wiring losses, Regulation loss, MPP applications, excess energy which cannot be used while the battery is complete. It's also include Normalized performance index, these types of array losses are accounted for within the "series Losses" L_C, that is the distinction between year (the proper array yield at STC) and YA (the effective yield as measured on the output of the array). Soiling losses - Irradiance losses, Module quality losses-Mismatch losses-Module degradation loss, losses-Auxiliaries consumption- External transformer losses-System Unavailability loss. The overall losses were accounted as 29.1% of the total energy production, and this is why we should oversizing off-grid solar PV system by 25% to 30% in order to compensate the expected losses and keeping the planning installation capacity of the solar system.

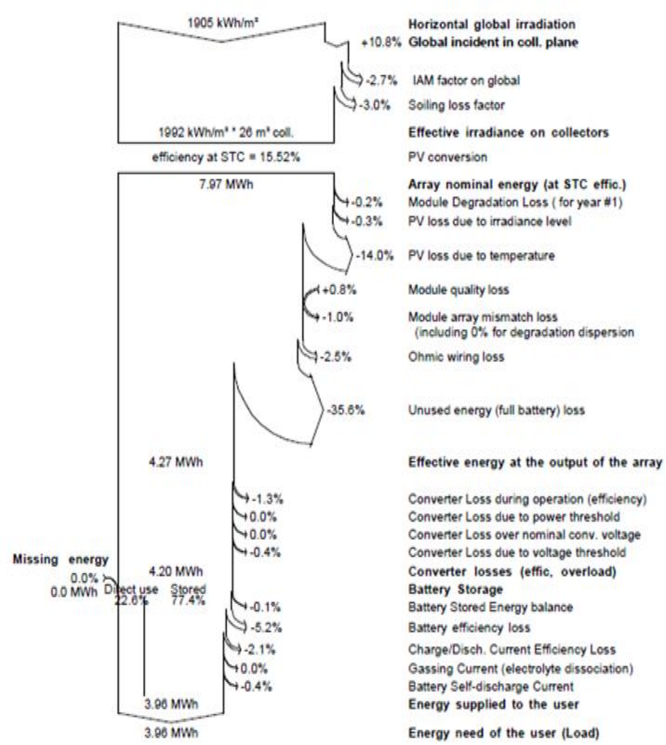

Fig. 18. Diagram losses of solar system

4. Economic evaluation of the home solar PV system

The economic cost of the stand-alone system has been evaluated based on PV modules, inverters and batteries, etc. Our results showed that the cost of maintenance and periodical replacement of the batteries is 150 US$/year, and the total investment cost for stand-alone system is 6050 US$. It has also been found that the production of solar energy was 3964 kWh / year, but the excess energy (battery full) was 1988 kWh / year. Finally, the used energy cost was 0.09 US$ / kWh.

5. Conclusion

The design procedure of sizing of 4.0 kW off-grid solar PV systems for providing electricity to a sample home in the Haur Al-Hammar region was completed to be as guideline for estimation and analysis by using mathematical equations with Excel worksheet and PVsys6.68 software simulation package. The research approved the following topics:

1. The solar photovoltaic home system could be solved the problem of electricity access in Haur Al-Hammar with adequate solar electric energy for all the home appliances.

2. There is an access generating energy which could be useful for future expansion in home loads.

3. The proposed stand-alone solar home systems satisfy the technical and cost effective to generate electricity for homeowner.

4. The availability of solar irradiation encourages installing large system scale for generating electricity in such area in a form of complexes Residential.

5. All appliances should be chosen for the lowest possible energy consumption (High efficiency lighting and Energy efficient refrigeration).

6. The solar photovoltaic home system could provide electricity at daylight for operation all the assumed appliances at full load and gives the user a current for appliances about (7.0A) for continuous 10 hours during night time at 50% depth of discharge.

7. The performance ratio PR varies from month to month throughout the year with an average value of 50.3%.

8. Total system cost of 6050 US$ with a unit used energy cost 0.09 US$ / kWh.

9. For lifetime of the solar system would be reduced the CO2 Emission balance of total 132.2 tCO2.

10. Finally, Electrification of a Rural Home by Solar Photovoltaic System is a feasible (technically and financially).

6. References

[1] Qusay, H., M. Jaszczur, M. Mohamed, K. Styszko, K. Szramowiat, J. Gołaś, “Off-grid photovoltaic systems as a solution for the ambient pollution avoidance and Iraq’s rural areas electrification”. E3S Web of Conferences 10, 00093, (2016).

[2] Rabee, A.. “Estimating the health risks associated with air pollution in Baghdad City, Iraq”. Environ. Monit. Assess. 187 (2015): 4187-4203.

[3] Hoffmann, W.. “PV solar electricity industry: Market growth and perspective”, Solar Energy Materials & Solar Cells, 90 (2006): 3285-3311.

[4] Cambclong, H., J. Sarr, A.T. Niang, J.A. Alzola,E.H.Sylla, M.Santos, “Micro grids project, Part 1: Analysis of rural Electrification with content of Renewable energy sources in Senegal”, Renewable energy, 34 (2009): 2141-2150.

[5] Stutenbäumer, U., T. Negash, A. Abdi, “Performance of small-scale photovoltaic systems and their potential for rural electrification in Ethiopia”, renewable energy, 18 (1999): 35-48.

[6] Givler, T., T. Lilienthal, Technical Report NREL/TP-710-36774, available from http://www.osti.gov/bridge, (2005).

[7] Adeoti, O., B.A. Oyewole, T.D. Adegboyega, “Solar photovoltaic-based home electrification system for rural development in Nigeria: domestic load assessment”. Renewable Energy, 24 (2001): 155–161.

[8] "Mesopotamian Delta and Marshes". World Wide Fund for Nature. Geographic Location: Middle East: Iran, Iraq, and Kuwait (2013).

[9] Bedaira, H. M., H. T. Al Saadb and N. A. Salmanb, “Iraq’s Southern Marshes Something Special To Be Conserved; A Case Study”, Marsh Bulletin, 2 (2006): 99-126.

[10] Al-Shamani, A. N., M. Y. Hj Othman, S. Mat, M.H. Ruslan, Azher M. Abed, K. Sopian, “Design & Sizing of Stand-alone Solar Power Systems A house Iraq”, Conference: Recent Advances in Renewable Energy Sources, (2015): 145-150.

[11] NASA Atmospheric Science Data Center: Solar Power Potential According to Location, ://thegrid.rexel.com/topics/energy_efficiency/w/solar_renewable_and_energy_efficiency/70.nasa-atmospheric-science-data-center-solar-power-potential-according-to-location.

[12] S Idowu, O., O. M. Olarenwaju, O. I. Ifedayo, “Determination of optimum tilt angles for solar collectors in low-latitude tropical region”, Int J Energy Environ Eng. 4: 29, (2013). https://doi.org/10.1186/2251-6832-4-29.

[13] Foster, R., M. Ghassemi, A. Cota, “Solar Energy: Renewable Energy and the Environment” 1st Edition, CRC Press, pp. 382, (2009).

[14] Liu, B., R. Jordan, “Daily insolation on surfaces titled toward the equator”, ASHRAE J. Vol. 10 (United States) (1961).

[15] Muneer, T., G.S. Saluja, “A brief review of models for computing solar radiation on inclined surfaces”, Energy Convers. Manage., 25 (1985): 443–458.

[16] Adaramola, S. Muyiwa, “Techno-economic analysis of a 2.1 kW rooftop photovoltaic-grid-tied system based on actual performance”, Energy Conversion and Management, 101 (2015): 85-93.

[17] A.Handoyo, E., D. Ichsani, “The optimal tilt angle of a solar collector”, Energy Procedia, 32 (2013): 166 – 175.

[18] Ayompe, L.M., A. Duffy, S.J. McCormack, M. Conlon, “Measured performance of a 1.72kW rooftop grid connected photovoltaic system in Ireland”, Energy Convers. Manag., Vol. 52, pp. 816-825, 2011.

[19] Dobaria, B., M, Pandya, M, Aware, “Analytical assessment of 5.05 kWp grid tied photovoltaic plant performance on the system level in a composite climate of Western India”, Energy, 111 (2016): 47–51.

[20] Kumar, K.A., K. Sundareswaran, P.R. Venkateswaram, “Performance study on a grid connected 20 kWp solar photovoltaic installation in an industry in Tiruchirappalli (India)”, Energy Sustain Dev., 23 (2014): 294–304.

[21] Adaramola, M.S., V. EET, “Preliminary assessment of a small-scale rooftop PV-grid tied in Norwegian climatic conditions”, Energy Convers Manag., 90 (2015): 458-465.

[22] Ozden, T., B.G.Akinoglu, R. Turan, “Long term outdoor performance of three different on-grid PV arrays in central Anatolia – an extended analysis”, Renew Energy, 101 (2017): 182–95.

[23] Kymakis, E., S. Kalykakis, and T.M. Papazoglou, “Performance analysis of a grid connected photovoltaic park on the island of Crete”, Energy Conversion and Management, 50 (2009): 433-438.

[24] Ayompe, L.M., A. Duffy, S.J. McCormack, M. Conlon, “Measured performance of a1.72 kW rooftop grid-connected photovoltaic systems in Ireland”, Energy Convers Manage., 52 (2011): 816–25.

[25] Ebenezer, N. K., A. Brew-Hammond, “Design and Analysis of a 1MW Grid- Connected Solar PV System in Ghana”, in ATPS WORKING PAPER No. 78, A.W.P.N. 78, Editor (2013): Ghana.

[26] Sharma, V., S.S. Chandel, “Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India”, Energy, 55

(2013): 476–85.
[27] Guenounou, A., A. Malek, M. Aillerie, “Comparative performance of PV panels of different technologies over one year of exposure: Application to a coastal Mediterranean region of Algeria”, Energy Conversion and Management, 114 (2016): 356–363.
[28] Ayompe, L.M., A. Duffy, S.J. McCormack, M. Conlon, “Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland”, Energy Conversion and Management, 52 (2010): 816-825.
[29] Sidi CEB, E., M.L. Ndiaye, M.E. Bah, A. Mbodji, A. Ndiaye, P.A. Ndiaye, “Performance analysis of the first large-scale (15 MWp) grid-connected photovoltaic plant in Mauritania”, Energy Convers Manag., 119 (2016):411–21.
[30] Pacific Power Association, SEIAPI Sustainable Energy, Technical Design Guidelines Off-Grid PV Systems, system design guidelines (2012).
[31] Felix, A. Ub, E. A. Sarsah, “Optimization of tilt angle for solar collectors in WA”, Ghana, 4 (2013):108-114.
[32] GLOBAL SOLAR ATLAS, Photovoltaic Electricity Potential, The World Bank, Solar resource data: Solargis, (2017). https://solargis.com/maps-and-gis-data/download/iraq.
[33] Surrette Battery Company Ltd,Rolls Battery Engineering, Recommended charging, Equalization and preventive maintenance procedures for Rolls Batteries. Canada, (2017).
[34] Shakya, S. R., Training Manual for Engineers on Solar PV System, Technical report of alternative energy promotion centre (aepc) & energy sector assistance programme(esap), (2011). www.aepcnepal.org.
[35] Fiorelli, J., M. Zuercher-Martinson, How oversizing your array-to-inverter ratio can improve solar-power system performance, Solar power world, (2013). http://www.solarpowerworldonline.com/.
[36] Didier, M., M. Heidenreich, Performance analysis of stand alone pv systems from a rational use of energy point of view, French Agency for Environment and Energy Management, Sophia Antipolis, France.