Design and Economic Evaluation of Electrification of Small Villages in Rural Area in Yemen Using Stand-Alone PV System

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Abstract- The photovoltaic (PV) technology potential for Yemen is relatively high, based on this fact, there are many isolated and remote locations located far away from the electrical national grid and cannot be integrated in the near future. Therefore, the electrification of these rural areas using PV system is very suitable solution to solve the problem of lighting and access to the development of these areas. This paper presents a study on design and cost estimation of stand-alone photovoltaic PV system (SAPS) to supply the required electricity for these villages. The sizing of the suggested SAPS is achieved, such as radiation data and electrical load for the typical household in the target villages also taken into account during the sizing steps. Furthermore, there are a maximum power point tracking (MPPT), an inverter, charge controller and lead acid batteries were designed. The MATLAB/Simulink was run to simulate the PV array sizing and its characteristics depending on incremental conductance MPPT technique to enhance the efficiency of the modules and get maximum available power. The simulation result has been matched the sizing calculation result. Finally, life cycle cost (LCC) analysis was used to evaluate the economic feasibility of the system. The economical results proved that, there is a difference between the conventional energy systems and PV system in that they have a low operating cost and high initial cost. The findings of the study encouraged the use of PV systems in order to electrify the remote Yemeni areas.

Keywords- Rural Electrification, Stand-alone Photovoltaic System, Maximum Power Point Tracking , Decentralize PV System, Life Cycle Cost.

1. Introduction

In the last years, there was a sharp increase in both energy consumption and population, while the conventional energy sources were retreating fast with the rise in cost so; the attention is being paid to renewable energy sources that consider more and more attractive alternative energy. Solar energy, which is copious consider with wind energy the best choice as economical energy sources in many applications. The sun has produced free energy for billions of years where the solar radiation that intercepted by the Earth is a massive amount of power reach to around 1.8×10^{11}MW [1]. There are a lot of renewable energy sources such as wave, biomass, wind, solar and geothermal power can be used for generation of electricity, but the Photovoltaic energy has become increasingly important as a renewable source because it is environmentally friendly, non-polluting, not noisy, free in its availability, requiring little maintenance compared to other resources and easy to expand. Therefore, these advantages make PV generation attractive for many applications, especially in rural and remote areas in most of the developing countries.

Yemeni population is predominantly rural where around 6,733,000 people (27%) of the total population lives in urban zones. From the opposite side, the bulk of the population at about 16,267,000 (73%) are rural spread over various villages live in isolated areas. Additionally, the service of the national electrical network is very poor because of the full load of the national electrical grid just about 1568.36 MW. The rate of individuals profiting from power electricity are only 49%, the vast majority of them live in urban areas by up to 77% [2]. Yemen is situated in the world's solar belt with very good solar irradiation extending between 5.3-6.4 kW/m^2/day and an annual average of daily sunshine hours is between 7.3 and 9.1 hours/day [3]. The natural geography in Yemen is complex because of that there are a large number of mountain villages in several rural areas far from the national electric grid, on the other hand, electrical loads in such villages are mostly small and can be covered using PV generators which are more feasible in terms of the economic side than utilizing diesel electric generators or extending the electricity network.

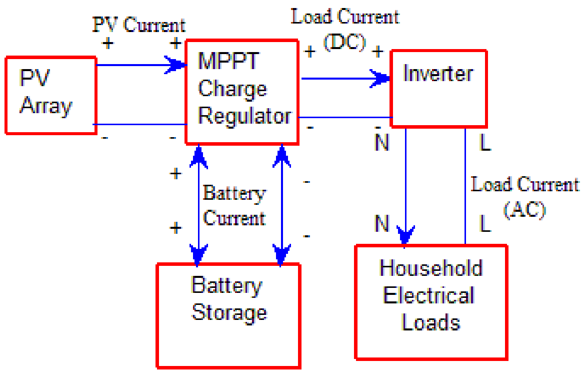

Fig. 1. The Stand-alone Photovoltaic system.

The SAPS is an independent system which is normally utilized in an isolated or remote area where the electric supply is unavailable or not available from the utility grid at a reasonable cost. Figure 1 shows the possible SAPS which consists of four main elements, including solar modules (array), MPPT charge regulator, battery and inverter. Solar array consists of modules connected in parallel /series to meet the required electricity demand. The output power of the PV modules varies according to weather conditions (e.g temperature and solar irradiance). Therefore, the inclusion of a MPPT is vital to keep the modules operating at their maximum power point [4-6]. A charge controller is used also to prevent the battery from being overcharged and to stop any reverse current flow from the batteries and back to the solar module during night. The inverter converts the direct current (DC) energy stored in the battery bank to 220V AC to run alternating current (AC) appliances.

This study presents sizing and an economic analysis for the SAPS to electrify non-electrified four small rural villages in a rural area in Yemen. These villages' tackles as the site of study are Alkala'a, Bani-Saleh, Albalad and Alzaidi which are located in Khawlan at the border of Dhamar.

2. Potential of Solar Energy

The villages are located in Khawlan between 15°-21' N latitude and 44°-12' E longitude. Its inhabitants are mainly worked in sheep grazing and farming. In spite of, the area of Yemen is relatively large (445,000Km^2) and consists of multiple of zones with different terrains for example costal, deserts, mountains, and has more than 200 islands so, the solar radiation (W/m^2) changes with respect to the nature of the zone, thus this study employed radiation data of the area that is taken as a case study [3].

2.1. Solar Radiation and Ambient Temperature

It is very necessary to collect the environmental data such as temperature and solar irradiation to forecast the PV system performance for any site location under consideration. Department of researches and renewable energy at ministry of electricity and energy in Yemen is a good source of these data [7].

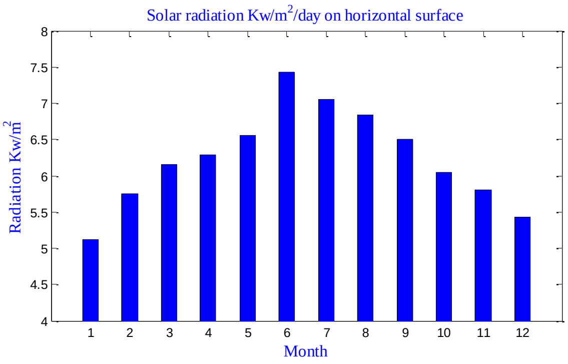

Fig. 2. Monthly average solar radiation for the target area.

Figure 2 illustrates the average data of solar irradiation for all months during the year 2009 taken by the department of researchers and renewable energy. It is clear that the highest radiation in the target area was in June at around 7.4kWh/m²/day, whereas the lowest radiation was in January at about 5.1kWh/m²/day. There was a gradual increase in solar irradiance from January to June, after that the radiation decrease steadily in the period between June and December. This study used the data of worst month radiation to ensure best design [7].

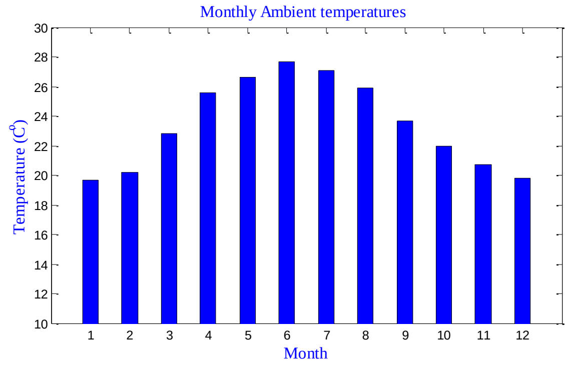

Fig. 3. Monthly ambient temperatures for target area.

The ambient temperature increasing is a very important factor which affects the efficiency of the PV module. The annual average of daily sunshine hours in Yemen is high and reaches to 9hours/day, e.g., at winter time the availability of solar energy is high because through the coldest months from October to February the daily average of sunshine hours is more than 7 hours per day. The monthly temperature variations during twelve months of the site were explained in Figure 3. During main summer months, the temperature is around 27^{o}C had been measured. The maximum temperature occurred between May and August at around 27.5^{o}C while during the period from November to February minimum temperature had been recorded at about 20°C [3, 7].

2.2. The Tilt Angle

The angle between the horizontal axis and the surface of the PV array is the so-called tilt angle. One of the important factors in PV system design is how to install the solar array with an adequate tilt angle to increase the collected energy from the PV panels. Furthermore, the best tilt angle for any PV installation is the location's latitude itself. Although, manual or mechanical tracking will yield more energy than fixing the array at the same angle all the time but, this design fixed the tilt angle at 15° facing to the south as the latitude of the target villages location because it is lower cost than manual or mechanical tracking [8].

3. The Electrical Load Analysis for each Village

These villages that selected as a case study are suitable for using SAPS for electrification purpose because they are very close to each other and have a shape almost like a circle shape consequently, this is adequate to install the PV system in the middle. Furthermore, the villages are far away from the towns, grid and a lot of life services. During the visiting of these villages noted that most of the houses almost very simple and similar to each other. The villages' load concentrates at night period since most of the inhabitants work during daytime in cattle pasture, agriculture fields and so on. The main electrical loads necessary for enhancing the living conditions in each village are lighting, mobile charger, radio, TV, refrigerator, washing machine, and maybe a fan. These are specified in Table 1.

Alkala'a village consists of 28 simple houses while, the village of Bani-Saleh consists of 30 simple houses with one mosque and school which consider the lonely school for all neighboring villages accordingly, it almost consists of 32 houses, 42 houses in Al-balad village one of them is a small mosque, Bait Al-zaidi also consists of 24 simple house. There is no clinic in the target villages but they have only school and two mosques that considered as houses in the sizing. The total households in the target rural village are 126 simple houses where every single house supposed to have on average three rooms, simple bathroom, and kitchen with electrical demand at around 2.771kWh/day as proposed in Table 1. As a result, the total power consumption per day of the target villages can be obtained by multiplying energy consumption (W/day/house) by the number of houses which means 126×2.771=349.14≈350kWh/day. If supposed that the electrical loss is about 5% (16kW) consequently, this system requires generating about 366kW.

Table 1. Electrical loads in each house for the target villages.

Electrical device	Power (W)	Time (h)	Number	Energy uses (w/day)
Fluorescent lamp	40	4	3	480
CFL Lamp	15	2	1	30
TV	120	6	1	720
Refrigerator	180	8	1	1440
Washing machine	225	0.20	1	45
Mobile charger	10	1	2	20
Other devices	60	0.30	2	36
Total	0.650kW/house	21.5	-----	2.771kWh/day/house

4. Stand-Alone PV System Design

To get a more accurate design, we used the data of the worst radiation month which is January with an average radiation of 5.12 Kwh/m^2 as shown in Figure 2. The peak sunshine hours (PSH) obtained by dividing the average of solar radiation by standard radiation 1000W/m^2 [9, 10]. Therefore, the PSH in this design is 5.12h with a constant radiation one kW/m^2.

4.1 Sizing of the PV Array

The peak power of the PV generator (P_{PV}) can be calculated from the following equation [9, 11].

$$P_{PV} = \frac{E_L}{\eta_V \eta_R PSH} \times S_f \tag{1}$$

Where E_L is the daily energy consumption equal 366 kWh/day, PSH is 5.12 h, S_f is the safety factor for compensation resistive losses and PV-cell temperature losses equal 1.15, η_R and η_V are the efficiencies of (inverter and charge regulator), respectively. Thus, the peak power of the PV generator is:

$$P_{PV} = \frac{366}{0.92 \times 0.9 \times 5.12} \times 1.15 = 99.284 \approx 99.3kW_P \tag{2}$$

Suntech polycrystalline-72, type 270 suntech STP-270S-Vb solar panel is selected to obtain the peak power value which is 99.3kW. The selected module has many advantages such as it reduces installation cost, saves both time and money so, more power per module means fewer modules per install, reliable and solid design [12].

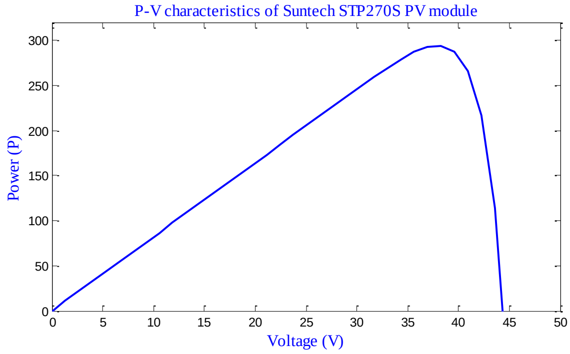

Fig. 4. P-V characteristics of the slected PV module at STC.

Figure 4 and 5 illustrate and verify the nonlinear I-V and P-V output characteristics of the proposed PV module that used in this study with the following specifications 270W power, 44.5V open circuit voltage and 8.2A short circuit current. The module is simulated at constant solar radiation and temperature (1kW/m^2, 25˚C). Figure 4 above shows that the power–voltage curves relations at Standards Test Conditions (STC)

Figure 5 below explains the current and voltage characteristics of the Suntech 2770STP PV module that measured at STC where the open-circuit voltage and short-circuit current values are 44.5 V and 8.2 A, respectively.

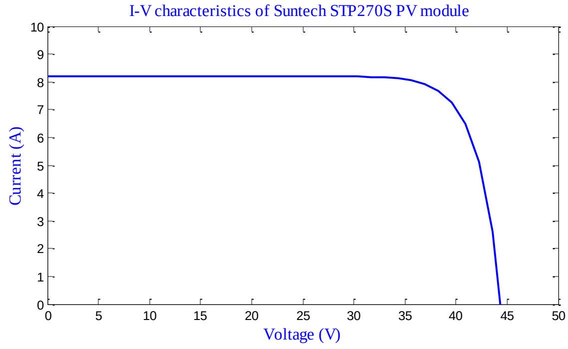

Fig. 5. I-V characteristics of the slected PV module at STC.

From the datasheet of the selected panel [12] founded that this solar module has dimensions of 1956×992 =1940352mm with an area of Apv=1.94m^2, rated at 240VDC and a peak power of Pmax = 270Wp. The number of the necessary PV modules (Npv) is obtained as Npvs = Vnom/Vmpp= 240/35= 7 modules. And a number of strings is 377/7= 54 string. The area of the array is calculated by multiplying the number of modules and the corresponding area of each module:

- The area of the array is (7×1.956) × (54×0.992) = 13.692×53.568 = 646 m^2.
- The actual maximum open circuit voltage is Voc= 7×44.5=311.5VDC.
- The actual maximum short circuit current is Ish = 54×8.2 = 442.8 A.

The configuration of this design will be as shown in Figure 6.

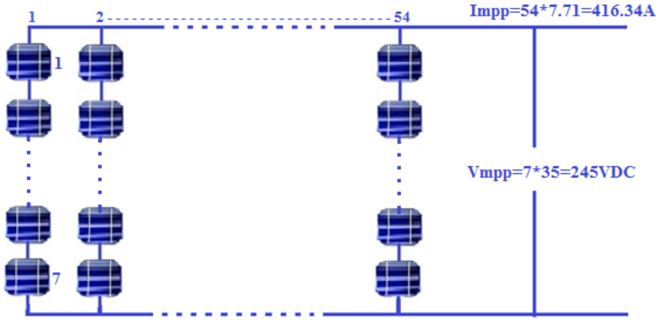

Fig. 6. The PV generators (PV array) configuration.

Accordingly, the maximum power point of this array based on I-V curve occurs at the coordinates of 245VDC and Impp of 416.34A. The actual maximum power obtained from PV is 245×416.34=102kWp, which is more than the required power needed.

4.2 Sizing of the Battery Block

The storage capacity of the battery block for such systems is considerably large. Therefore, a special lead–acid battery cells (Prostar-block type) of a long lifetime are higher than ten years, high cycle stability-rate, and capability of standing very deep discharge is selected [13]. The ampere-hour capacity (C_{Ah}) and watt-hour capacity (C_{Wh}) of the battery block are important in the battery sizing. The number of days of autonomy (days without the sun) required for critical need which depends on the location of the system. In locations with relatively high average radiation, even during the worst part of the year, less storage is needed. Because of the target area almost has clear days (seasonal climate) during the year, we considered that the days necessary to cover the load demands for a period of one day without sun (one day of autonomy), the battery sizing is obtained as follows [9, 14]:

$$C_{Ah}=\frac{\text{days of autonomy}\times E_L}{V_B\times DOD\times\eta_B\times\eta_V} \qquad (3)$$

$$C_{wh}=C_{Ah}\times V_B \qquad (4)$$

Where V_B and μ_B are voltage and efficiency of the battery bank, while DOD is the depth of discharge, C_{Wh} is the watt-hour capacity. The values of μ_B =0.85, DOD=0.75 and V_B= 240V [13], consequently, C_{Ah} and C_{Wh} are obtained as follows:

$$C_{Ah}=\frac{1\times366\times10^3}{240\times0.75\times0.85\times0.90}=2657.95\text{ Ah}$$

$$C_{wh}=2657.95\times240=637.9\text{ kWh}$$

12V/1200Ah lead-acid battery is selected for this design. The batteries distributed as 20 batteries in series rated at 240V whereas, the number of parallel-connected batteries is determined by dividing Ampere-hour capacity by battery capacity so, the batteries in parallel is 2657.95/1200 = 3. As result of that, the number of batteries adequate to storage

366kW is 2.22×20= 44≈45 battery were selected. The batteries are arranged as shown in Figure 7.

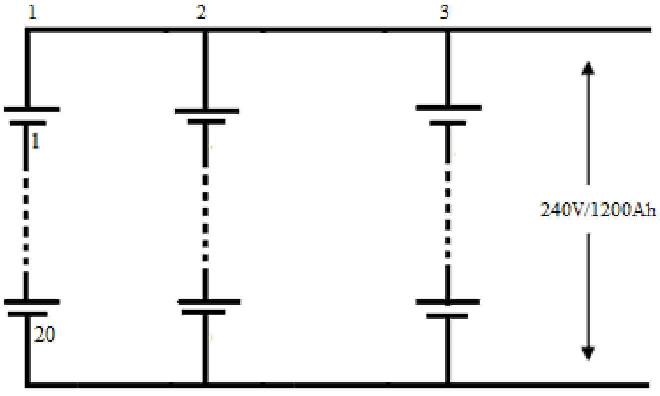

Fig. 7. The configuration of battery blocks of the PV system for the target villages

4.3 The MPPT Charge Regulator and Inverter Sizing

The MPPT Charge Regulator (CR) normally was used to protect the battery block against overcharge or deep discharge also to transfer the maximum available power from the PV array. Furthermore, it was used to inform the PV generators to shut down in the case of batteries reach a required level of charge while allowing the generators to work when the batteries were discharged. The PV generators has a peak power reahed to 102kW, while the nominal voltage of the battery bank is 240V therefore, the current is 412A. In addition, The MPPT must be capable of carrying the short circuit current of the PV array. As a result, the current value of selected CR should boost with 20% [14, 15]. Thus, 490A MPPT CR has to be selected or six in parallel every one rated at 80A and maintained DC bus voltage to around 240V.

The inverter must have the same nominal voltage as the system batteries, large enough to deal with a number of total watts and be able to handle the maximum power of AC load. Therefore, the inverter size has to be 20-25% higher than the total power of the appliances shown in Table 1. [14]. As a consequence, the inverter in the proposed system will be rated at 150kW higher than the nominal system power 102Kw. The specifications of the required inverter will be 150kW, 240VDC, 220VAC, and 50Hz.

5. Incremental Conductance (IC) MPPT Algorithm

The output of the solar panel varies with the sun movement, temperature, and solar radiation level. The MPPT varies during the day and the load has match MPPT in order to utilize the maximum generated power from the modules. The effect of the different levels of irradiance on the voltage-current (V-I) and voltage-power (V-P) characteristics for the panels is presented in Figure 8.

IC method is a simple, old algorithms, and independent on devices. The theory of this method is presented in [16-18]. The IC MPPT method is based on instantaneous conductance and incremental conductance of the PV modules.

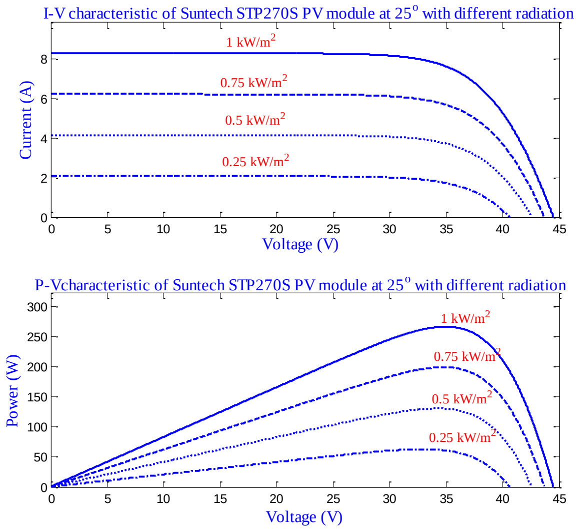

Fig. 8. I-V&P-V curves of the system array at different levels of irradiation.

By measuring and comparing these two values can determine the direction varying of the terminal voltage. When the value of instantaneous and incremental conductance is equal, it means the point of maximum power is found. Figure 9 explains that the basic idea of IC method based on the P-V curve of the solar module. It is clear that at Maximum Power Point (MPP) the slope of the PV array power curve is zero, decreasing on the right and increasing on the left of MPP. The basic equations of IC method are equations (4-6) [18]:

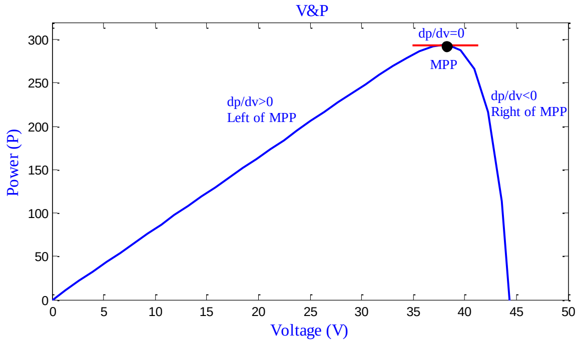

Fig. 9. The Basic idea of IC method on a P–V curve of a solar module.

$dP/dV=0$ At MPP (4)

$dP/dV>0$ Left of MPP (5)

$dP/dV<0$ Right of MPP (6)

The output power is proportional to the terminal voltage when the PV array operating within the constant current area. Thus, when the terminal voltage of the PV array increase (dp/dv >0, positive slope of the power curve) the output power increases linearly. In the case of the terminal voltage of the PV array is falling (dp/dv <0, negative slope of the power curve) the output power decreases linearly. When the operating point of the PV array is just at the MPP that means (dp/dv =0, the slope of the power curve is zero). And can be further expressed as [16, 18]:

$$\frac{dp}{dv}=\frac{d(VI)}{dv}=I\frac{dv}{dv}+V\frac{di}{dv}=I+V\frac{di}{dv} \tag{7}$$

From the relation dP/dV = 0, equation (4) can rearrange as:

$$I=-V\frac{di}{dv}\Rightarrow\frac{-I}{V}=\frac{di}{dv} \tag{8}$$

Where dV, dI represent voltage and current error before and after the increment, respectively.

5.1 Boost DC-DC Converter & PWM Control

The controlling of MPPT system can be achieved by two independent control loops. The first control loop is the IC algorithm itself, whereas the second loop is PI controller. The algorithm of this method tries to find the error signal which is zero at the MPP by using incremental and instantaneous conductance. On the other hands, the purpose of the PI controller loop is to make the error from the points of maximum power near to zero [18, 19].

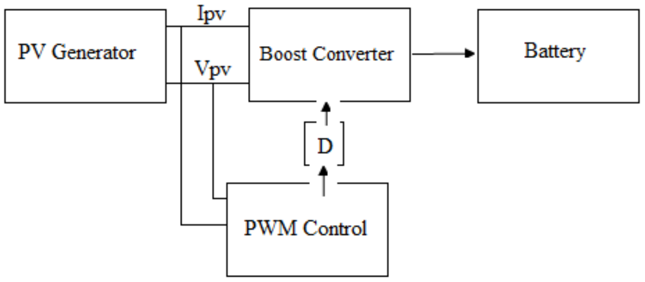

Fig. 9. DC – DC converter operation at the MPP based on PWM control.

Figure 9 shows that the boost DC-DC converter acts as an interface between the PV array and the CR or batteries for the purpose of transferring the maximum available power by adjusting the duty cycle. The MATLAB function generates pulse width modulation (PWM) waveform to control the duty cycle of the converter switch according to the IC algorithm. The setp up converter relations are Vo/Vin=1/(1-D), and Io/Iin=(1-D) where D is the duty cycle. The converter fixes the current and voltage at maximum values, but on the other side change the duty cycle continuously.

6. MATLAB/SIMULINK PV Array Sizing Result

After the calculation of decentralized (without distribution network) stand-alone PV sizing above; now the testing of this sizing by using Simulink will be implemented and the results will be shown. The PV array is connected to the battery block via a DC-DC boost converter where the IC MPPT method was integrated with the converter according to the controller (Simulink model) shown in Figure 10. After that a DC-AC converter was used to convert the storage energy to AC power for household electrification purpose.

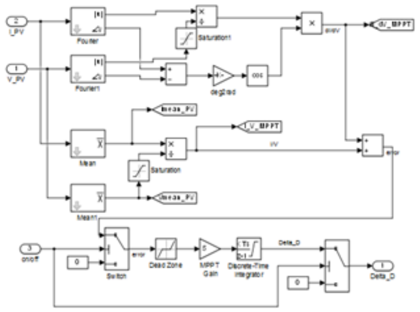

Fig. 10. block diagram of MPPT controller using IC technique.

From the data which illustrated in Figure 2, it is clear that the lowest average solar irradiation in the target area was in January, it was around 5kWh/m² and this value will be ideal radiation to guarantee best design. The PV modules consider one of the most important parts of any photovoltaic system since, after empirical study and calculations the needed number of modules was 378 modules Suntech STP270S type with maximum power equally to 270W in order to cover such load calculated in Table 1. Also, it is clear from the size of PV generators that to electrify the target villages should generate around 99.3kW with taking losses into accounts.

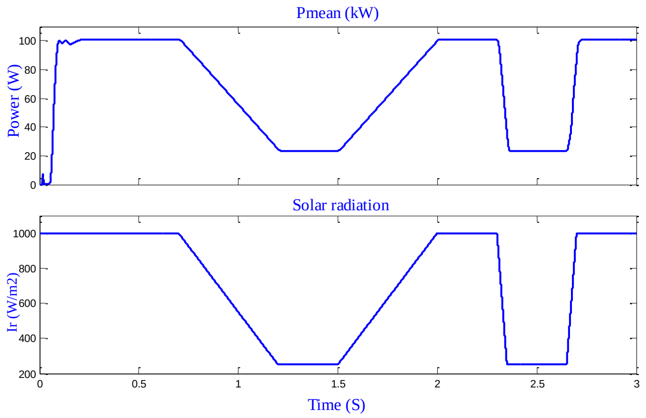

Fig. 11. Output power of the PV generators.

By using the same number of module and implementing IC MPPT algorithm in Simulink, Figure 11 shows the result which illustrates that the PV array delivering a maximum power of 102kW at 1000W/m^2 sun irradiance with five peak sunshine hours, if the sun irradiation decreased to 250 W/m^2 the maximum obtained power is about 20 kW but, this study should generate 99.3kW to feed the target villages consequently, the design fix the radiation at 1 kW/ m^2 with 5PSH to produce about 366 kW per day and this is the required demand.

From the configuration shown in Figure 6, this design requires 378 PV modules distributed as seven series panels and fifty-four strings to provide the required power for village electrification. Furthermore, the PV array has actual maximum PV array voltage Vpv=245VDC, and actual maximum PV array current Ipv = 416.34A. Figure 12 illustrates that by using a Simulink model, the result is as same as in the calculation result.

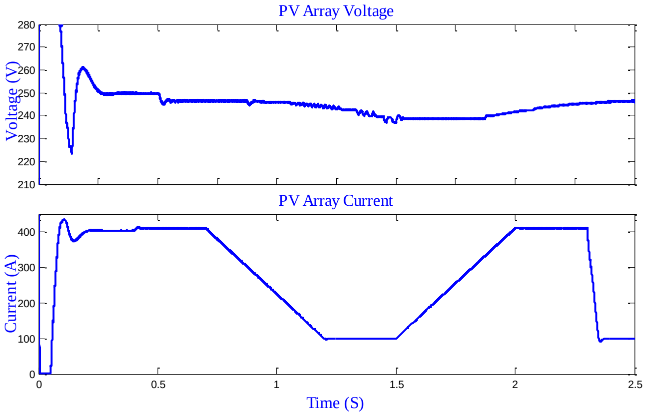

Fig. 12. Maximum voltage and current of the PV array.

Figure 13 below explains the I-V and P-V characteristics of the system array which were used in this design that consist of 7 series module and 54 strings at a different level of radiation. The result of the calculation sizing demonstrated that the actual maximum open circuit voltage was V_{oc}=311.5VDC and the actual maximum current short circuit current I_{sh} was 442.8A. This simulation result supports the theoretical sizing study because it gets an equivalent values. This figure also showed the SAPS array with different sun radiation to provide the system operator with a background by the amount of the power and current of the system which could be generated in case of increasing or decreasing the radiation levels.

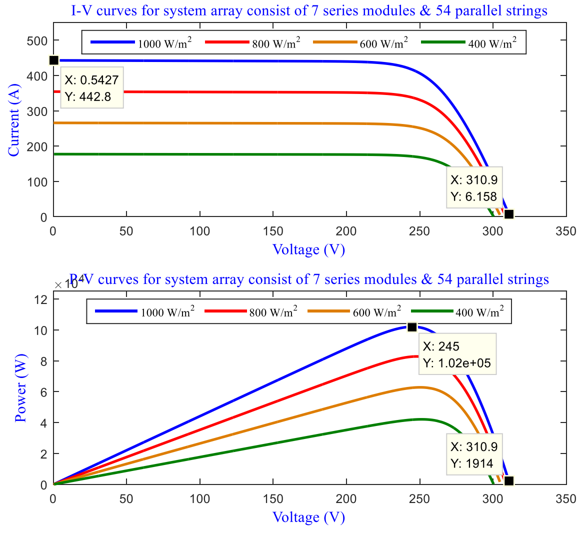

Fig. 13. I-V and P-V for PV system array at different levels of radiation.

The maximum output voltage produced from the PV array should be at about 245VDC. Figure 14 illustrates how the pulse width modulation controll the DC-DC converter in order to changeing the duty cycle continuously in order to guarantee that the PV array will provide this voltage value permanently. Also, we can show that the duty cycle either remains constant or increase, this because every time the voltage decreases the duty cycle increases for the purpous of getting maximum require voltage or stay constant in case of the voltage at the required value. The PWM inform the converter if the voltage decreases by giving pulses to the converter in order to increase the value according to the new change since if the radiation decrease to 250W/m^2 the voltage stays in high level as much as possible.

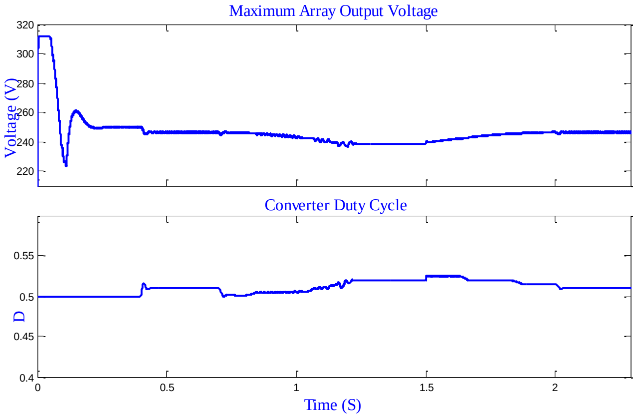

Fig. 14. The voltage behaviour according to duty cycle changes.

7. Economic Evaluation of the PV System Using Life Cycle Cost Analysis

Economics is the basis of most engineering decisions so, this section presents an economic analysis of the proposed stand-alone PV system estimated by using the life cycle cost method. The LCC of an item consists of the total costs of operating and owning it over its lifetime [20]. The costs of this system items include buying cost expressed in today's price, operating cost, maintenance and repeating cost. The economic evaluation using LCC was carried out to estimate the cost per unit of electricity generated by decentralized SAPS. Since the villages are located in a rural area supposed that the land of the project is free of money.

7.1 Economic Evaluation Mathematical Model

Depending on LCC, the mathematical model for any economic evaluation consist of multi-steps which determined that the power supply system can be cost competitive with other energy systems. Equation (9) represents LCC for the decentralized configuration of the SAPV system [20-23].

$$LCC=C_{tcc}+C_{amc}+C_{rc}-C_{sal} \qquad (9)$$

Where, C_{tcc} is the total capital cost for the designed SAPS that including PV modules, MPPT charge regulator, batteries, and inverter. Whereas, C_{amc} is the present worth (PW) value of the annual maintenance cost of the system, the worth value of the replacement cost denoted by C_{rc} whereas C_{sal} is the present worth value of the salvage amount.

7.2 The Economic Evaluation of Decentralized SAPV System

The LCC of the PV system includes the sum of all the PW for the costs PV panels, MPPT charger regulator, the batteries and the inverter. Also, the cost of the installation in addition to the operation and maintenance (O&M) cost of the system. Most of SAPV power system components supposed to have a lifetime of 25 years while others have a different lifetime. In such system, the interest rate is about 10% [22]. With the assumption the project's land is free of money, Table 2. explicates the associated costs of the components, materials, and installation of the decentralized PV power system.

The yearly cost of O&M and salvage value are taken at around 2% and 15% of the initial cost of the project, respectively [22]. Therefore, the cost of these two components is 4816$/year for O&M and 36120$ for the salvage value after 25 years. The cost of the first group which has a lifetime of 25 years is 240800$. The second group such as MPPT CR and inverter with a lifetime of 12 years costing 78000$ whereas, the cost of the third group which includes batteries, switches and CB are equal to 24500$ with a lifetime of 10 years. LCC of The system is obtained by the cash flow shown in Figure 15.

Table 2. The cost of components, materials and installation of SAPV system.

Component	Quantity	Total Price (US$)	Time (year)
Solar panel SuntechSTP 270W	378	132300	25
PCM 80CX MPPT solar charge controller	6	8000	12
Prostar solar Batteries 12v/1200Ah	45	22500	10
PowerGate 150kW Inverter	1	70000	12
Support Structure	1	5000	25
Switches & C.B.	-----	2000	10
Box Work	-----	1000	25
Total Capital System Cost	240800		
Installation Cost	-----	8000	-----
O&M System Cost	-----	4816	-----
Salvage Value	-----	36120	-----

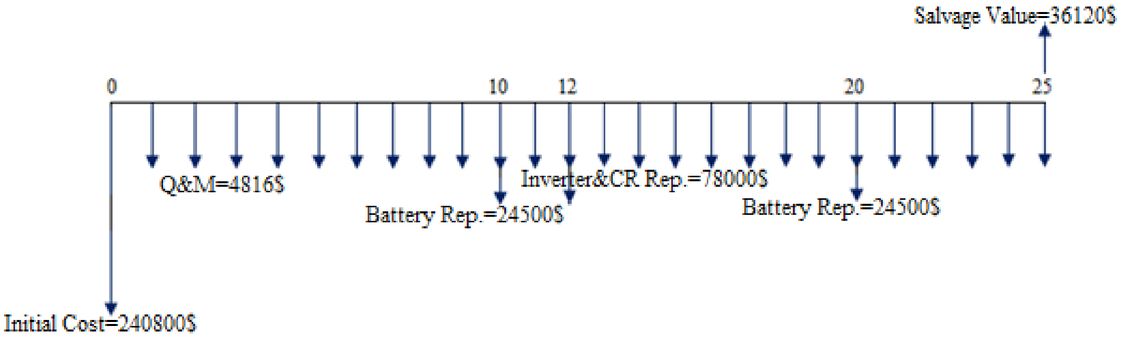

Fig. 15 Cash flow cost of the proposed decentralized SAPVS.

To calculate the uniform series amount and randomly placing amount that included in the annual series of cash flow explained in Figure 15 should convert everything to present (P) or future (F) worth, then by using P/A or P/F factor the uniform series (A) can be founded. According to equation (9) the LCC of the system calculated as [22, 23]: LCC= 240800 + 4816 (P/A, i,n) + 78000 (P/F, i,n) + 24500 (P/F, i,n) + 24500 (P/F, i,n) – 36120 (P/F, i,n). Where n is the number of years and i is the interest rate. P/A and P/F can be calculated using equations (10) and (11), respectively [15, 22, 23]. The tables of factors value and compound interest prepared to shorten the economical calculation since instead of substitution in equations (10), (11) and (13) this table has been made for the period of time from 1 to 100 n value and interest rate ranging from 0.25% to 50% [24].

$$P/A=\left(\frac{(1+i)^n-1}{i(1+i)^n}\right) \quad i\neq 0 \qquad (10)$$

$$P/F=\left(\frac{1}{(1+i)^n}\right) \qquad (11)$$

This study determined the interest value of 10% through economic evolution. From the table of factors, the PW calculated as follows: LCC = 240800 + 4816 (P/A,10%,25) + 78000 (P/F,10%,12) + 24500 (P/F,10%,10) + 24500

(P/F,10%,20) - 36120 (P/F,10%,25). This term (P/A, 10%, 25) depict that the present value at the life time of 25 years can be found from the annual value and at the interest rate of 10%. (P/F,10%,10): this relation means can calculate the present value at the life time of 10 years from future value at the interest rate of 10%. Thus, PW is 240800+ 4816 (9.077) + 78000 (0.3855) + 24500 (0.3186) + 24500 (0.1486) - 36120 (0.0923) = 322695.6 $. The equivalent annual worth (AW) is obtained with appropriate A/P from the following equation [22].

$$\text{Annual Worth= Present Worth Cost}\left(\text{A/P, i , n}\right) \qquad (12)$$

The annual cost is AW = PW (A / P, i,n) = 322695.6$ (A/P, 10%,25). The term P (A/P, i,n), is so-called the capital-recovery factor, or A/P factor, yields the equivalent uniform annual worth A over n years of a given investment P when the interest rate is i. (A/P) factor solved by using the following equation [22, 23].

$$A/P=\left(\frac{i\left(1+i\right)^{n}}{\left(1+i\right)^{n}-1}\right) \qquad (13)$$

From the table of compound interest [24] or by substitution in equation (13), the term (A/P 10%, 25) is equal to 0.1102, then: AW is 322695.6$ x 0.1102 = 35561$. As the daily production of electricity is 366 kWh, the annual production of electricity will be 366 kWh × 365 = 133590 kWh. Therefore, the cost of 1 kWh from the PV generator is equal to 35561$/ 133590 kWh= 0.266 $/ kWh.

8. Conclusion

In most of the developing country like Yemen, the electrification of isolated and rural locations is very important solution to solve the problem of lighting and access to the development of these villages. For that reason, this study tried to examine the economic and technical feasibility of the SAPV system in order to provide the required electricity for a single household in the target area. The design and economic evaluation study for electrification of small rural villages was carried out using SAPS. The theoretical sizing calculation results of the system were proved by using Matlab/Simulink software. Furthermore, this study depicts the economic evaluation depends on LCC, the cost evaluation result explains that the annuity cost of the decentralized SAPV system was about 0.266$/kWh and this value is higher than PV system costs in Oman where the costs of kWh there was 0.21$/kW [25] and lower than PV system cost in Palestine which the kWh costing 0.662$/kWh [26]. The result of this paper indicates that electrification of rural sites in case of long term investment is beneficial and suitable, especially if the efficiency of the PV system increases and its initial cost price decreases as well.

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