Stand-Alone PV Generator Comparing with Conventional Systems for Electrification of Small Social Centres in Remote Area

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Abstract
Many isolated rural communities are located in regions where there is an abundant and reliable supply of solar energy, but where the distance to the nearest power station is many tens or even hundreds of kilometre. It is therefore mainly in these areas that rural electrification is now being provided by PV generators. since Stand-Alone PV generator can offer the most cost-effective and reliable option for providing power needed in remote places. Accordingly these isolated rural canters are fitted with PV for lighting, a refrigerator, a television and socket to supply kitchen appliances .

Key words
Stand-Alone PV system, conventional power station , feasibility study ,remote isolated rural canters

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مقارنة عمل مولد مستقل يعمل بالخلايا الشمسية مع أنظمة توليد تقليدية لكهربة مراكز اجتماعية صغيرة في منطقة نائية

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الخلاصة:
يوجد العديد من التجمعات السكانية في مناطق تتوفر فيها الطاقة الشمسية وبوثوقية عالية في استمرار تدفقها في هذه المواقع والتي تقع بعيدة بمئات والآف الكيلومترات من اقرب محطة تقليدية لتوليد الطاقة الكهربائية. ان تلبية حاجة الطاقة الكهربائية في الوقت الحاضر لمثل هذه المواقع البعيدة يكون باستخدام الالواح الشمسية لتحويل الطاقة الشمسية الى الطاقة الكهربائية. وان عمل مولد مستقل يعمل بالخلايا الشمسية يوفر أفضل الاسعار وعليه ستكون ذات جدوى اقتصادي في استخدامه مع وجود وثوقية عالية في استمرار توفير الطاقة الكهربائية المطلوبة باستخدام مثل هذه المنظومات. إن استخدام هذه المنظومات يعطي حلا مثاليا في توفير الطاقة الكهربائية اللازمة من إنارة وتشغيل الأجهزة المنزلية للمراكز السكنية المعزولة والمتواجدة في مواقع نائية .

1. Introduction
Photovoltaic systems are especially well suited to locations where accessing an tradition sources of energy is either not feasible or expensive. In many such locations, photovoltaic technology is the

least-cost option to meet energy needs for the operation of electric appliances to run the normal activities for the settlement in these remote places.Therefore it is feasible to use this technology to provide the energy for running a social welfare centre al located at these far distance places since it is easy to extend the size of the PV system to include supply electric energy to other essential equipments such as a deliver decent amounts of underground water that necessary to the inhibitors of the centre. Diesel generators were, for a long time the traditional solution for such applications , continuous need for maintenance and repairing, in addition to their noisy operation and bad effect on the environment. On the other hand Photovoltaic has proven to be a reliable source of electric energy and have minimal impact upon the environment because they are clean and inexhaustible. Therefore it is the most suitable alternative sources of energy that can deliver the power needed in this places .Therefore a Stand-Alone PV Generator is provided the right tool that can be used for such important application[1, 2] .The PV system design can be easily modified in order to provided the extra power needed to run the pumping system for domestic used and for water sterilization . The right power and conditions of system operation depend on the daily load used by the inhabited and the amount of daily isolation at the site of the social centre [3,4]. Also one can used this PV system for other important applications such as satellite telephone communication , lighting, vaccine refrigerator at the local medical centre and household appliances.

In order to minimized the power required for sufficient operation for the system so its become more feasible to be used in such application , a continuous progress and develop is currently going on by advocated the merit of those parameter which have the major role in the operation of PV power station such as the solar insulation at the site of the centre and other weather parameter like temperature, beside the power require to operated all the necessary appliances the centre needed to provide the easy and comfort living for the inhibitors of the centre[1,5].

As a conclusion of all the displayed considerations, it has been done to submit this research project of the typical Stand-Alone PV system design to provide the right electricity to run the various social activities of centres locate at far distance from the traditional source of energy such as a national grid. These are requiring precise utilization and evaluation of all the data related to the system design included the terrestrial of solar insulation at the site of social centre.

2. Current Status with Diesel Generators

The mentioned social center is insatlled in the state of Sharjah away from the electricity grid, at not easily accessible sites of sandy nature. Sharjah province is located at 24.3 latitude, 55.5 altitude, 170km from Abu Dhabi, the capital of the United Arab Emirates(UAE).

2.1 Predicted load demand of the social center

The social center includes various alternating appliances distributed on offices, bedrooms, kitchen, bathrooms and others. These includes eight tons air-conditioners, refrigrator,deep freezer, telecommunication facility, and other miscellaneous devices. At the present time, all of the electrical demand is supplied through two diesel generators, that are operating successively. According to the information provided by the local authority of the center for the last three years, the average amount of annual diesel consumption in the center is 62000 liters, which is in the range of 55800 kg.

In the same course, the technical sheets of the utilzed generators show that their peak duty cycle is about 40%, when loaded to full capacity. Actually, it's found out that the used generators are being loaded on annual daily average to not more than 15% of their rating.

It's clearly known that running the generator for long periods at loads below its rated capacity is an expensive practice. As an example, the cost of kWh from 10% loaded generator is around six times that from a fully-loaded generator. Consequently the currently average duty cycle of the generators used at the centers are predicted to be 13%[5,6].

Using the transfer coefficients of converting 1kg diesel to heat energy in kWh [7], considering 13% as average duty cycle and 0.9 power factor, the annual consumption of electrical energy per center on the average last three years is about 81608 kWh.

2.2 Calculation of kWh cost supplied by diesel generator

Accordingly, to calculate the overall Cost of electrical Energy per kWh generated by the diesel Generators (CEG), the following equation is applied:

$$CEG = \frac{GC + RC \times Age}{AE \times Age} \qquad (1)$$

Where:

GC - Generators capital cost, equals \$24500 US for two units per center.

RC - Total annual running cost of generators, equals \$39150 US.

AE - Average electrical energy supplied by the generators annually, in kWh.

Age - Generators life span, assumed 6 years on the average.

Applying equation (1) returns CEG = \$0.53 US.

3. Alternative of Stand-Alone PV System

The process of sizing any stand-alone PV system needs detailed information on two basic parameters: first, the amount of electrical power required by the load; and second, the amount of solar energy available at the site[8,9].

3.1 Load demand and sizing of stand-alone PV array

Concerning the load demand, both the electrical power required and the daily operating hours for each load throughout the year are estimated. The estimation is placed accurately according to the centers daily requirements, taking into account many procedures, of active and passive approaches, to minimize the energy consumption[1,2]. Figure (1) shows the new estimated daily monthly average demands of electrical energy per center throughout the year.

As shown in the figure, the existence of eight air-conditioners makes the highest load demand of summer about six times the lowest demand of winter. While, according to the meteorological data of the area, the soalr radiation energy during the highest load period is no more than twice that of the lowest load period[8]. Figure (2) indicates the monthly rates of solar radiation per m^2 to the daily average demand of electrical energy per center, throughout the year.

To assure a reliable supply of electrical energy all the months throughout the year, the sizing of PV array is placed according to the month of lowest rate, which is August as shown in figure (2).

On the above basis the PV array sizing is placed according to the meteorology of the area for multi inclinations. The optimum solution of the array is found to be 56.4 kW at 20^o inclination[10]. This can be achieved through installing 120W solar modules, assembled in 47 parallel branches each consisting of 10 series modules.

The storage batteries system is calculated according to the maximum monthly daily average demand of electrical energy throughout the year. Calculations show that the required storage batteries system specifications are: 6420 AH at 120 volt.

The required specifications can be met by assembling 12 volt -1605 AH batteries in 4 parallel branches, each branch consists of10 series batteries[11].

3.2 Surplus energy of stand-alone PV system

Since the PV array is sized according to the worst month, August, there will be a surplus electrical energy during other months as shown in figure (3). Arrangements could be made to make use of such surplus energy by adding suitable loads at the corresponding periods.

3.3 Calculation of kWh cost from PV stand-alone system

To calculate the approximated Cost of electrical Energy per kWh generated by stand-alone PV system (CEPV), the following equation is be applied[11]:

$$CEPV = \frac{PSC + SBC \times BN \times BRT}{AE \times Age} \qquad (2)$$

Where:

PSC - PV system cost, considered to be $11 US per watt peak.

SBC - Single battery cost, considered to be $1620 US per unit.

BN - Total number of batteries in the system.

BRT - Batteries replacement times throughout system age.

AE - Total possible electrical energy generated by the PV array annually, in kWh.

Age - PV system age, considered 25 years.

Considering 6 years batteries age, BRT is set to be 3. As for AE, it can be realized by the total summatin of values in figures (1) and (3) that result in 81780 kWh. Hence, applying equation (2) yields CEPV = $0.399 US.

4. Alternative of Hybrid PV/Diesel Generator System

It is clear so far that utilizing stand-alone PV system needs sizing the PV array according to the summer load demand. Consequently the PV array will be over-size during other periods throughout the year. Accordingly, the PV array size, as well as the cost, could be minimized effectively by installing a suitable diesel generator so as to support the PV system during peak load periods.

Referring to figure (2), it can be seen that the peak load periods have increased the PV array sizing, so as to provide a reliable supply throughout the year, in spite of being over-sized during other periods. Accordingly, it has been placed a new system design to reduce the PV array sizing, that is by installing a suitable diesel generator to support the PV system during peak load periods.

Integration of diesel generator in the system requires two important considerations these are running the generator close to its rating so as to increase the duty cycle, and driving it to run during limited periods throughout the day. In this light, the load demand is categorized, theoretically, into three groups as follows:

1. The continuous loads throughout the year, like lighting, refrigerators, TV.
2. Air-conditioners of bed rooms during night hours.
3. Offices air-conditioners, and bed rooms air-conditioners during day hours.

Hence, the diesel generator is dedicated to afford for the loads of item 2, leaving the rest of loads to be supplied by the PV array. This way it will be most likely for the generator to be run only during sleeping hours in summer months. Consequently, the running period of the generator will be limited that prolongs its life span effectively. Assuming 8 years life span, the generator will need to be replaced only two additional times over the 25 years of the age of PV array extends to 25 years .

In, this essense, single diesel generator of 40 KVA capacity that costs about $7000 US is considered in this study.Concerning the running efficiency of the generator, its new rating and limited operation hours will make it loaded not less than 50% of the rating, hence the average duty cycle of the generator is assumed to be 20%.

4. 1 Load demand and sizing of hybrid PV array

Basing on the load distribution senario mentioned above, figure (4) depicts the initial assumption of energy demands that to be supplied by PV array, and diesel generator.

Referring to the PV curve in figure (4), the monthly rates of solar radiation per m^2 to the daily average demand of electrical energy supplied by PV array is shown in figure (5).
Then the PV array sizing is placed, for multi-inclinations, according to the meteorology of the site along with the worst month, which is shown in figure (5) as August. Based on that, the optimal size of the PV array is found to be 32.4 kW at 20^o inclination. Thist could be installed with 120W solar modules assembled in 27 parallel branches each consisting of 10 series modules.
The capacity of storage batteries is calculated according to the maximum monthly daily average demand of electrical energy supplied by PV array. Calculations show that the required specifications of the batteries are 3210 AH at 120 volt. Hence, assembling 12 volt -1605 AH batteries in 2 branches, each branch with 10 series batteries can meet the required specifications.

4.2 Actual sharing and resulting PV surplus energy

In actual conditions, both of the PV array and generator are connected to the distribution panel of the loads. Therefore, the generator would not be run unless the PV array fails to provide the whole load demand. Accordingly, the predicted actual load sharing is different from that assumed initially in figure (4). In this respect the total daily monthly average amounts of electrical energy that can possibly be generated by the PV array is calculated to determine the practical amounts of electrical energy to be supplied by the generator. Results are as indicated in figure (6).
Consequently, the yielded amounts of surplus electrical energy that can be generated by the PV array would be small in this case. Figure (7) illustrates the monthly daily average amounts of such surplus energy.
In the same regard Table (1) shows the percentages of surplus PV array energy in both stand-alone and hybrid PV systems. It shows clearly that the hybrid PV system yields small amounts of surplus energy than that in stand-alone PV system.

Table (1) PV surplus energy in stand-alone and hybrid PV system.

	PV Stand-alone	PV Hybrid
PV surplus energy	32%	7%

4.3 Calculation of kWh cost from hybrid system

Based on figure (6) the annual electrical energy to be provided by the generator is about 13435 kWh. Now, by considering 20% as average duty cycle of the generator along with 0.9 power factor and using the transfer coefficients of converting 1 kWh heat energy into diesel in kgm, the annual consumption of diesel per center will be about 5971 kgm.
Consequently, it is found that the local running cost of the generator, including diesel, transportation, and maintenance equals about $2344 US annually.
To calculate the approximated Cost of electrical Energy per kWh, generated by Hybrid PV system (CEH), the following equation is applied[11]:

$$CEH = \frac{(GC \times GRT) + (GRC \times Age) + PSC + (SBC \times BN \times BRT)}{AE \times Age} \quad (3)$$

Where:
GC - Diesel generator cost.
GRT - Generator replacement times.
GRC - Total annual generator running cost.
Age - PV system age, assumed 25 years.
PSC - PV system cost, considered $11 per Wp + first diesel generator cost.
SBC - Single battery cost, considered $1620 US per unit.
BN - Total number of batteries in the system .
BRT - Batteries replacement times throughout system age
AE - Total annual electrical energy generated by PV array and generator, in kWh.

Considering 6 years batteries age, BRT is set to be 3. As for AE, it can be calculated by the total summatin of values in figures (6) and (7) that results in 59939 kWh. Hence, applying equation (3) yields CES = $0.364 US.

5. Economical Comparison

To evaluate the feasibility of the discussed alternatives, in comparing the current case of diesel generators, figure (8) is prepared. It indicates the accumulated expenses of each case throughout the considered system age. Note that the figure is placed considering constant costs throughout the whole 25 years. However, speculations say that energy markets will face a futuristic increasing in fossil fuel costs along with decreasing in PV system components cost. Thus, this would strengthen the position of PV systems utilization among other traditional approaches.

Figure (8) manifests that the option of hybrid PV system is cheaper than the stand-alone PV system since the first day of installation. Aditionally, the hybrid option can beat the current option of diesel generator after around the tenth year of continuous operation. In the same essence, the PV-stand alone system can beat the diesel generator after around the sixteenth year of installation.

6. Conclusion

Diesel generators usually used to electrify the social centers, located at different places away from the utility grid, are not the right solutions both economically and environmentally. Three alternatives have been studied and evaluated represented by diesel generators, stand-alone PV system and hybrid PV system. It was found that the hybrid PV system is more economical among the three. However, from environmental point of view the stand-alone PV system will be the more suitable, bearing in mind that the stand-alone PV system can afford for additional load demands during off-peak load demand periods.

The outcomes of the current study case will enable the investigators to recognize the sutible approchs that are associated with real implementations of solar energy system for providing the electrical power to run any application in this area such as a desgin for solar energy saving house that conforms the optimum requirements and to supply all the energy demands by the human settlement in villages located in remote-area.

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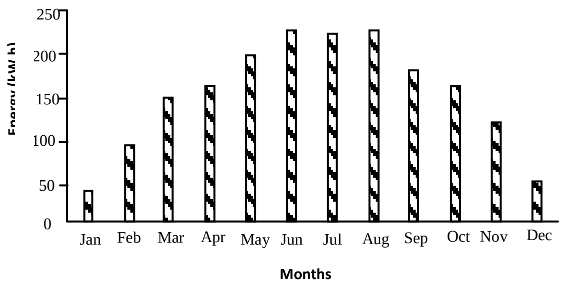

Fig. (1) Monthly daily average demands of electrical energy

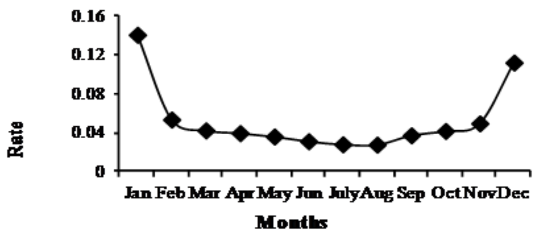

Fig. (2) Monthly rates of solar radiation per m^2 to the daily average demands

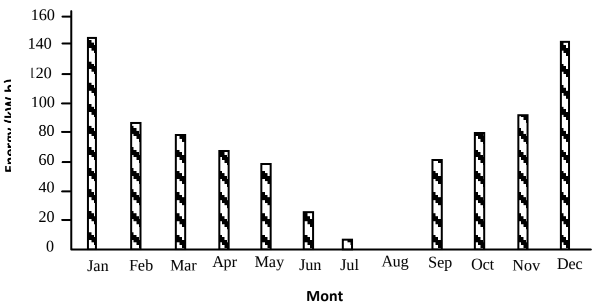

Figure (3) Annual surplus amount of electrical energy with stand-alone PV system

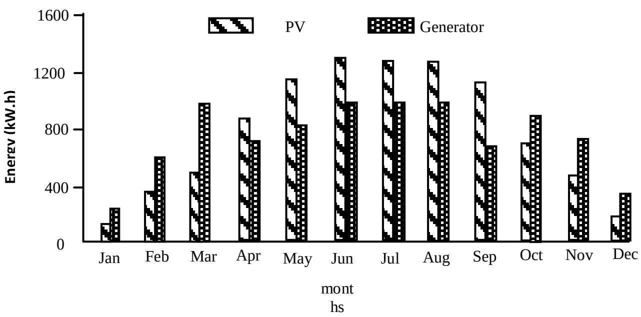

Fig. (4) Initial load sharing between diesel generator and PV system

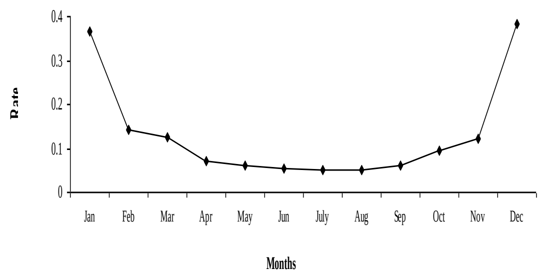

Fig. (5) Solar radiation per m^2 to monthly daily average demand supplied by PV array

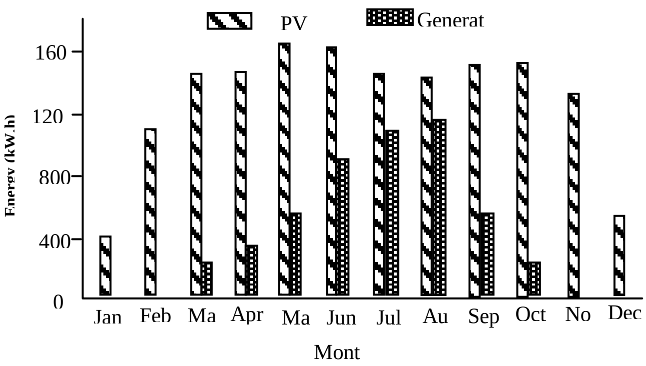

Fig.(6) The practical sharing between PV array and generator

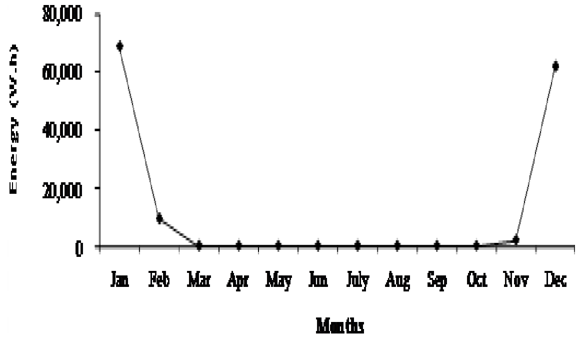

Fig. (7) PV surplus energy associated with the PV hybrid system.

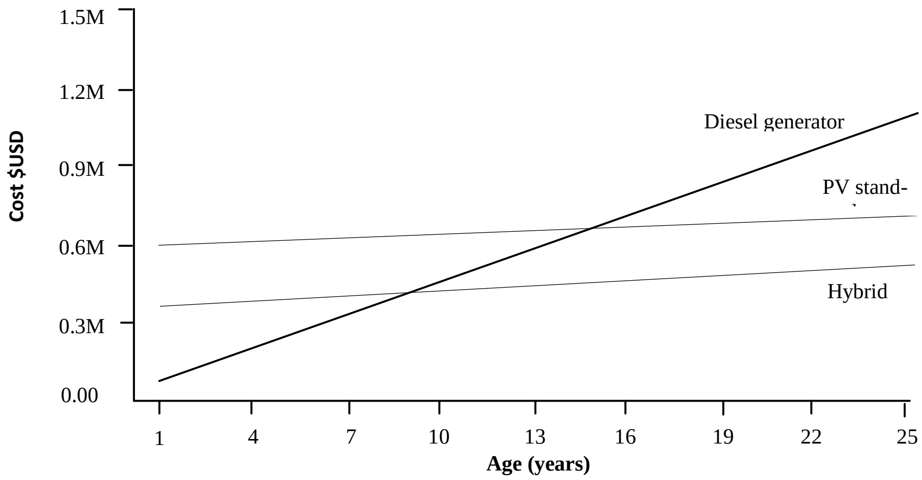

Fig. (8) Accumulated cost of electrification alternatives throughout 25 years.