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DESIGN OF A PV/DIESEL STAND ALONE HYBRID SYSTEM FOR A REMOTE COMMUNITY IN PALESTINE

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ABSTRACT

Hybrid system based on photovoltaic is considered an effective option to electrify remote and isolated areas far from grid. This is true for areas that receive high averages of solar radiation annually. Using diesel generator as a standby source will make utilization of hybrid systems more attractive. An economic feasibility study and a complete design of a hybrid system consisting of photovoltaic (PV) panels, a diesel generator as a backup power source and a battery system supplying a small community in Palestine were presented in this paper. Other scenarios were also studied and analyzed in this paper to ascertain which of them the most appropriate considering cost and pollutant emissions are. A simulation program using iterative approach is developed to optimize the sizes of PV system and battery bank. Specifications of the hybrid system components are then determined according to the optimized values. Solar radiation data is firstly analyzed and the tilted angle of the PV panels is also optimized. Costs of different components, hourly solar radiation and ambient temperatures and other design considerations are inputs of the simulation program. It is found that electrifying rural small community using this hybrid system is very beneficial and competitive with other types of conventional sources as it decreases both operating costs and pollutant emissions.

Key Words: Photovoltaic, Hybrid system, Economics, Rural region

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INTRODUCTION

Different types of renewable energy sources are nowadays used to supply different applications in rural and urban areas (Bhandari, 2011). Increased reliability and energy security issues are of the most benefits that can be achieved by using hybrid renewable systems (Kamalapur,2011;Daud, 2012). Hybrid systems that depend on photovoltaic (PV) are considered the most popular among other types of renewable systems. The main advantages of this technology are their low maintenance costs and low pollutant emissions (Twaha, 2012).

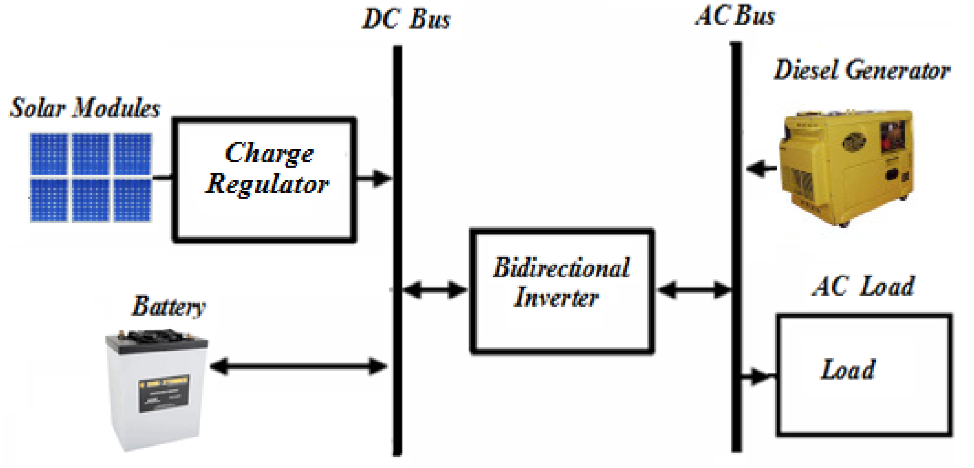
In this paper, a hybrid PV–diesel generator–battery system for generation of electric energy for a small Palestinian community is analyzed. The block diagram of this system is shown in Figure 1.

The type of the hybrid system and its configuration depend mainly on the availability of the renewable source in the location selected for installing this hybrid system. For the Palestinian case, the average daily solar radiation intensity on a horizontal surface is about 5.6 kWh/m^2 while the total annual sunshine hours amounts to about 3000 hours. These values are relatively considered high and very encouraging for using PV generators. For the optimized tilted surface, it is found that this average is about 6.1 kWh/m^2. The highest averages are in summer months (June to August).

Optimization of sizes of different components constructing the hybrid system is one of the important issues that shall be considered while designing this system. Maximizing utilization of the renewable source, minimizing the cost of generating energy and minimizing the pollutant emissions are objective functions of this optimization. Khatib (2011) has concluded that a PV/diesel generator hybrid system is the more feasible system compared to a diesel generator system or standalone PV system for Malaysia case. Hrayshat (2009) has used HOMER software to optimize a suggested PV/diesel hybrid system in Jordan that has a climate that approximately likes climate of Palestine. He has reached to the conclusion that the most optimal configuration in for the scenario that involves PV and diesel. A similar study done for a village in Saudi Arabia, Rehman (2010) has suggested many configurations of the desired system using different types and sizes of components to select the optimal one.

In this paper, different components making the hybrid system shall be modeled, studied, specified, and chosen appropriately to minimize the system cost. Data analysis of solar radiation measurements are also reviewed and studied in this paper. It is assumed that the optimized configuration shall fulfill the load requirement for each hour in the year (no interruption of power supply).

Figure-1. Block diagram of the hybrid system



SIMULATION APPROACH

As it is stated before, a reliability of 100% is assumed in this study. An energy balance is calculated for each hour in a year to achieve this. This is done by a developed simulation program where hourly data for solar radiation, ambient temperature and load are inputted to it.

The energy generated by the PV panels and stored in the battery bank has priority to supply the load. When the battery is discharged to its minimum allowable level, the diesel generator as a backup source is switched on. For each hour step, the developed simulation program compares the load requirement and the available generated energy by the PV system. A decision to charge the battery, discharge it or operate the diesel generator will be taken according to this comparison.

In certain cases where the generated energy exceeds the load requirement and the battery bank is fully charged, this excess energy is consumed by a dump load. As it mentioned before, a decision to operate the diesel generator is taken when the battery is discharged to its depth of discharge level and there is no sufficient generated energy by PV system to supply the load. This case continues until the battery is fully recharged where the bidirectional inverter works as a rectifier and permits to charge the battery.

The power generated by the PV panels is given by Equation (1) (Daud, 2012):

$$P_{PV\text{-}out} = P_{N\text{-}PV} \times (G/G_{ref}) \times [1 + K_T(T_c - T_{ref})] \quad (1)$$

where $P_{PV\text{-}out}$ is the output power generated from the PV panel , $P_{R\text{-}PV}$ is the PV rated power at reference conditions , G is solar radiation (W/m²) , G_{ref} is solar radiation at reference conditions (G_{ref} =1000 W/ m²), T_{ref} is the cell temperature at reference conditions (T_{ref} =25°C), K_T is temperature coefficient of the PV panel (K_T = - 3.7 x 10-3 (1/°C)) for mono and poly crystalline silicon. Equation (2) is used to calculate the cell temperature T_c such that:

$$T_c = T_{amb} + (0.0256 \times G) \quad (2)$$

where T_{amb} is the ambient temperature in °C. The rated power $P_{R\text{-}PV}$ can be calculated using the equation

$$P_{R\text{-}PV} = (E_L \times SF) / (\eta_R \times \eta_V \times PSH) \quad (3)$$

where E_L is daily load energy, SF is stacking factor considered to compensate for resistive and PV-temperature losses , η_R,,η_V are efficiencies of solar charging regulator and bidirectional inverter respectively, and PSH is the peak sun shine hours (numerically equals to daily average of solar radiation at the specified location).

The storage capacity of the battery (C_{Wh}) is calculated using Eq.(4)(Khatib,2011):

$$C_{Wh} = (E_L \times AD) / (\eta_V \times \eta_B \times DOD) \quad (4)$$

where DOD is allowable depth of discharge of the battery, AD is number of autonomy days, and ηB is battery efficiency.

The fuel consumption of the diesel generator depends on the rated power of the generator and the actual output power supplied by it. The fuel consumption of the diesel generator (FC_G) in (l/h) is given by Eq. 5

$$FC_G = A_G \times P_G + B_G \times P_{R\text{-}G} \quad (5)$$

where P_G, $P_{R\text{-}G}$ are the output power and the rated power of the generator in (kW) respectively. A_G and B_G are the coefficients of the consumption curve in (l/kWh) where A_G = 0.246 l/kWh and B_G = 0.08145 l/kWh for the diesel generator (Daud,2012).

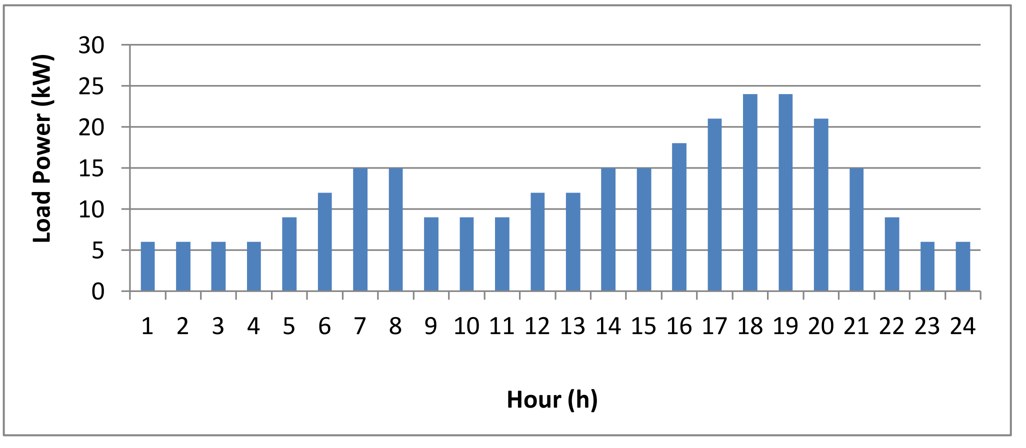
Table 1 includes different inputs and part of outputs of the simulation program. Other inputs like metrological data and location specifications are inputted to the simulation program directly or through EXCEL files. The load curve of the small community under study which is also inputted to the simulation program is shown in Figure 2.

Table-1. Different inputs and part of outputs of the simulation program

Quantity	Value	Quantity	Value
PV cost($/kW)	2700	PV panel size (kW)	70.5
PV installation cost ($/kW)	300	Battery capacity (kWh)	335.7
Bi-directional inverter cost ($)	25000	Yearly load demand (kWh)	109500
PV regulator cost ($)	10000	Yearly energy generated by PV panel (kWh)	141370
Battery cost ($/kWh)	225	Yearly energy generated by diesel generator (kWh)	17290
PV regulator efficiency (%)	95	Yearly dump energy (kWh)	29950

Bi-directional inverter efficiency (%)	92	Diesel generator operating hours (hour)	576.4
Battery Wh efficiency (%)	85	Yearly fuel consumption (liter)	5708.5
PV life (year)	24	COE ($/kWh)	0.326
Battery life (year)	12	Yearly CO_2 produced (kg)	14271
Diesel generator rated power (kW)	30		
Diesel generator cost ($/kW)	800		
Diesel fuel price ($/l)	1.73		
Diesel engine life (hours)	24000		

Figure-2. Hourly typical load curve.



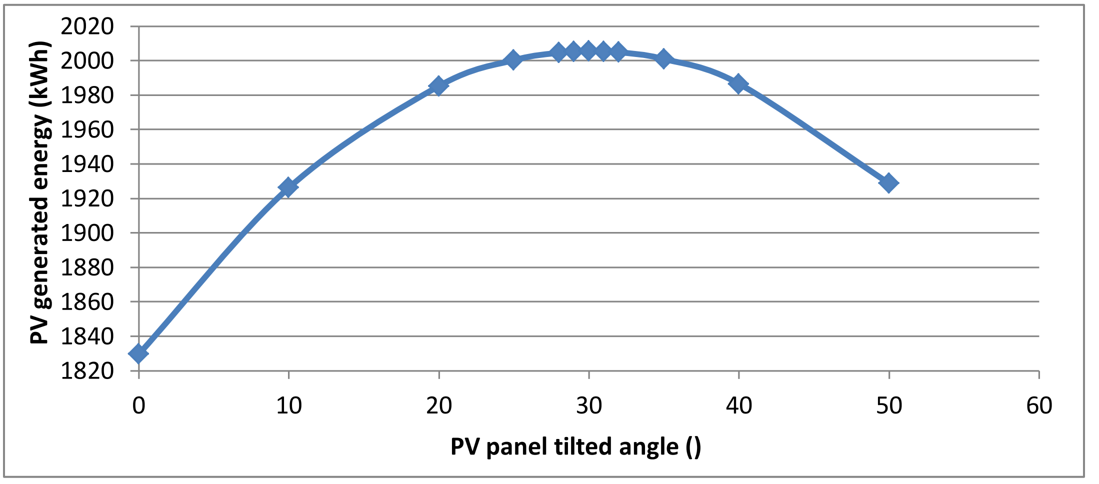
In this paper the economic analysis is done based on life cycle costing method where all types of costs for different components (initial costs, maintenance costs, fuel and operation costs, replacement costs, and salvage value) are taken into account. Cost of energy (COE) which is the cost required to produce 1 kWh is the indicator used in the optimization process. It is the ratio between the total annual cost and the total annual energy required by the load. Different economic factors that affect the value of money over the life time of the project are also considered. These rates are: inflation rate and discount rate. The life cycle period of the project is considered 24 years. It is the life cycle of the component that has maximum life time.

RESULTS AND DISCUSSION

PV data analysis results

Analysis of the available hourly PV data for a one year shows that yearly average daily solar radiation on a horizontal surface amounts to 5.6 kWh/m^2. Figure 3 shows yearly energy generated by a 1 kW PV array for different tilted angles in the location considered where hourly data for solar radiation and ambient temperatures are available. It is obvious that the optimum tilted angle is at 30 ^{o}. The yearly average daily solar radiation is 6.1 kWh/m^2 at this optimum tilted angle

Figure-3. Effect of tilted angle variation on PV generated energy



Simulation results

The results of the simulation program indicate that the lowest COE obtained is 0.326 $/kWh achieved at 100% PV contribution and 0.7 autonomy days (AD). Table 2 illustrates this result and other results considering different values of PV contribution and different values for autonomy days.

Figure 4 shows the contribution of the PV modules and the diesel generator in supplying the load in each month in the year. It is obvious that the diesel generator is off in months May to September where the solar radiation in these months is high.

Figure-4. Energy contribution of PV and diesel generator in each month

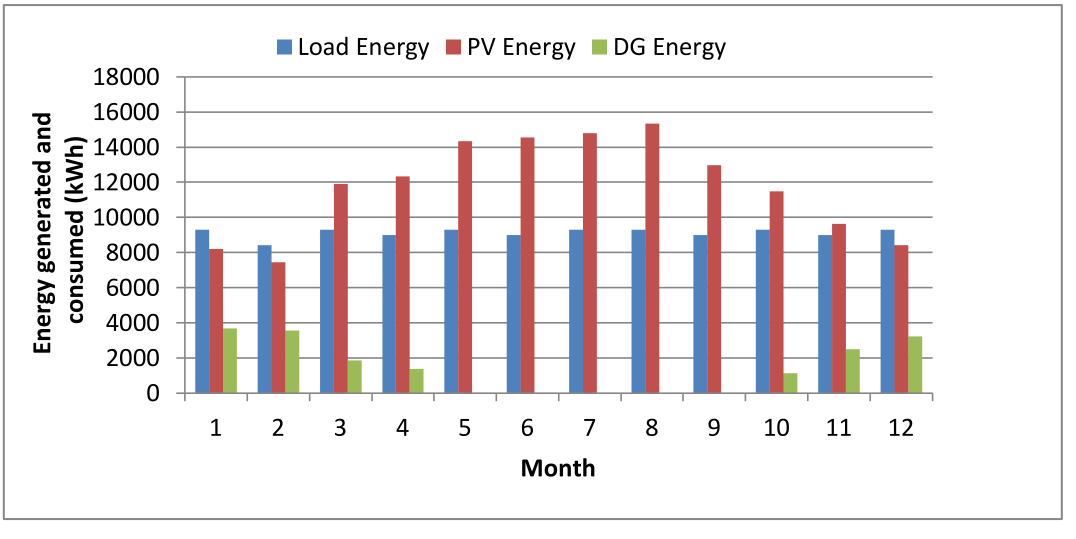


Table-2. COE ($/kWh) for different PV contributions and autonomy days (AD)

AD (day)	PV contribution (%)									
	20	40	60	80	100	120	140	160	180	200
0.1	0.704	0.609	0.586	0.585	0.592	0.603	0.620	0.635	0.653	0.606
0.2	0.715	0.558	0.510	0.508	0.519	0.533	0.549	0.567	0.585	0.672
0.3	0.705	0.587	0.583	0.592	0.600	0.612	0.625	0.638	0.652	0.661
0.4	0.743	0.646	0.599	0.531	0.496	0.485	0.486	0.490	0.503	0.516
0.5	0.767	0.616	0.529	0.396	0.364	0.361	0.369	0.379	0.389	0.403
0.6	0.753	0.634	0.508	0.360	0.334	0.331	0.336	0.349	0.363	0.380
0.7	0.756	0.634	0.492	0.353	0.326	0.330	0.342	0.351	0.367	0.383
0.8	0.775	0.632	0.487	0.359	0.333	0.334	0.340	0.352	0.370	0.387
0.9	0.797	0.631	0.488	0.363	0.335	0.339	0.344	0.356	0.374	0.394
1.0	0.790	0.641	0.494	0.370	0.344	0.344	0.348	0.364	0.382	0.402

Other scenarios are also analyzed in addition to the main scenario. It is found that the COE for a PV standalone system (i.e. without diesel generator) is 0.491 $/kWh and occurs at 200% PV contribution and 2 AD. The rated power of the PV modules in this case is 141 kWp and the required storage capacity is 959 kWh. The other scenario is the diesel generator only scenario. For this scenario the COE is 0.774 $/kWh and the amount of yearly produced CO_2 is 97.04 Ton.

Hybrid system design

The recommended voltage for the DC bus for this hybrid system is 220 V. Other specifications and design issues of main components making his hybrid system are shown in Table 3.

Table-3. Specifications of different components constructing the hybrid system

Component	Specification	Number	
PV Modules	Each PV module has 200 Wp,26.3 V as Vmp, and 32.9 V as Voc	Number of series PV modules in each string	11
		Number of parallel strings	32
Battery system	Each battery has 2 V DC and 400 Ah	Number of series batteries in each string	110
		Number of parallel strings	4
Diesel Generator	30 kW, 3ph, 400 V, 50Hz		1
Charge Controller	30 kW, 360 V input, 220 V output		1
Bidirectional Inverter	30 kW, 400 V, 3-ph ac ouput, 220 V DC input		1

CONCLUSION

Solar radiation data analysis for the location of the study shows that the yearly average is 5.6 kWh/m^2 .day while tilting the PV modules at the optimized angle results in yearly average equals to 6.1 kWh/m^2 .day. This angle is found to be 30 º. Three scenarios are analyzed in this paper. The most economic scenario is the one that includes in addition to the PV panels, the battery system and the diesel generator. The COE for this scenario is found to be 0.326 $/kWh and happens at 100% PV contribution and 0.7 AD. Other scenarios dependent on standalone PV and diesel only give results of COE greater than this value. For the diesel only scenario, both the COE and amount of produced CO2 are greater. The amount of produced CO2 is about 7 times greater compared to the hybrid one. This is in fact a very important environmental issue that shall be focused on. Considering remote areas which are far away from the grid, this solution is the most feasible one even compared with electrifying these remote areas from the grid.

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