Passive and Active Solar Systems for High Schools in Babylon, Iraq: Design and Economic Study

A. Al-Karaghouli*, H. Hason** and L. Coplen***

* National Renewable Energy Laboratory
Golden, Colorado, 80401, USA, Ali.Al-Qaraghuli@nrel.gov
** Al Rasheed General Company, Iraqi Ministry of Industry and Minerals
Kerbala Province (Iraq), hyderhason@yahoo.com
***McKissack & McKissack, New York, NY, USA, lonnie.coplen@gmail.com

ABSTRACT

Solar energy is an ideal application for Iraqi schools, where most energy demands are confined to the daytime, when the solar radiation is at its maximum value.

The study compares the life cycle cost of a solar PV system to that of a diesel generation for meeting the electricity needs of a case-study school in Babylon, Iraq. The PV system is modeled using accepted principles for photovoltaic applications from Solar Energy International and the Sandia National Laboratory Handbook of Recommended Design Practice. HOMER software, developed by the U.S. DOE National Renewable Energy Laboratory, is used for economic feasibility analysis. The study finds that the life cycle cost of a PV generation system is approximately 35% that of a diesel generation system.

Furthermore, the PV system does not produce the noise, pollution and odor of diesel generators, which are ubiquitous in Iraq today.

Keywords: Schools, solar energy, PV, feasibility, HOMER.

1 INTRODUCTION

Schools are ideal for demonstrating the benefits of solar energy applications. They reliably demand significant energy during the daytime when solar energy is at its maximum. Use of solar photovoltaics (PV) for electricity generation, solar thermal for water and space heating, and passive methods for energy demand management in school settings is growing around the world [1]. Solar systems can be designed into building rooftops or a building's shell (as building integrated PB or BIPV), optimizing investment in building materials that is not possible with renewable application retrofits. A benefit of early incorporation of renewables is the opportunity to include these systems as part of the overall facility financing package.

This paper presents a complete PV system design and economic analysis for a school that would be located in Babylon, Iraq. We used design and installation manuals of the Solar Energy International [2], the Sandia National Laboratory Handbook of Recommended Design Practice [3], and the HOMER software developed by the U.S. DOE National Renewable Energy Laboratory [4]. A later study will incorporate this system into an ultra-high efficiency school model, and include total cost estimates for different energy and envelope options.

2 CASE STUDY

The location for the study is Hillah, Babylon governorate (32o30’ N latitude and 44o25’ E longitude). Iraqi schools are usually in session from September to June. Iraqi high schools have six grades, and an estimated 24 total number of classes (four for each grade). The estimated number of students is 720 (24 classes of 30 students each), and the number of staff is about 80 (teachers and administrative staff). The school is assumed to be running 12 hours per day (two shifts) and five days per week.

2.1 Design Criteria

This case-study assumes the following: three administration rooms; one teachers’ room/hall; one library or a study room; twenty-four teaching classrooms; two science laboratories; one cafeteria; six restrooms (four for the students and two for teachers and staff); corridors, common areas, and courtyards; power and water usage typical for an Iraqi high school. Design criteria assumed in these case-studies include: maximize natural light; match the school appearance with the rest of the neighborhood; provide typical school facilities; provide each student with a locker around a cafeteria or common room; use durable, cost effective building materials; leverage all possible means to yield an energy-efficient facility.

2.2 Power needs

Lighting and other electrical devices used in the school are listed in Table 1.

Table 1: School Load Worksheet

AC load	Qty	V	Amp	Watt	Use		D/wk	Avg daily load (W-h)
					Hr/d	D/wk		
Lamps (Int)	154	220	0.09	3080	12	5	7	26400
Lamps (Ext)	26	220	0.09	520	12	7	7	6240
Refrig.	2	220	1.09	480	14	7	7	6720
Freezer	1	220	1.09	240	14	7	7	3360
TV	1	220	0.6	130	3	5	7	279
VCR	1	220	0.14	30	3	5	7	65
Comm set	1	220	0.14	30	12	5	7	257
H2O pump	1	220	0.46	100	6	5	7	429
Comp. set	6	220	0.23	300	12	5	7	2572
Ceiling fan	36	220	0.28	2160	12	5	7	18515
Evp. cooler	6	220	2.3	3000	12	5	7	25715
Power tool	1	220	1.4	300	3	5	7	643

AC total connected watts = 10,370
AC average daily load = 91,195 W-h/day

This case study assumes a solar thermal heating system will provide energy efficiently and economically for space heating. In hot months during school time, evaporative coolers are assumed, which work economically in the hot, dry weather typical of Babylon. Heating and cooling loads are estimated only. A subsequent effort will propose properties of walls, roofs and windows, orientation, heating and cooling loads, and consider various cooling options. That effort will provide cost estimates for different options.

2.3 Modeling the System

The feasibility analysis was performed using the HOMER software developed by the National Renewable Energy Laboratory (NREL). HOMER software models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. Various iterationsofthe system are modeled, and energy-balance simulations are calculated for each of the 8,760 hours in the year. For each hour, the electric demand is compared to the energy that the system can supply in that hour, and it calculates the flows of energy to and from each component of the system. The software also decides for each hour how to operate the generators and whether to charge or discharge the batteries. HOMER inputs follow in this section.

- Load: The total connected load power is 10,370 W; average daily load is 91,195 Wh. The main load occurs from 7 a.m. to 6 p.m. A small load occurs from 7 p.m. to 7 a.m. due to exterior lighting, refrigerators, and freezers.

- Solar input: The school is located in Babylon Iraq, which is at 320 30' N latitude and 44025' E longitude. Solar radiation was obtained from NASA surface metrology and a solar energy Web site [6]. The annual daily average solar radiation for this site is found to be 5.56kWh/m2/d.

- PV modules: The input data of the PV panels were suggested as 0, 8, 10, 12, 14, 16,18,20,22,24,26,28 kW. The panels are assumed to be fixed and tilted at an angle of 320 30' (site latitude) and to have a 25-year lifetime with a derating factor of 90%. Capital and replacement costs were assumed at US$ 3.0/W, including shipping, tariffs, mounting, hardware, control system, wiring, installation, and dealer mark-ups.

- Batteries: The battery type is Trojan T-105, 225 Ah and 6 V; the lifetime throughput is 845 kWh. Various numbers of batteries (0, 80, 100, 120, 140, and 160) were considered. The estimated price of each battery is assumed to be U$200.

- Inverters: Inverters of various sizes (0, 4, 6, 8, 10, 12, 14, 16 kW) are considered. Efficiency, price, and lifetime are assumed at 90%, US$ 0.8/W and 15 years.

- Generator: Various sizes of generator (0, 1, 2, 3, 5, 6, 8, 10, 12, and 14 kW) are considered. The estimated price and lifetime of the generator is assumed to be US$ 1.5/kW and 15,000 operating hours.

- Fuel for generator case: A diesel fuel cost of U.S. $ 0.8/L is used in this analysis.

- Interest rate: 5% interest rate is used in the analysis of performance comparison.

2.4 Results: Case Study Design

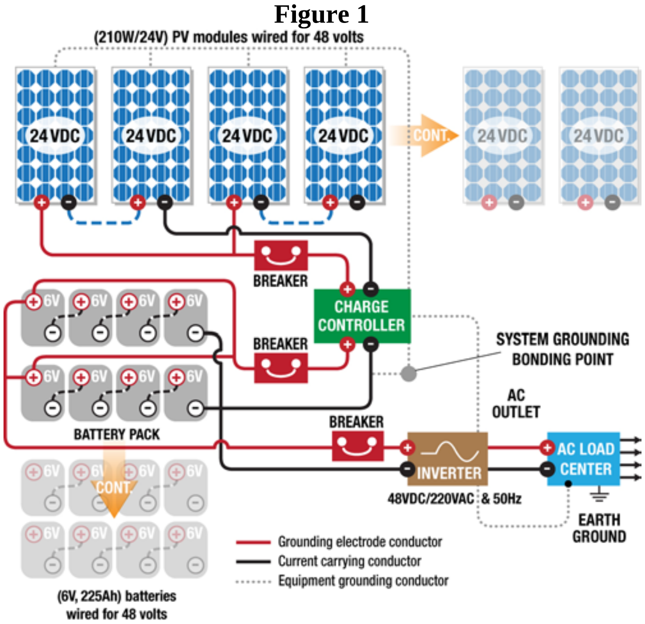
In HOMER, the optimal system configuration satisfies the load constraints at the lowest total net present cost. Based on input, HOMER modeled five systems. The first system, the case study, comprises PV modules, batteries, and inverter. The fifth comprises a diesel generator only. The case-study system is the optimal system configuration—meaning the one with the lowest total net present value (NPC) of US$ 133,632 (including capital, operation, maintenance, and replacement costs).

Cleantech 2012, www.ct-si.org, ISBN 978-1-4665-6277-6

The case-study PV system is designed to provide electricity for the basic needs at the school. The daily hourly load is the major consideration in PV system design. The system comprises components to generate, store, and convert DC to AC power. (For hot-water production, a simple solar water heating unit is used.) Components of the PV power generation system follow. Figure 1 shows the PV system schematic diagram. The case-study system consists of the following:

- The total number of modules needed to satisfy the array peak current load of 471 amperes is 120 (118) modules, specification: 210-W/24-V.
- For the school daily load of 91,195 Wh/d and for one day of autonomy, the system needs 112 batteries , specification 225-Ah/6-V batteries
- 11 kW inverter, 48VDC/220VAC and 50 Hz, 90% efficiency
- One or more charge controllers with LVD and metering that can handle 632 A from the PV array. Voltage must match the system voltage of 48V.
- Balance of systems (BOS) that includes modules structure, wiring, fuses, and other safety devices.

Figure 1



2.5 Life Cycle Cost Comparison: Case Study PC System versus Diesel Generator

The system net present and the annualized costs for PV array, batteries, inverter are about 70%, 20% and 9% respectively of the total system initial cost and they are 58%, 30%, 10% of the total cost during the system life time. The difference between the two set of values is because the PV array does not require reaplcement during the system life time, whereas batteries and inverters must be replaced.

The annual cost of the diesel generator only system over the system life is US$377,955, distributed as follows: 3.2% for initial cost, 25.1% for replacement cost, 16.3% for operation and maintenance cost, and 55.4% (18,687 liter/ year) for fuel cost. The life cycle cost of the PV system is much cheaper than the diesel generator system over a 25-year period.

The analysis also shows that using a PV system instead of a diesel generator results in preventing the annual emission of 49,209 kg CO2, 121 kg CO, 13.5 kg hydrocarbons, 9.16 kg of suspended particles, 98.8 kg SO2, and 1,084 kg NOx. These harmful gases could be prevented by using a PV system. The PV system would also avoid the noise and stink of diesel generation, which is nearly ubiquitous in Iraq today.

3.0 SUMMARY AND CONCLUSIONS

We modeled a high school power load of 91,195 Wh/day using solar data for Babylon, Iraq. Using HOMER to consider several system configurations, we found the case study PV system has a total life cycle cost that is lower than that for a diesel generator system. The case study has initial, net present, and electricity costs of U.S$110,000, U.S$ 133,633, and U.S$ 0.256/kWh, respectively. The diesel generator only system has initial, net present, and electricity costs of U.S$ 12,000, U.S$ 377,995, and U.S$ 0.702 respectively.

REFERENCES

[1] National Best Practices Manual for Building High Performance Schools. Department of Energy, USA 2007.

[2] Solar Energy International, 2004. *Photovoltaic Design and Installation Manual*. New Society Publisher, Canada.

[3] Sandia National Lab oratories, 1988. *Stand-Alone Photovoltaic System: A Handbook of Recommended Design Practice*. SAND8 7-7023. Updated March, 1995.

[4] Lambert, T, Lilienthal, P. HOMER: the micro-power optimization model. Software produced by NREL. Available at www.nrel/gov/HOMER; 2004.

[5] Solarbuzz LLC, August 2011, Solar energy electricity prices report," www.solarbuzz.com.

[6] NASA Surface Meteorology and Solar Energy, 2004, www.eosweb.larc.nasa.gov.