

Full Length Research Paper

Design and performance of photovoltaic power system as a renewable energy source for residential in Khartoum

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Accepted 7 February, 2012

This paper discussed the efficient system of sustainable renewable energy for domestic used and its total cost. The method of this paper was the collection of the basic data of solar radiation, wind speed and other required input data, and then hybrid optimization simulation model was developed using the electric renewable energy software hybrid optimization model of renewable energy (HOMER). Simulation model has been used to find out the best technically viable renewable based energy efficient system for different numbers of household. The result of some topologies of hybrid power was found. Simulation results have been presented as the most efficient achievement and economic way for different numbers of household. The overall cost of energy would be low if the turbine cost decreases in Khartoum. The project life time has been considered for 25 years and the annual real interest rate has been taken as 4%. The coast in 25 homes was found to be 1,567,220 USA\$.

Key words: Khartoum, hybrid optimization model of renewable energy (Homer), renewable energy, power system, domestic.

INTRODUCTION

A hybrid energy system generally consists of a primary energy source working in parallel with standby secondary energy storage units. Hybrid optimization model of renewable energy (HOMER) has been used to optimize the best energy efficient system for Khartoum considering different load and wind photovoltaic (PV) combination. Figure 1 reflects the propose scheme as implemented in HOMER simulation tool. HOMER software developed by National Renewable Energy Laboratory (NREL), USA for micro-power optimization model, has been used to find out the best energy efficient renewable based hybrid system options for Khartoum. It contains a number of

energy component models and evaluates suitable technology options based on cost and availability of resources (HOMER, 2005). HOMER optimum configurations of appropriate power stations were suggested in the plan depending on the energy resources available in specific locations (Indradip and Chaudhuri, 2008). Analysis has been done for single home user as well as combination of 10 and 50 home users to get the most economic and technical viable options (James and James, 2005). HOMER models each individual system configuration by performing an hourly time-step simulation of its operation for one year duration. The available renewable power is calculated and is compared to the required electrical load (Dalton et al., 2009).

Sudan lies between latitude 3°N 23° N and longitude 21°.45/E and 39°E. This large area enjoys a variety of

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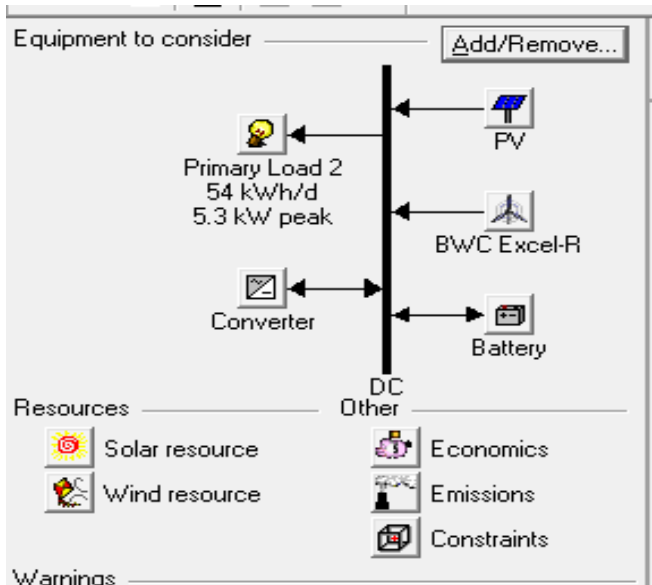


Figure 1. Schematic diagram of hybrid power system.

climates, from desert regions in the north to tropical in the south, and makes it a favourable environment for all activities of the integrated agricultural investment from production to processing industries. Sudan is a relatively sparsely populated country (UN.UONISCO, 2004). Khartoum climate region in the summers are invariably hot (mean maximum 41°C and mean minimum 25°C) with large variation and low relative humidity averages (25%). Winters can be quite cool. Sunshine is very prevalent. Climate is a typical desert and rain is infrequent and annual variation in temperature is large. Fluctuations are due to dry and rainy seasons. Two main air movements determine the general nature of the climate. First, a very dry air movement from the north that prevails throughout the year.

Khartoum is located at 15.38 latitude and 32.28 longitudes. Energy planners have long envisioned large utility-scale solar power plants covering large expanses of desert (Alnaser et al., 2004), while this vision has many favorable attributes, the economics require careful investigation. Ground-mounted PV systems require the allocation of land, which must be acquired and prepared to accept the PV system. The cost of land and the cost of site work can be considerable (Anonymous, 1996). In Sudan and many other developed countries, lack of available large open tracts of land has effectively precluded the grid connected PV option as afforded to develop in Sudan. As interest in solar electricity increases, there is a growing consensus that spread PV systems that provide electricity at or near the point of use will be the first to reach prevalent commercialization (IEA, 2002).

This paper describes the designing and implementation process for hybrid system in Khartoum capital of the

republic of Sudan that took about 12 months, starting from January 2009, and HOMER simulation tool has been at length used in order to compare and optimize the electrical demand to the electrical energy that the system is bright to supply, on an hourly base.

DESIGN PROCEDURE

Hybrid power system

HOMER simulates the operation of a system by making energy balance calculations for each of the 8,760 h in a year. For each hour, it compares the electric and thermal demand in the hour to the energy that the system can supply in that hour, and calculates the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER also decides for each hour how to control the generators and whether to charge or discharge the batteries. HOMER performs these energy balance calculations for each system configuration. It determines whether a configuration is feasible. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel and interest. System in HOMER information about the load, resources, economic, constrains, controls and other component that have been used in HOMER are as shown in Figure 1.

Electric load material

A typical load system (Table 1) for single home in the remote areas has been considered for the analysis. Monthly average hourly load demand (Sudanese perspective) has been given as an input of HOMER and then it generates daily and 2.3 kW/day monthly load profile for a year as shown in Figure 2. It has been found that for this system, each home user consumes energy around (338 W/day of Wh/day) with a peak demand of nearly. The system also gives the opportunity for expanding its capacity in order to cope with increasing demand in the future. This can be done by increasing either the rated power of diesel generator, renewable generator or both of them (Nayar et al., 1993).

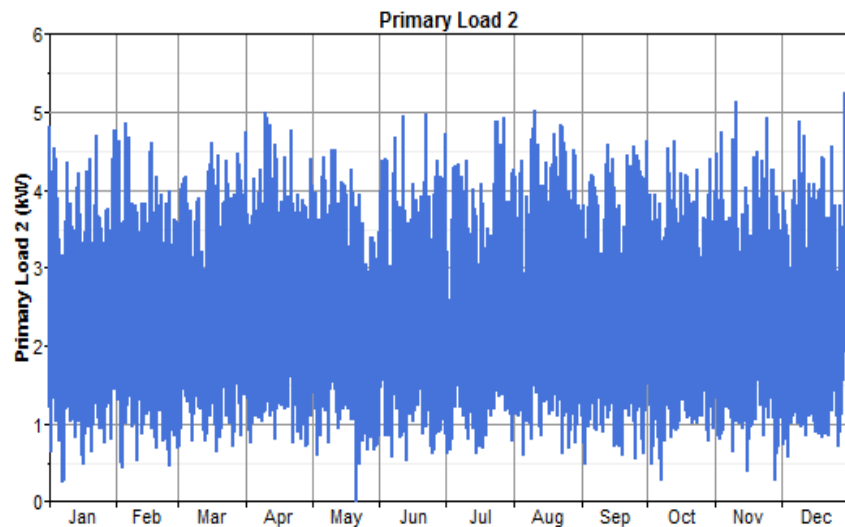
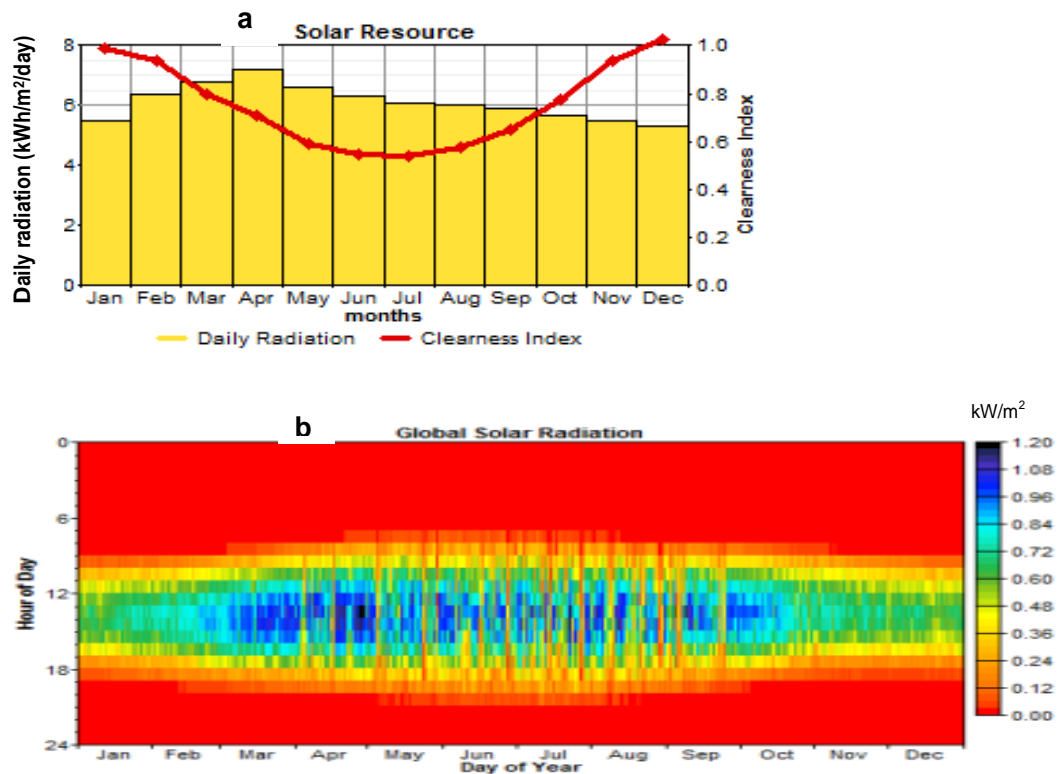
RESULTS AND DISCUSSION

Renewable resources

Since hourly data is not available, therefore, monthly averaged global radiation data has been taken from NASA (2008). HOMER introduces clearness index from the latitude information of the selected site and this index values are shown as in Figure 3. HOMER creates the synthesized 8760 hourly values for a year using the Graham algorithm (Graham and Holland, 1990) which results in a data sequence that has realistic day-to-day and hour-to-hour variability and autocorrelation (HOMER, 2005). For wind, monthly averaged (1999 to 2007) measured data from (SEI) have been used along with the information of height = 30 m, elevation = 3 m ASL and surface roughness = 0.01 m (Benemann and Chehab, 2000). HOMER create these monthly average data based on other parameters, such as, Weibull factor "k" = 1.8, autocorrelation factor (randomness in wind speed) =

Table 1. Appliances for single home user.

Appliance	Quantity	Capacity (W)	Maximum use hour/day
Florescence light	4.2	10	4
B/W TV	1.5	15	4
Radio/Cassette	1	5.5	5

**Figure 2.** Primary load 2.**Figure 3.** Solar analysis diagrams; (a) global solar radiation; (b) daily radiation-clearness.

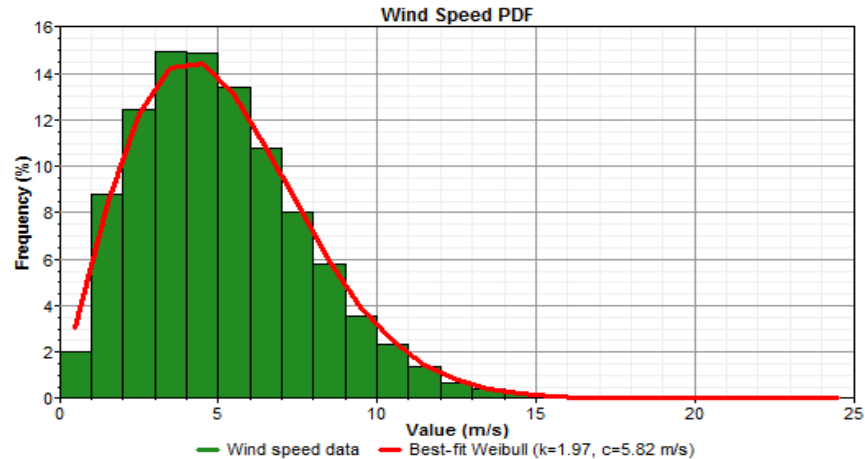


Figure 4. Daily wind speed.

0.90, diurnal pattern strength (wind speed variation over a day) = 0.25, hour of peak wind speed = 22 m/s to generate hourly data for a year as shown in Figure 4 (Ahmad and Nayar, 2004). Certain systematic result depends on different location that obtains the analysis. Combining the renewable energy generation with conventional wind, PV power generation will enable the power generated from renewable energy sources to be more reliable and affordable (Rohinton, 2009).

Photovoltaic module

The cost of PV module, including installation has been considered as 220 SP/W for Sudan (Anonymous, 1998). The life time of the modules has been taken as 25 years and these are tilted at 21° with no tracking mode (ISE, 2008). As of this analysis obtained, the continuous energy depends on the life time of a hybrid power system which has an ability to provide 24 h grid quality electricity to the load. This system offers a better efficiency, flexibility of planning and environmental benefits compared to non renewable energy (Steven, 2005). It was found out that PV calculates the electric behavior of large, and in homogeneously light up, PV arrays that obtained the scale of Photovoltaic Module should become more gorgeous as costs of usual supplies increase (Dalton et al., 2009). Capacity shortage and fraction of excess electricity and cost of useful energy varies from 24 to 39 kW/h which is comparable to solar home system (Shafiuzzaman, 2005), which means that the scale of solar system is one of the main factors of designing the hybrid system.

Wind generator

Load demand is very low for a single home system and

the price per kW turbine cost is very high for low capacity wind turbine compare to that of high capacity ones. Low capacity wind turbine is not much available (Awea, 1999); research and development are going on to improve the technology and design of low capacity turbine with low cut-in speed at around 2.5 m/s. For this analysis, a 3 turbine with a capacity of 0.5 kW has been considered as shown in Figure 5. The cost of turbine with tower and installation has been considered as 96000 SP/turbine. For load higher than 1 kW, turbine from southwest wind power (model: W175, capacity, 3 kW) has been considered at the cost of 200000 SP/turbine with tower and installation. Options analysis was done for only PV and wind acquired after 2007 power demand, including reverse system, is supplied by using mini-grid connected hybrid power system with quite a few power options: PV/wind. HOMER optimum configurations of appropriate power stations were suggested in the plan depending on energy resources available in specific locations. Total of 35 power stations have been proposed in the plan. All of them are of hybrid types with wind and battery bank (Indradip and Chaudhuri, 2008) for a 400 W capacity of wind home system (three home users) in coastal areas at a speed of 5 m/s. The internal rate of return (IRR) payback period and benefit-cost ratio are found to be around 16%, 8 years and 2, respectively. Results show that considering energy consumption, environmental effects and remote accessibility, most of the coastal regions are viable for wind home system (Shafiuzzaman, 2005), that was obtained to the scale of project depending on the suitability for individual locations of project of wind type of hybrid system.

Battery with control

As the system considered the DC load only, battery and

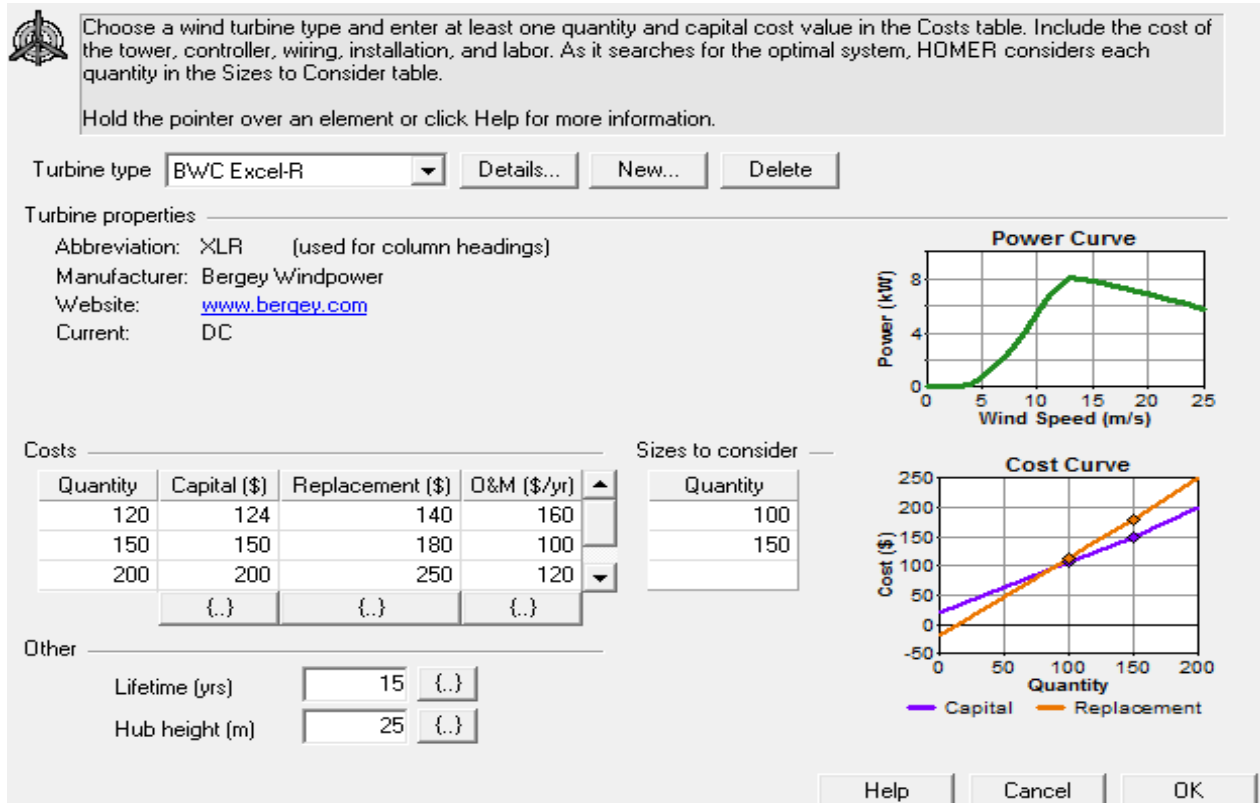


Figure 5. Wind turbine input.

controller were also formed as a main part of the performance evaluation of 10 kW PV power system (Sasitharanuwat and Rakwichian, 2007). For isolated battery from Trojan Company (Model: Trojan T- 105, nominal V: 6 V, nominal capacity: 225 Ah) has been used at a cost of 10,000.00 SP/battery with charge controller. Optimized HOMER found for Algiers were composed of PV systems, wind generators and batteries (Malika, 2009). On the basis of local inspections and analysis with the HOMER model, the following design specifications were found to be optimal for a solar penetration of about 25%: PV capacity of 12 kWp, battery capacity of 108 kWh (50 batteries, 360 Ah, 6 V) and 12 kWp converter at Maldives (Nayar et al., 1993).

Constraints and economics

The project life time has been considered to be 25 years and the annual real interest rate has been taken as 4% (IEA, 2002). Since the system has been designed for single and also for multiple home users like 10 to 50, but load consumed by the user is low, so operation and maintenance cost has been taken as 500 SP/year. There is no capacity shortage for the system and operating reserve is 10% of hourly load. Analysis shows that the cost of energy (KWH) is low for the system, which is the

combination of 50 homes (Roaf and Fuentes, 1997D). Table 3 shows the load demand for each combination of homes with system architecture and financial summary. Dalton et al. (2009) found out that as a result of the optimization of a model for designing a hybrid system using HOMER software demonstrated that, at 2004 prices, the net present cost (NPC) of the grid/renewable energy source (RES) hybrid configuration is comparable with the grid-only supply and resulted in a RF of 73%, a payback time of 14 years and a reduction in greenhouse gas emissions of 65%. Optimization modeling also showed that whilst a RES-only configuration can potentially supply 100% of power demand, at present electricity prices, which have nearly quadrupled since 2004, and predicts that a configuration of 3 Vestas WECS (1.8 MW), an 800 kW converter and 3500 batteries provides the lowest NPC after 20 years at \$19.1 M (Shafiuzzaman, 2005) and found as result that payback period and benefit-cost ratio are found to be around 16%, 8 years and 2, respectively. Results show that considering energy consumption, environmental effects and remote accessibility of most of the coastal regions are viable for wind home system.

van Sark and Meijerink (2004) found the system simulations showing that with a daily load of 207 kWh/day, the combination of a 12 kWp PV system with a battery backup capacity of 108 kWh would be optimum,

Table 2. HOMER details results.

Home	Load	PV module (kW)	Wind generator (quantity)	Battery (quantity)	Initial cost SP	Total NPC	COE (SP/Wh)
Single	338 Wh/day 115 kW Peak	0.15	0	2	61,890	98,470	49.5
10	6.8 kWh/day 2.3 kW peak	1.0	1	16	780,000	841,480	25.8
15	10.1 kWh/day 3.5 kW	2.0	1	24	978,890	1,463,300	23.8
20	13.5 kWh/day 4.6 kW	2.5	2	24	2,188,330	1,999,590	24.7
25	16.9 kWh/day 5.8 kW	3.5	2	8	1,567,220	1,940,985	20.1

given the most suitable strategy for the use of two differently sized diesel generators now present. Future demand growth can be accommodating by only a slight change in diesel generator operating strategy. This hybrid system which was design for topologies need higher early resources cost, but it has less total net present cost, as a result of higher efficiency operation for the PV generators. Reducing solar radiation and wind power also means less emission from the system as shown by the PV/wind system. In addition, the hybrid system rewardables also consider providing enough electricity for domestic use as needed by people in this particular remote area as shown in Table 2.

Conclusion

This paper could be summarized from the analysis that the project life time has been considered to be 25 years and the annual real interest rate has been taken as 4% as the system has been designed for single and also for multiple home users like 10 to 25, but the load consumed by the user is of low operation and maintenance cost. It will be better to use wind-PV combination system for 50 homes instead of single home system. The overall cost of energy would be low if the turbine cost decreases in Khartoum.

The simulation results display that utilizing renewable generators, such as PV and wind generator reduces the operating costs using a third class of housing at Khartoum state.

ACKNOWLEDGEMENTS

The authors would like to thank Prof. Dr. Muhammad

Fauzi Mohd. Zain, for his support and for fully accommodating and providing the necessary equipment, and for giving the principals of scientific experience in this area; and thanks to Prof. Dr. Kamaruzzaman Sopian for providing necessary information about HOMER software. The authors express their blessing to all members of the research group for their cooperation.

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