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Sizing of Hybrid PV/Battery Power System in Sohag city

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Abstract: *This paper gives the feasibility analysis of PV- Battery system for an off-grid power station in Sohag city. Hybrid PV-battery system was used for supplying a combined pumping and residential load. A simple cost effective method for sizing stand-alone PV hybrid systems was introduced. The aim of sizing hybrid system is to determine the cost effective PV configuration and to meet the estimated load at minimum cost. This requires assessing the climate conditions which determine the temporal variation of the insolation in Sohag city. Sizing of the hybrid system components was investigated using RETscreen and HOMER programs. The sizing software tools require a set of data on energy resource demand and system specifications. The energy cost values of the hybrid system agrees reasonably with those published before.*
Key-words: *Renewable energy source, energy cost, PV, battery, HOMER, RETscreen.*

I. Introduction

The energy from sunlight reaching the earth is a huge potential that can be exploited and used for generating electricity. Among several available technologies, solar photovoltaic (PV) is the most promising, PV technology converts sunlight into direct current (DC) electricity. When light falls on the active surface of the solar cell, electrons become energized and a potential difference is established, which drives a current through an external load [1]. However, deeper spread of renewables in the overall energy portfolio poses a new set of challenges. Renewable energy sources are intermittent due to inherent variability in the source itself, the wind does not always blow, and sunlight is not always available [2]. Renewable energy resources become very popular and commonly used nowadays. As a result of using PV as a renewable energy resource, components of PV such as an inverter become widely used for this purpose [3]. The photovoltaic systems applications have developed rapidly in many fields [4].

A Solar photovoltaic (PV) have advantages of no moving parts and without generating any noise or pollution. They must be mounted in an unshaded area. Rooftops, carports, and ground mounted arrays are common mounting locations. The amount of energy produced by PV array depends on several factors, including the type of collector, the tilt and azimuth of the collector, the temperature, the level of sunlight, and weather conditions [5]. A study was made perform simulations of hybrid (solar PV/wind) systems for street-lighting applications, in Greater Toronto Area, Canada [6]. A feasibility study of a solar and wind hybrid system is procedure for highway energy requirements, such as lighting, billboard …etc. [7].

A residential size hybrid system powered by wind and solar Energy has been developed, to supply a small building through net metering [8]. Since solar and wind energies mainly depend upon statistical parameters with respect to changing climate and environment, focus on hybrid generation system design increases the availability of the power generation system. The hybrid system also reduces the dependence on one environmental parameters thus providing the consumer with reliable and cheap electricity. Therefore optimal combination and sizing design of hybrid generation system considering the battery have a very important role in the use of renewable energy effectively and economically. Several approaches were developed to achieve the optimal configurations of the hybrid systems such as the least square method, the trade-off method and the probabilistic approach method [9]. A hybrid energy system consists of two or more energy systems, energy storage system, power conditioning equipment, and a controller [10].

RETscreen uses a number of built in algorithms in combination with user provided data, such as monthly solar radiation values, temperature, and PV module specifications, to calculate expected energy production from the PV power plant [11]. RETscreen is a renewable energy decision support and capacity building tool to make sizing of Renewable Energy source. This standardized and integrated renewable energy project analysis software evaluates the energy production, life-cycle costs and GHG emission reductions for various types of RETs [12]. The Hybrid Optimization Model for Electric Renewables (HOMER), is most widely used, freely available and user friendly software. The software is suitable for carrying out quick prefeasibility, optimization and sensitivity analysis in several possible system configurations [13].

This paper presents the feasibility analysis of PV- battery system for an off-grid power station in Sohag city. The power demand of a combined pumping and residential load. The power demand is served by PV-Battery hybrid power system. Sizing of the hybrid system components is to be investigated the cost of production energy for system.

II. Economic Feasibility Study

2.1 Proposed Hybrid PV/ Battey System

The components of the proposed hybrid system include solar PV panels, storage batteries, DC/DC converter, inverter, etc. as shown in Fig. 1.

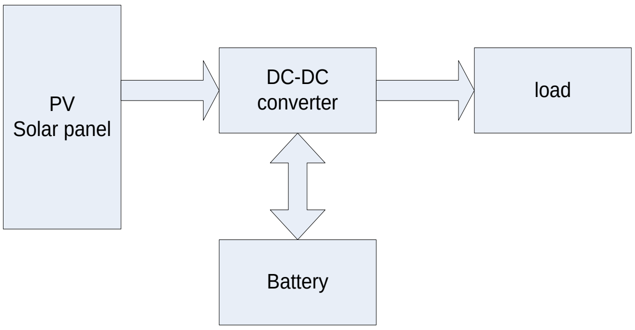

Fig. 1 General block diagram of PV system

The PV modules circuit parameters are given in Table 1. The electrical specifications are under test conditions of irradiance of 1 kW/m2, spectrum of 1.5 air masses and cell temperature of 25co.

Table 1 Electrical parameters of solar PV module

Rated Power	250 W
Voltage at Maximum power (Vmp)	29.65V
Current at Maximum power (Imp)	8.51A
Open circuit voltage (Voc)	37.22V
Short circuit current (Isc)	8.51 A
Total number of cells in series (Ns)	60
Total number of cells in parallel (Np)	1

2.2 Sizing of hybrid system components

Sizing of the hybrid system is to meet the estimated load at minimum cost. This calls at first for assessing the climate conditions which determine the temporal variation of the insolation in Sohag city. The sizing of the hybrid system is determined using RETscreen and HOMER. Used introduces two concepts underlying the rest of this paper the accuracy the methodologies used by HOMER and RETscreen in estimating PV energy output. Descriptions of HOMER and RETscreen in [14] and [15].

III. Meteorological resources

For study purpose, the data for solar resource was obtained from the National Aeronautics and Space Administration (NASA) Surface Meteorology and Solar Energy web site [16].

The specific geographical location Sohag city is at a location of 26^{o}.6 N latitude and 31^{o}.7E longitude. Meteorological data base of RETscreen software is used for simulation in HOMER software also. On the basis of the project location and local meteorological data, the scaled annual average value of solar radiation is, pumping and residential load 100 kW, 5 kW respectively the maximum power of the load is 105 KW. The scaled annual average value of monthly average daily total Global Solar Radiation (GSR) using RETscreen is 6.08 KWh/m2/d, the highest values of GSR are gained during the months of May to August with a maximum of 8.13 KWh/m2/d, as can be seen from Fig. 2. The monthly solar radiation in Sohag city using Homer is shown in Fig. 3.

	Unit	Climate data location	Project location
Latitude	°N	26.6	26.6
Longitude	°E	31.7	31.7
Elevation	m	259	259
Heating design temperature	°C	7.5	
Cooling design temperature	°C	37.0	
Earth temperature amplitude	°C	22.5	

Month	Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	13.9	41.6%	3.85	98.4	3.7	15.2	126	122
February	15.0	34.8%	5.02	98.3	3.8	17.0	85	139
March	18.8	29.0%	6.15	98.0	4.2	21.8	0	273
April	24.1	22.3%	6.94	97.7	4.4	27.9	0	422
May	28.0	21.6%	7.37	97.6	4.4	32.2	0	557
June	29.9	22.4%	8.13	97.5	4.7	34.3	0	597
July	31.0	23.7%	7.91	97.3	4.5	35.7	0	652
August	30.8	25.5%	7.50	97.4	4.4	35.2	0	645
September	29.0	28.4%	6.74	97.7	4.4	32.7	0	571
October	25.1	34.2%	5.52	97.9	4.2	27.9	0	468
November	20.0	37.5%	4.24	98.2	3.7	21.7	0	299
December	15.5	40.9%	3.57	98.4	3.6	16.6	77	171
Annual	23.5	30.2%	6.08	97.9	4.2	26.6	288	4,915
Measured at m					10.0	0.0		

Fig. 2 RETscreen Meteorological data of project site

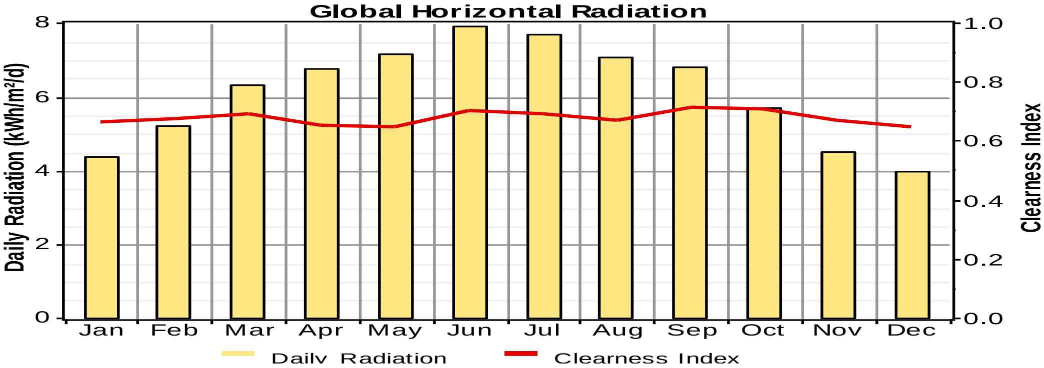

Fig. 3 HOMER Monthly solar radiation

IV. Load Modeling

An estimate of the pumping load is of annual average of 2,400 kWh/day. The average power consumption throughout the operation period is almost fixed and the daily curve of the pump load with a peak of 100 kW load is give in Fig. 4 [17]. The daily load curve of the residential load with a peak of 5 kW load is give in Fig. 5 [18]

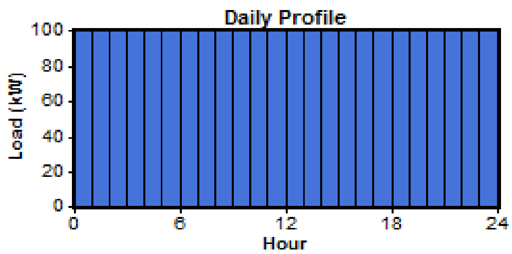

Fig. 4 Load Profile for pumping

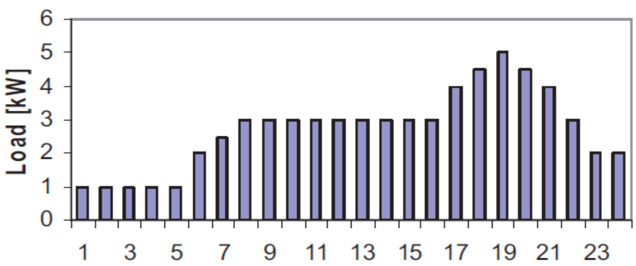

Fig. 5 Load Profile for residential

V. Calculation of kWh cost.

Operation cost of year of project = 2539$/yr.Eq (1) gives the factor of capital recovery, which is an important factor in economic analysis and abbreviated as CRF (capital recovery factor).

$$CRF = \frac{i(1+i)^N}{(1+i)^N - 1} = \quad (1)$$

$$= \frac{0.06(1+0.06)^{25}}{(1+0.06)^{25}-1} = 0.0782$$

Where *i* is the interest rate and *N* is the project life time in years.
Total cost = NPC + O&M Cost (2)
Total cost = 84171 + 24288= 108459$
Where;
NPC is the minimum Net Present Cost, which includes PV cost, Battery cost and Inverter cost.
O&M *Cost* is the operation and maintenance cost.
Total annualized cost.

$C_{ann} = CRF\ (i, R_{proj})\ .\ C_{NPC}$ (3)

$= 0.0782 \times 108459 = 8481.5\ \$$

COE (Cost Of Energy) $= C_{ann,tot} / E_{served}$ (4)

$= 8481.5 / (25 \times 365 \times 24) = 0.039\$$

HOMER calculates the discount factor *fd* using the following equation:

$$fd = \frac{1}{(1+i)^N} = \frac{1}{(1+0.06)^{25}} = 0.23 \quad (5)$$

where *i* Real Interest Rate, %. N: Number of years.

Global radiation should be in daily values in H_G kwh/m^2/d if monthly values are available monthly average values can used in order to calculate the daily average value, using (eq. 6). The irradiation on the module surface is.

$H_{G,t} = (1.1 \text{ to } 1.5) \times H_G$ (6)

Where H_G: Daily average global irradiation received by the PV array surface (kwh/m^2) [19].

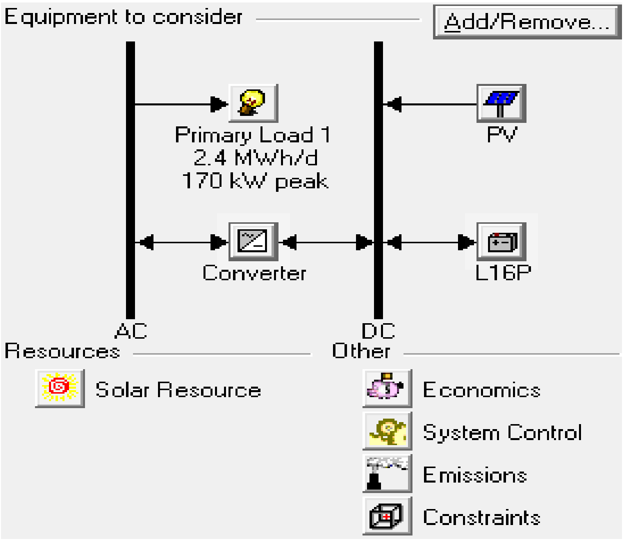

Fig. 6 Homer System Model

VI. Sizing Using HOMER Package

National Renewable Energy Laboratory (NREL), USA developed the software HOMER which helps to design off-grid and grid- connected systems. It provides a method for finding the least-cost system design on the basis of a given load size, system components and data for energy sources. The optimization results it get by Homer System Modeling Fig. 6 and corresponding to the total minimum cost is shown in Fig. 7.

	PV (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
	25	40	100	$ 51,720	2,539	$ 84,171	0.151	1.00	1.00
	25	40	105	$ 52,434	2,567	$ 85,246	0.153	1.00	1.00
	25	40	110	$ 53,148	2,595	$ 86,321	0.155	1.00	1.00
	25	40	115	$ 53,862	2,623	$ 87,396	0.157	1.00	1.00

Fig. 7 Optimization results of system.

VII. Simulations and Results

7.1 Results using of Homer

The models are simulated using Homer. The purpose of the simulations is to evaluate and compare the use of PV and battery terms of efficiency and capital cost. The optimization results of the system are summarized as shown in Fig. 7. The cost of the numbers of units which is used during operating hours was specified. The Economic inputs allow entering the interest rate, project lifetime, and other inputs that affected the system as a whole, rather than a single component of the system. System costs include the net present cost (life-cycle cost) and cost of energy is based on the assumption that the project would operate for 25 years. The annual real interest rate as 6%. Furthermore, the annual capacity shortage penalty is not considered results optimized show the hybrid system of 25kW of PV panel, 40 batteries and 100kw power converter to be purchased as a suitable system and the capital cost is $ 51,720 over the lifetime of the system. The optimization results show that the optimal PV battery hybrid has lowest net present cost (NPC) 84,171$ with cost of energy (COE) 0.151$/KWh and operating cost 2,539$/yr as homer.

7.2 Results using of RETscreen

The base case of power system, which is an off-grid system, its power generation relies on PV module the fuel rate is 1.5$/L and the total electricity cost is 46938$. In general, it's not easy for the typical clients to afford to these high fees [20]. As shown in Fig. 8, with the used renewable sources considered, all configurations contributing to 100% renewable energy and reduced emission is an advantage because of no need for diesel generator.

Power project		
Base case power system		
Grid type		Off-grid
Technology		Grid electricity
Fuel rate	$/kWh	1.500
Capacity	kW	100.00
Annual O&M cost	$	8,613
Electricity rate - base case	$/kWh	1.837
Total electricity cost	$	46,938

Fig. 8 Base case power system

Compared to base case power system, the proposed power system if the project uses PV, as shown in Fig 9. The amount of electricity delivered to load is 98%, to Data of PV of proposed system Fig. 10.

Proposed case power system			
Inverter			
Capacity	kW	2.5	Peak load - annual - AC
Efficiency	%	90%	
Miscellaneous losses	%	0%	
Battery			
Days of autonomy	d	3.0	
Voltage	V	24.0	
Efficiency	%	85%	
Maximum depth of discharge	%	60%	
Charge controller efficiency	%	95%	
Temperature control method		Ambient	
Average battery temperature derating	%	1.4%	
Capacity	Ah	100	16,222
Battery	kWh	2	

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Peak load power system

Technology		Grid electricity	
Fuel rate	$/kWh	1.500	
Charger efficiency	%	95.0%	
Suggested capacity	kW	50.0	
Capacity	kW	100	200.0%
Electricity delivered to load	MWh	25.0	98.0%

Fig. 9 Proposed case of Hybrid PV power system

Photovoltaic

Type		mono-Si	
Power capacity	kW	0.25	0.5%
Manufacturer		Lumin	
Model		mono-Si - LDK-250D-20	1 unit(s)
Efficiency	%	15.3%	
Nominal operating cell temperature	°C	45	
Temperature coefficient	% / °C	0.40%	
Solar collector area	m²	1.6	
Control method		Maximum power point tracker	
Miscellaneous losses	%	0.0%	

Summary

Capacity factor	%	23.2%	
Electricity delivered to load	MWh	0.51	2.0%

Fig. 10 Data of PV of proposed system

From the financial analysis, the total cost of renewable energy is lower than that of non-renewable energy considerably. Even though the renewable system invests much in the construction and equipment's the management and operation cost less relatively. And project life is 25 years, the annual savings and income is 46,938$/yr, the Net Present Value (NPV) is 82,655$, the annual life cycle savings is 7,093$ while the Internal Rate of Return (IRR) is 31.4%. At the same time, the benefit-cost ratio (B-C) is 6.33 and the simple payback is 7.2 yr. In a word, as compared to other systems, its project payback peaks to the maximum, as shown in Fig 11. The financial viability as shown in Fig. 12 and the cumulative cash flows graph is shown in Fig. 13.

Project costs and savings/income summary			
Initial costs			
Feasibility study	9.7%	$	5,000
Development	1.9%	$	1,000
Engineering	48.4%	$	25,000
Power system	12.8%	$	6,591
Balance of system & misc.	27.2%	$	14,054
Total initial costs	**100.0%**	**$**	**51,645**
Incentives and grants		$	70
Annual costs and debt payments			
O&M		$	210
Fuel cost - proposed case		$	39,540
Debt payments - 12 yrs		$	3,471
Total annual costs		**$**	**43,221**
Periodic costs (credits)			
User-defined - yrs		$	3,000
End of project life - credit		$	-30,987
Annual savings and income			
Fuel cost - base case		$	46,938
Total annual savings and income		**$**	**46,938**

Fig. 11 Project costs and savings/income summary.

Financial viability		
Pre-tax IRR - equity	%	31.4%
Pre-tax IRR - assets	%	12.5%
After-tax IRR - equity	%	31.4%
After-tax IRR - assets	%	12.5%
Simple payback	yr	7.2
Equity payback	yr	3.6
Net Present Value (NPV)	$	82,655
Annual life cycle savings	$/yr	7,093
Benefit-Cost (B-C) ratio		6.33
Debt service coverage		2.13
GHG reduction cost	$/tCO2	No reduction

Fig. 12 Financial viability

Where the Net Present Value is found 82,655$. While the Internal Rate of Return (IRR) was found to be more than the discount rate which is 31.4%. The benefit to cost ratio (B-C) is found equals to 6.33, Fig. 13 shows that pay back duration becomes 3.6yr, which indicates feasible results compared to previous financial viability.

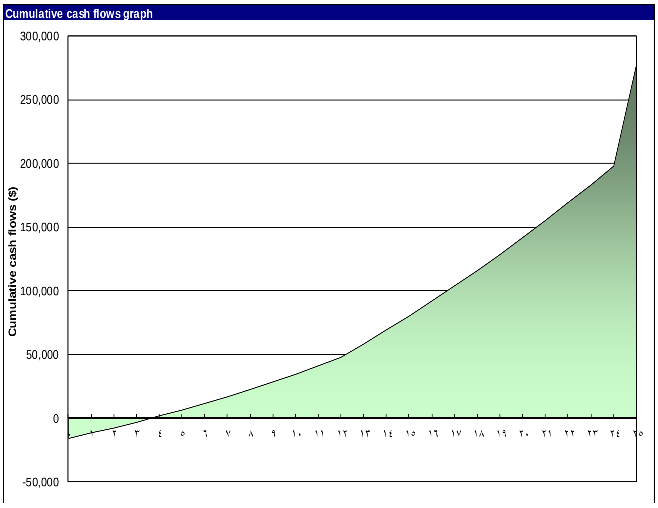

Fig. 13 Cumulative cash flows graph

In terms of risk analysis, the most critical factor is fuel cost. However, the reduction of fossil fuel and the cost of the system are able to lessen investment risk and sensitivity.

VIII. Comparison of HOMER and RETScreen softwares

A comparison of two widely used softwares HOMER and RETscreen is shown in this section. HOMER and RETscreen have some similarities like both take only global irradiation as input, and synthesize the diffuse irradiation internally. RETscreen uses Microsoft Excel to perform analysis based upon statistical monthly averages with lots of meteorological and geographical inbuilt information. RETscreen uses Evans electrical model with month averaged ambient temperature and the PV panel material characteristics data to calculate power output, whereas HOMER uses basic relation model. Main strength of RETscreen is the detailed economic analysis and strong database whereas HOMER is better suited for more advanced user and can handle a much denser simulation which makes HOMER one of the most widely used hybrid system optimization tool [13].

Table 2 Comparison between system components sizing by HOMER and RETscreen.

Homer's result	**RETscreen's result**
Net present cost (NPC) 84,171$	Net present value (NPV) is 82,655$
Operating cost 2,539$/yr	Annual savings and income is 46,938$/yr
Capital cost 51,720$	Total initial costs 51,645$

IX. Conclusion

This paper aimed the feasibility analysis of PV/ Battery system for an off-grid power station in Sohag city. The project life time is taken as 25 years and the annual real interest rate as 6%. According to results show on before, the hybrid system composed of 25kW of PV panels, with 100kW power converter and 40 batteries. Results show that the optimal PV battery hybrid has lowest net present cost (NPC) 84,171$ with cost of energy (COE) 0.151$/KWh and operating cost 2,539$/yr. The use of the Homer and RETscreen has been presented to evaluate the economic value of the proposed technique. In addition, the use of PV-battery hybrid system economically suitable. Sizing of the hybrid system agreed satisfactory with that obtained using the RETscreen and HOMER.

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