Performance analysis of integrated wind, photovoltaic and biomass energy systems

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Abstract: In this paper performances of different combinations of integrated RE systems are analyzed and compared for various suitable locations in India for a load demand of 1.5 MW. These combinations of integration of REs are wind energy system (WES) and photovoltaic (PV) system; PV system and biomass energy system (BES); and BES and WES. Maximum annual electricity generated by integrated PV system and BES 8,672 MWh while maximum annual income from electricity export is $ 561,078 from integrated BES and WES system. Reduction in net annual greenhouse gas (GHG) emission is found highest of 8,850 tonnes of CO_2 in the case of integrated BES and WES with income from the GHG reduction of $ 177,013 and total annual saving/income of $ 738,091. Equity payback period of integrated BES and WES is estimated as minimum of 2.7 years when cash flow becomes positive.

Performance analyses and cash flows of the integrated RE systems are carried out using RETScreen software tool. It is concluded from the results that integration of BES with another RE is more feasible than without BES in terms of electricity generation, electricity export income, GHG emission reduction, income from carbon trading and equity payback period.

Keywords: *Emission, Renewable Energy Integration, World Renewable Energy Congress 2011*

1. Introduction

Integration, which is also referred as hybridization, of renewable energy (RE) sources involves combining two or more systems of energy resource that naturally over a period of time. This time scale is derived directly from sun (such as for thermal, photochemical, and photoelectric), indirectly from the sun (such as for wind, hydropower, photosynthesis, energy stored in biomass), from other natural movements and mechanisms of the environment (such as for geothermal and tidal energy). The depletion of fossil fuels reserves, the increasing demand for electricity and the harmful effect of CO_2 output on the climate force nations - especially developed countries and their governments - to find new ways of generating the sufficient amount of energy in demand. The integration of alternative energies to reduce emissions and to conserve available fossil sources is a well known fact.

Like other developing countries, India faces a formidable challenge in meeting its energy needs and providing adequate and affordable energy to all sections of society in a sustainable manner. The country today faces an energy demand-supply gap of 8% with peak shortages to an order of 11%-12%. The hospitality industry is one of the major energy and water intensive sectors and to deal with the situation, the utilization of RE sources has to maximize for meeting energy demands [1].

An evaluation of integrated system of PV and wind energy sources of those systems has been done to study reliability of the systems [2]. The supply pattern of different RE sources can be intermittent with different patterns of intermittency. It is often possible to achieve a better overall supply pattern by integrating two or more sources, sometimes also including a form of energy storage system. In this way the energy supply can effectively be made more secure, less intermittent, or more firm. [3]. A comparative study has been made for energy security of the two locations for the same load demand by simulating hybrid renewable energy systems (HRESs) [4].

Some of the reasons of using integrated/HRES are outlined as under:

- Reduction of greenhouse gas (GHG) emissions through increased use of RE and other clean distributed generation
- Increase in use of integrated distributed systems and customer loads to reduce peak load and thus price volatility
- Enhancement in RE system (RES) and energy efficiency
- Increase in reliability, security, and resiliency from microgrid applications in RES to improve system

In this analysis integration of wind energy system (WES), photovoltaic (PV) system and biomass energy system (BES) are carried out for the purpose of analysis to achieve the objectives.

2. Methodology and Objectives

The following objectives of the paper are achieved by using Renewable Energy Technology Screen (RETScreen) Version 4 software simulation tool. The RETScreen International Clean Energy Project Analysis Software is a unique decision support tool designed with the contribution of numerous experts from government, industry, and academia. The software can be used worldwide to evaluate the energy production and savings, costs, emission reductions, financial viability and risk for various types of Renewable-energy and Energy-efficient Technologies (RETs). The software also includes product, project, hydrology and climate databases, a detailed online user manual, and a case study. RETScreen International is getting financial support from Natural Resources Canada's (NRCan) CANMET Energy Technology Centre - Varennes. The software is developed in collaboration with a number of other government and multilateral organisations, and with technical support from a large network of experts from industry, government and academia [5].

For this purpose of simulation, weather data of various places is taken from drop down list and used for analysis purpose so that suitability of integrated RE system may be judged. The software provides simulation by Method 1 and Method 2. Second method is an extension of Method 1 providing more detail analysis. The main inputs used in the analysis are multiple technologies options from drop down list, power capacity required, initial cost, type of fuel, selection of RE system from drop down list, rate of energy export, transmission and distribution loss, rate of inflation, project life, rate of interest and debt term etc. Energy models are prepared using above mentioned input data to obtain the following outputs:

- Calculation of energy exported to grid from RE sources
- Income from energy export
- Gross and net GHG emission reduction
- GHG reduction income
- Total annual cost
- Total annual saving and income
- Financial viability including simple and equity payback
- Cumulative cash flow

3. Integration of RE systems

A large-scale integration of optimal combinations of PV, wind and wave power into the electricity supply has been carried out by Lund (2006) using computer software namely EnergyPLAN [6]. In another paper a load balance model has been suggested to evaluate economic and environmental effects of integrating wind power into three typical generation mixtures. The results have been indicated that the system operating cost increased by 83%–280% (depending on generation mixture) at a wind penetration of 100% of peak demand and system emissions decreased by 13%–32% (depending on the generation mixture) [7]. In the present paper RE integration of WES, PV system and BES are carried out. Costs of RES per kW are taken as $ 1,900, $ 9,100 and $ 467 for WES, PV system and BES respectively. Cost of energy to be exported from the microgrid of the proposed system is taken as $ 70/MWh [5, 8]. The following combinations of integration are chosen:

- WES and PV system
- PV system and BES
- BES and WES

3.1. Integration of Wind and Photovoltaic Energy Systems

Weather data of Jaisalmer found suitable for integration of wind and PV energy systems which is used to develop energy model and cash flow curve of the integrated RES. The place is situated in the western state of Rajasthan, India at latitude of 26.9° N, longitude 70.9° E and elevation of 130 m. The daily average radiation of the place is 5.16 kWh/m^2/d and average wind speed of 3.9 m/s, maximum 4.9 m/s in June and minimum 3.4 m/s in Oct. Government of India has an elaborate program to install 1000 MW PV system at a nearby place in the desert of Rajasthan Thar desert in the coming decade. The area is selected for a proposed distributed generation from integrated WES and PV system to study the feasibility of integrated system. A load demand of an area Manak Chowk of Jaisalmer is chosen, having a load of 1.47 MW, say 1.5 MW to install an integrated system of WES and PV system [9].

Before building a system with several intermittent energy sources and variable consumption, guidance on selecting the dimensions of the individual components should be obtained by simulating the system operation under the local conditions like weather, insolation, wind speed etc. In general, a key objective of such a system is to use the maximum proportion of RE as mentioned above, but other factors including the financial investment, social aspects, local infrastructure, durability etc. must also be considered.

3.1.1. Results of Performance and Emission Analysis of Integrated 750 kW Wind and 750 kW Photovoltaic Energy System at Jaisalmer

Although the behaviour of wind and PV energy systems are different, equal power capacity of 750 kW each considered shown in Figure 1. Simulation results are obtained indicating total energy export to the grid 3,285 MWh giving an income $ 229,950. The results are shown in the energy model in Table 1 achieving net GHG emission reduction 3,730 tCO_2 (tonnes of CO_2), GHG reduction income $ 74,607 giving a total annual saving and income of $ 304,557. Complete GHG emission analysis, total annual cost, and financial viability are also shown in Table 1. The detail specification, manufacture and models are suggested by the tool itself. Wind turbine 15 units of Atlantic Orienet make with Model No. AOC 15/50-23m and PV system 3000 units of Uni-Solar make with Model No. a-Si-SSR-256W are chosen from the drop down list of the software tool. Other options of wind turbines and PV systems are also available in the list which may be selected depending upon requirement of the site and load demand. Cumulative cash flow graph is illustrated in Figure 2, showing equity pay back starts after 6.9 yr when cash flow becomes positive [9, 10].

Table 1. Results of Energy Model of 1.5 MW integrated energy project of WES 750 kW and PV energy system 750 kW indicating detail of proposed case power system, GHG emission analysis and financial analysis

Proposed power case system		**Financial parameters**	
Technology 1	Wind turbine	**Inflation rate**	2.0 %
Power capacity	750 kW	**Project life**	20 yr
Capacity factor	30%	**Debt ratio**	70%
Manufacturer	Atlantic Orienet	**Debt interest rate**	5.00%
Model	AOC 15/50 -23m – 15 units	**Debt term**	14 yr
Electricity exported to grid	1,971 MWh	**Annual savings and income**	
Total initial costs	$ 1,384,666	**Fuel cost - base case**	$ 0
Technology 2	PV	**Electricity export income**	$ 229,950
Power capacity	750 kW	**GHG reduction income -14 yr**	$ 74,607
Manufacturer	Uni-Solar	**Total annual saving & income**	$ 304,557
Model	a-Si-SSR-		
Capacity factor	20%	**Emission analysis**	
Electricity export rate	$ 70		
Electricity exported to grid	1,314 MWh	**GHG emission propose case**	0
Country-Region	India	**GHG credits transaction fees**	2.0%
Fuel type	Coal	**Net annual GHG emission reduction**	3,730 tCO_2
GHG emission factor Excl. T&D losses	0.927 tCO_2/MWh	**Acres of forest absorbing carbon**	1,283
T&D losses	20%	**GHG reduction credit rate**	**20** $/ tCO_2
GHG emission factor Incl. T&D losses	1.159 tCO_2/MWh	**GHG reduction credit duration**	14 yr
GHG emission base case	3,806 tCO_2	**GHG reduction credit escalation duration**	2.0 %
Annual costs and debt payments		**Financial viability**	
O&M (savings) costs	$ 0	**Pre-tax IRR – equity**	16.3 %
Fuel cost - base case	$ 0	**Pre-tax IRR – assets**	2.8%
Debt payments - 10 yrs	$ 203,994	**Simple payback**	9.5 yr
Total annual costs	$ 203,994	**Equity payback**	6.9 yr

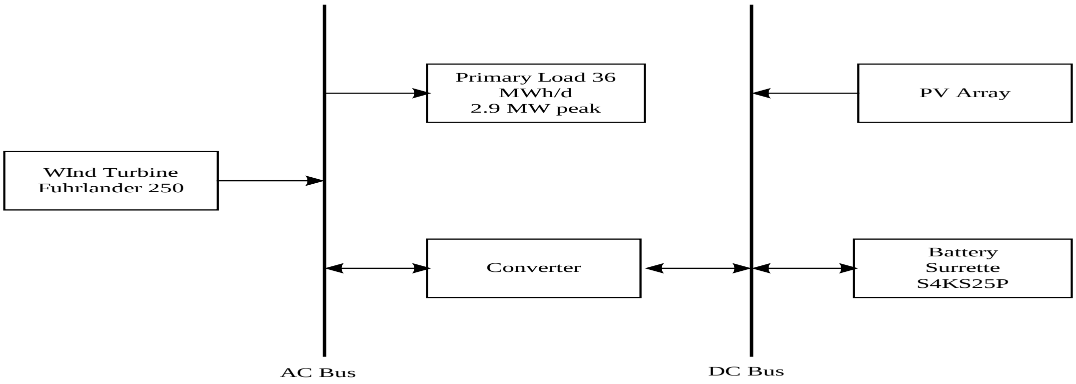

Fig. 1. Basic block diagram of integrated wind and PV energy systems

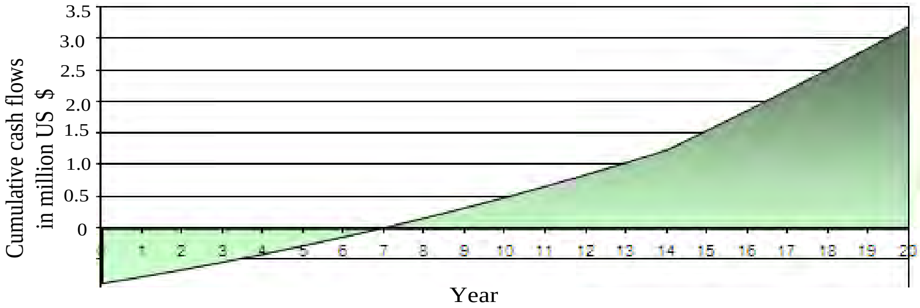

Fig. 2. Cumulative cash flows graph of integrated WES 750 kW and PV energy system 75

3.2. Integration of other RE Systems

Minambakkam, a suburb of Chennai, India is selected for a project of integrated of PV energy system and BES suitable for a comparable load demand of 1.5 MW as in the case of section 3.1. Rice is one of the main agricultural products in this area; hence availability of rice husk is sufficient to supply any biomass gasifier generating electricity. Simulation by RETScreen software is based on specific fuel consumption of rice husk 2.096 kg/kWh with heat rate of 22,200 kJ/kWh [11, 12]. Sufficient amount of solar insolation is also available at the site. The place is located at a latitude 13.0° N, longitude 80.2° E and elevation 16.0 m. The daily average solar radiation is 5.49 kWh/m^2/d with maximum 6.78 kWh/m^2/d in April and minimum 4.17 kWh/m^2/d in December and average temperature 28.8° C [13]. All these weather and agricultural data are used to develop energy model, the results of which shown in Table 2 and cash flow curve as shown in Figure 3.

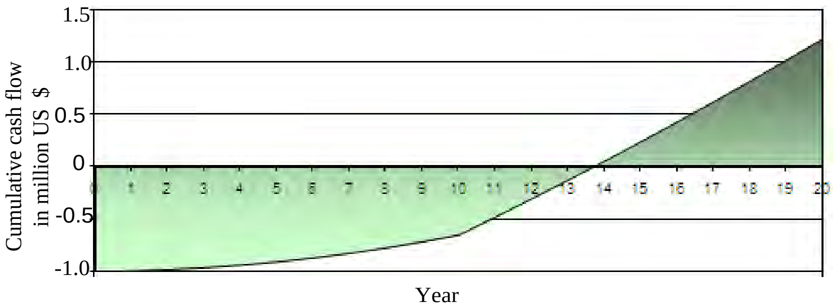

Fig. 3. Cumulative cash flows graph of integrated PV energy system 750 kW and BES 750 kW

Integration of BES and WES suitable for the same load demand of 1.5 MW is proposed to carry out at a coastal area Veraval in western Indian state of Gujrat, located at latitude 20.9° N, longitude 70.4° E at an elevation of 8 m. Mean temperature of the area is 26.6° C, average daily radiation 5.94 kWh/m^2/d and average wind speed 4.3 m/s, maximum wind speed 7.1 m/s in July and minimum 2.7 m/s in Nov. Rice is the main foodstuff of the people of Veraval; hence rice husk is available in abundance around the vicinity of the place suitable to supply rice husk based gasifier for the proposed BES. Uninterrupted flow of wind is available in the coastline area, making WES option feasible particularly during summer days, when the wind speed is high [13]. Energy model of the system prepared, the results of which are shown in Table 2 and cash flow of the project shown in Figure 4.

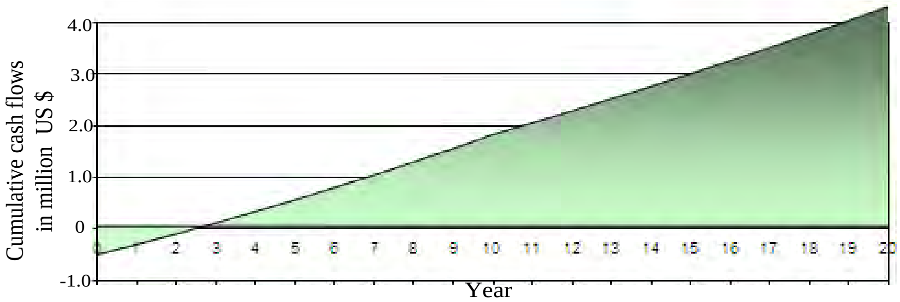

Fig. 4. Cumulative cash flows graph of integrated BES 750 kW and WES 750 kW

4. Comparative results obtained from energy models

Comparative results of analysis of integrated systems on annual basis are tabulated from the energy models data of the various integrated systems, i.e. WES 750 kW with PV energy system 750 kW, PV system 750 kW with BES 750 kW and BES 750 kW with WES 750 kW shown in Table 2.

Table 2. Comparative results of Energy Models of 1.5 MW integrated energy project of WES, PV system and BES each of 750 kW indicating detail energy generated, GHG emission analysis and financial analysis

Integration systems	WES+PV system	PV system +BES	BES+WES
Electricity generated MWh	3,285	**8,672**	8,015
Income from electricity export $	229,950	515,088	**561,078**
Total annual cost $	203,994	**677,523**	546,779
GHG emission reduction tCO_2	3,730	8,105	**8,850**
Income from GHG emission reduction $	74,607	162,092	**177,013**
Total annul saving /income $	304,557	677,180	**738,091**
Equity payback period yr	6.9	13.7	**2.7**
Feasibility/remarks	Not so feasible	Not so feasible	Most feasible

5. Conclusions and recommendations

- Maximum energy 8,672 MWh generated and exported annually from integrated PV system and BES whereas nearly half energy 3,285 MWh is generated in the case of integrated WES and PV system. Therefore, the integrated system of PV system and BES is recommended for energy generation rather than using other integrated RES of similar power rating.

- Annual energy export income $ 561,078 is highest in the case of integrated BES and WES and less than half $ 229,950 from integrated WES and PV system. The integrated system of BES and WES is economically most feasible. Hence, this system is recommended for a windy place where biomass is cheaply available.

- Total annual cost $ 677,523 is highest in integrated PV system and BES and lowest of $ 203,994 (nearly less than one third) in integrated WES and PV system. The high total annual cost is due to consumption of biomass (rice husk) used with the BES gasifier. Hence, integrated system of PV and BES not feasible to opt for generation purpose if low annual cost is the preference. Integration of WES and PV system is suggested where lesser annual cost is desirable for a windy place.

- Annual reduction in GHG emission is least of 3,730 tCO_2 in case of integrated WES and PV energy system whereas highest of 8,850 tCO_2 (nearly 2.5 times) in case of integrated BES and WES. Annual GHG emission of 8,105 tCO_2 is found in case of integrated PV system and BES. In the present scenario of the world growing air pollution, GHG emission reduction is the prime factor while considering electricity generation options. Therefore, integrated system containing BES should be given preference over other integration of RE systems without BES.

- Annual income from GHG emission reduction $ 177,013 is highest in integrated BES and WES and lowest of $ 74,607 (nearly less than half) in integrated WES and PV system. Whereas the annual income is $ 162,092 in integrated PV system and BES. The analysis results show that income from integrated systems containing BES with other RES is more than any other RE integration running without BES because of higher reduction in GHG emission. Therefore, integrated system BES with WES should to be preferred over other integrated systems to get more annual income from carbon trading.

- Total annual saving /income $ 738,091 is also maximum from integrated BES and WES and nearly less than half $ 304,557 from integrated WES and PV system. Total annual saving/income is estimated as $ 677,180 in case of integrated PV system and BES. It is found that results are in favour of integration of BES with other RES. Hence, integration of BES with WES and PV system with BES is suggested to use in any part of the world wherever biomass available.

- Equity payback period is shortest of 2.7 years in case integrated BES and WES and longest of 13.7 years (nearly more than 5 times) in case of integrated PV system and BES. A major portion of cash flow curve of integrated of PV system and BES lies in the negative side and positive cash flow starts after 13.7 years indicating non-feasibility of the system; hence this system of RE integration is not suggested to opt. Integrated BES and WES is estimated to be the best option since a major portion of cash flow curve lies in positive side and system starts giving return just after 2.7 years.

Therefore to get quickest positive cash flow, integrated system of BES and WES is recommended.

- Comparing all positive and negative aspects of combinations of integration, best system for integration is BES with WES. Moreover, this integration of RE has minimum environmental impact while generating electricity. That also provides huge income from carbon trading.

- The not-so-feasible combination of integration is PV system with BES due to high total initial annual cost. But it may be also suggested for use because of more generation, high GHG emission reduction and total annual saving. WES and PV system may be opted where less total annual cost required.

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