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DESIGN AND OPTIMIZATION OF HYBRID RENEWABLE ENERGY SYSTEM (2MWH/D) FOR SUSTAINABLE AND ECONOMICAL POWER SUPPLY AT JEC JABALPUR

Madhav Singh Thakur[1], Bhupendra Gupta[1], Veerendra Kumar[1], Mukesh Pandey[2]

[1]Department of Mechanical Engineering, Jabalpur Engineering College, Jabalpur, India
[2]Department of Energy and Environment, UIT, RGPV, Bhopal, India

E-mail of Corresponding Author: madhav22278@yahoo.co.in

ABSTRACT

A hybrid renewable energy system may be used to reduce dependency on either conventional energy or renewable system. Optimization of hybrid renewable energy systems looks into the process of selecting the best components and its sizing with appropriate operation strategy to provide cheap, efficient, reliable and cost effective alternative energy. In this paper a methodology has been develop for optimum planning of hybrid PV-Wind system with some battery backup. The local solar radiation, wind data and components database from different manufactures are analyzed and simulated in HOMER to assess the technical and economic viability of the integrated system. Performance of each component will be evaluated and finally sensitivity analysis will be performed to optimize the system at different conditions.
The system architecture includes PV System 100KW, 5 Northern Power NW100/19 Wind Turbine, Diesel Generator 10KW, Battery 25 (Beacon Smart Energy), Inverter 100KW and Rectifier 100KW. This paper gives the design idea of optimized PV-Solar and Wind Hybrid Energy System for Jabalpur Engineering College, Jabalpur electrical load over conventional electrical grid system for a particular site in central India (Jabalpur). For this hybrid system ,the meteorological data of Solar Insolation, hourly wind speed, are taken for Jabalpur -Central India (Longitude 79^{o}.59'and Latitude 23^{o}.10') and the pattern of load consumption of JEC electrical load data are studied and suitably modelled for optimization of the hybrid energy system using HOMER software. The simulation and optimization result gives the best optimized sizing of wind turbine and solar array with diesel generator. This system is more cost effective and environmental friendly over the conventional grid system. It should reduced approximate 70%-80% running cost over conventional grid system and also reduced the emission of CO_2 and other harmful gasses in environments. It is expected that the newly developed and installed system will provide very good opportunities for MPEB in near future.

Keywords: Hybrid energy system, Grid connected system, Wind turbine, Solar PV-cells, Convertor and HOMAR 2.81.

INTRODUCTION

India is gifted with Renewable Energy (RE) potential like wind, hydro, solar, tidal, geothermal energy resources etc. Reliable and cost effective power solutions for the Jabalpur Engineering College, Jabalpur into rural and remote areas presents a very challenging problem. Grids are either not available or their extensions can be extremely costly in remote area. Although initial costs are low, powering these sites with generators require significant maintenance, high fuel consumption and delivery costs due to high in fuel prices. Recent research and development of Renewable energy sources have shown excellent potential as a form of contribution to conventional power generation systems. In order to meet sustained load demands of Jabalpur Engineering College, Jabalpur during varying natural conditions, different energy sources and converters need to be integrated with each other for extended usage of alternative energy sources such as wind-solar Hybrid Energy System for Jabalpur Engineering College, Jabalpur. The use of the stand-alone solar-wind with diesel and Battery backup system for the power supply of remote areas may give an economically attractive alternative for grid source in near future. This paper gives the design idea of wind, solar photovoltaic hybrid energy system. Based on the energy consumption of Jabalpur Engineering College, Jabalpur and the availability of renewable energy sources, it was decided to implement an innovative stand alone Hybrid Energy System combining small wind turbine-generator, solar photo-voltaic panels, battery storage, advance power electronic equipment and existing diesel generators.

Renewable Energy Sources for Hybrid System

The availability of renewable energy resources at Jabalpur Engineering College, Jabalpur is an important factor to develop the hybrid system .Many parts of the India wind and solar energy is abundantly available. The energy sources are intermittent and naturally available; due to these factor our first choice to Power the Jabalpur Engineering College, Jabalpur will be renewable energy sources such as wind and solar. Weather data are important factor for pre- feasibility study of renewable hybrid energy system for any particular site. In central India wind speed is an average and sun brightness is strong. Here the Wind and Solar energy resources data are taken from NASA for Jabalpur India (Longitude 79^{o}.59'and Latitude 23^{o}.10') and shown in Table 1.

Table 1- Solar and Wind data of JEC Jabalpur

(Source: http://eosweb.larc.nasa.gov/sse)

Month	Solar Insolation (kWh/m^2/day)	Wind Velocity (m/s)
January	4.481	3.350
February	5.253	3.890
March	5.911	3.395
April	6.822	3.885
May	6.822	4.956
June	5.682	5.176
July	4.083	4.796
August	3.883	4.376
September	4.950	3.666
October	5.553	3.600
November	4.807	3.500
December	4.372	3.420
Average	5.214	4.001
Maximum	6.822	5.176
Minimum	3.883	3.350

Solar Resource

The solar resource was used for a site in Jabalpur Engineering College, Jabalpur at a location of 23^{o}.10'N latitude and 79^{o}.59'E longitude. Solar radiation data for this region was obtained from the NASA Surface Meteorology and Solar Energy web site. The annual average solar radiation for this area is 5.43 kWh/m^2/d. Figure 1 shows the solar radiation profile over a one-year period. Solar and wind energy systems are characterized by relatively high capital costs, low operation and maintenance (O&M) costs, and zero fuel costs.

The high capital cost has been a major barrier to widespread use by utilities. However, the costs of both PV and wind systems have decreased substantially in recent years and further reductions over the next 10 years are expected. Renewable energy systems such as PV, solar thermal electricity such as *Dish-Stirling systems*, and *WT* are appropriate solar and wind technologies that can be considered for electric power generation at the distribution system level. Other renewable energy technologies, such as the solar central receiver, hydro-electric generation, geothermal, and large wind farms, are normally connected to the grid at the sub transmission or transmission level because of the higher power capacities of these systems. Presently, PV and WT technologies appear to be the most viable candidates for integration into power distribution systems. Sunlight is converted directly to direct current (dc) electricity by PV cells made of semiconductor materials such as silicon. The cells are wired in series-parallel combinations to form modules or panels. The dc is converted to alternating current (ac) by an inverter or power conditioning unit.

Figure 1. Solar Radiation available at Jabalpur

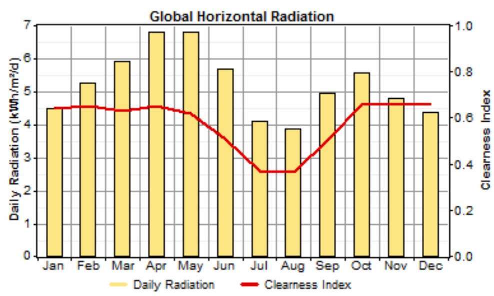
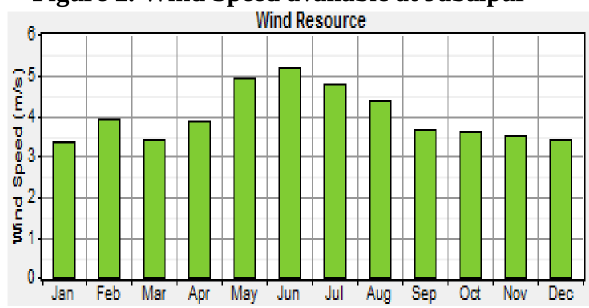


Figure 2. Wind Speed available at Jabalpur



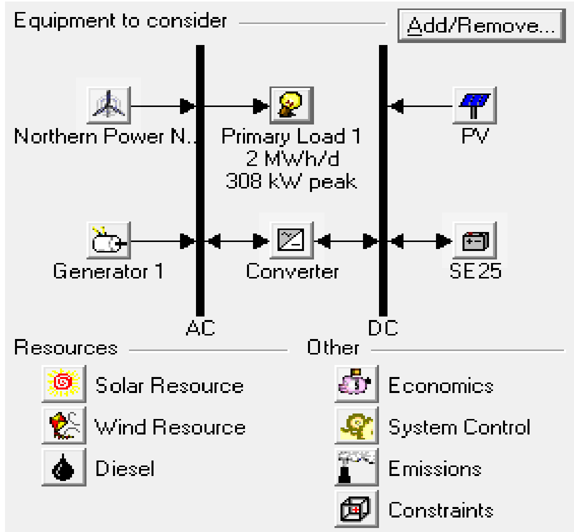
Wind energy resource

A monthly average wind dataset for Jabalpur ware collected from Environment Jabalpur climate. This is an average of last ten year and indicates that annual average wind speed and shown in Figure 2. From the above given data, wind speed probability function and average hourly wind speed throughout the year is shown in Figure 2. The autocorrelation factor (randomness in wind speed) is found to be 0.85. Average wind speed in the summer season is slightly higher than the winter season as shown in Figure 4. Wind turbines generate electric power by extracting kinetic energy from the wind to drive a turbine connected to an ac generator. The power in wind available to a turbine is proportional to the cube of the wind speed. Thus, wind speed variations will cause variations in the wind turbine power output.

Methodology of Hybrid Energy System Design

Jabalpur Engineering College, Jabalpur is situated at Longitude 79^{o}.59'and Latitude 23^{o}.10' location having 7 department and electrical load 2Mwh/day and of electricity bill 70-72 lakh per year. In this research work we are designing a hybrid renewable energy system which can replace the existing one or partially replace with cost effectiveness and payback period. For 2Mwh/day we propose this hybrid renewable energy system as shown in figure 3.The simulation and optimization result gives the best optimized sizing of wind turbine and solar array with diesel generator.

Figure 3. Schematic representation of the Hybrid Energy System



Electrical Load

The load profile is based on a hypothetical Jabalpur Engineering College, Jabalpur (MP). Figure 1 illustrates this profile. A small base load of 15 KW occurs throughout the day and night. Small peaks of 30 KW occur in the morning and at noon, while the majority of the load occurs in the evening. This evening load, with a peak load of 60 KW, would likely include compact fluorescent lighting and a radio. The total daily load averages 2 Mega watt-hours per day. HOMER can perform a sensitivity analysis by accepting multiple values for a particular input variable such as the average load. This analysis determines how changes in the input variable affect the performance of the system and the relative ranking of different systems. By performing the sensitivity analysis over a large range of load sizes, the study simulates a range of load types from a single home to a large community. While this scaling may represent the overall total load of a larger village, in reality the profile would not necessarily remain the same shape. Variations in individual home loads would tend to smooth out the overall profile. Additionally, daytime loads such as microenterprises, schools, and clinics would most likely change the shape of the profile. For simplicity of analysis, the load profile was not modified as the load was increased, but rather kept constant in shape and scaled in size.

Figure 4. Hourly load Profile of JEC Jabalpur

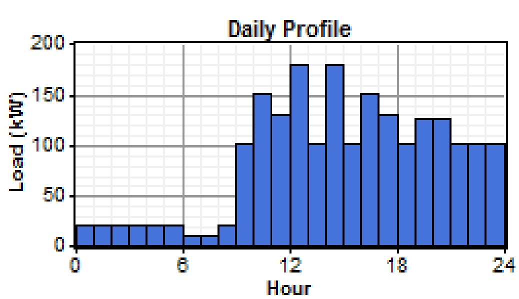
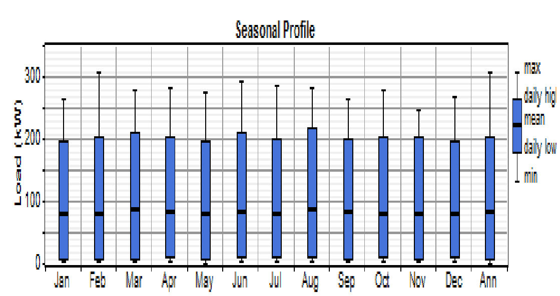


Figure 5. Monthly Load Profile of JEC Jabalpur



Wind Turbine

The wind resource is ultimately generated by the sun, but it tends to be very dependent on location. Over most of the earth, the average wind speed varies from one season to another. It is also likely to be affected by general weather patterns and the time of day. It is not uncommon for a site to experience a number of days of relatively high winds and for those days to be followed by others of lower winds. The wind also exhibits short term variations in speed and direction. This is known as turbulence. Turbulent fluctuations take place over time periods of seconds to minutes. For this study BWC Northern Power Nw/100/19kw AC wind turbine has been used which is manufactured by Bergey Wind power. The installation, capital and O&M cost of this turbine is respectively $110000, $70000 and $500. The wind speed is typically modelled as increasing with height according to a 1/7 power law.

$$V = V_o [h/h_o]^{1/7} \quad \text{………………………………………(i)}$$

Where

V_o = Wind speed

h_o = Original height

h = Change in height

V = Resulting Speed

Solar Radiation

Solar energy is the most promising of the renewable energy sources in view of its apparent unlimited potential. The sun radiates its energy at the rate of about 3.8 x 1023 kW per second. Most of this energy is transmitted radially as electromagnetic radiation which comes to about 1.5kW/m^2 at the boundary of the atmosphere. After traversing the atmosphere, a square metre of the earth's surface can receive as much as 1kW of solar power, averaging to about 0.5 over all hours of daylight. The solar radiation resource is fundamentally determined by the location on the earth's surface, the date, and the time of day. Those factors will determine the maximum level of radiation. Other factors, such as eight above sea level, water vapour or pollutants in the atmosphere, and cloud cover, decrease the radiation level below the maximum possible. Solar radiation does not experience the same type of turbulence that wind does, but there can be variations over the short term. Most often, these are related to the passage of clouds. The initial installation cost of photovoltaic arrays are taken approximate as $5000 and $3000, respectively. The lifetime of the PV arrays are taken as 25 years and no tracking system is included in the PV [5].

Figure 6.Cost Curve of Solar PV System

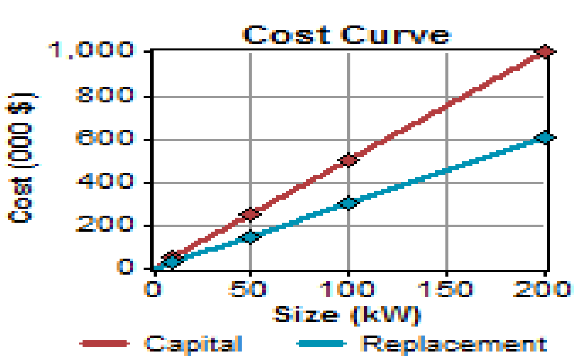
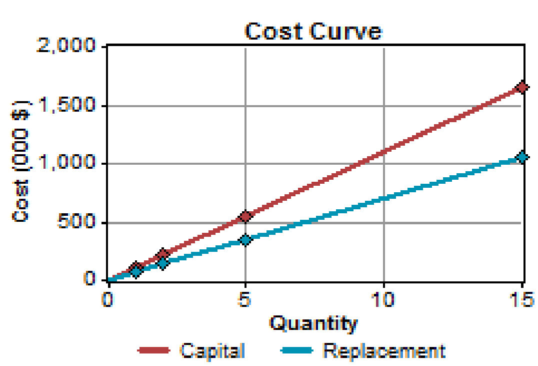


Figure 7. Cost Curve of Wind Turbine (NW/100)



Power Converter

A power electronic converter is needed to maintain the flow of energy between the AC and DC buses. Three different sizes of converter (0, 10 and 20 kW) were fed into the analysis. Lifetime of a unit was assumed to be 25 years with an efficiency of 90%. According to the components defined a converter is required to convert AC-DC or DC-AC. The installation costs for a 1.0kW converter is $700, replacement cost is $460 and O&M cost is considered practically zero. A power electronic converter is needed to maintain flow of energy between the ac and dc components [5].

Grid

This proposed system is a grid-connected system in which the Grid acts as a backup power component. The grid is activated and supplies electricity when there is not enough renewable energy power to meet the load.

Batteries

For the purpose of energy storage, lead acid batteries are included in this analysis for economic considerations. The use of hydrogen as another possible storage alternative is not currently economically viable given the prohibitive costs of electrolyzers and fuel cells and the low efficiency resulting from the electricity–hydrogen–electricity conversion cycle. In this case, commercially available battery models, such as Surrette 6CS25P model (6 V, 1156 Ah, 9645 kWh), were used in the scheme. Cost of one battery was considered $500 with replacement and operation and maintenance (O&M) costs of $300 and $5/year, respectively. To find an optimum configuration, the battery bank was assumed to contain any number of 0, 10, 20, 30, or 50 batteries.

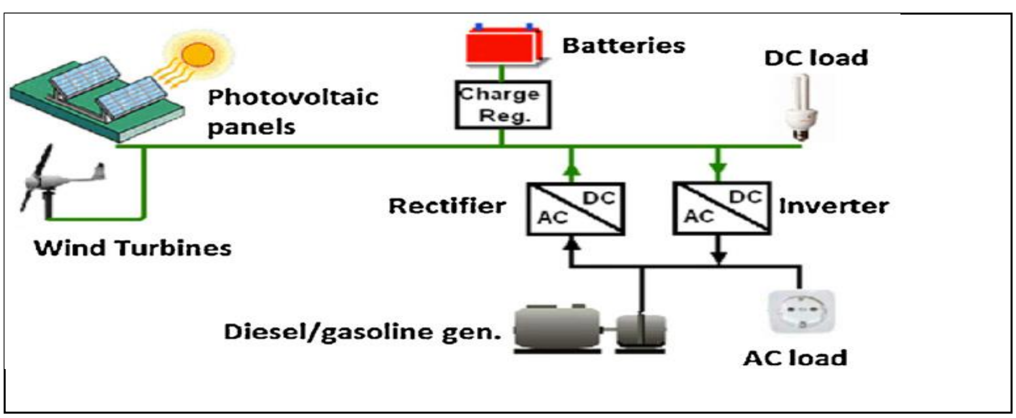
Generator

A generator consumes fuel to produce electricity, and possibly heat as a by-product. HOMER's generator module is flexible enough to model a wide variety of generators, including internal combustion engine generators, micro turbines, fuel cells, Stirling engines, thermo photovoltaic generators, and thermoelectric generators. HOMER can model a power system comprising as many as three generators, each of which can be ac or dc, and each of which can consume a different fuel. The principal physical properties of the generator are its maximum and minimum electrical power output, its expected lifetime in operating hours, the type of fuel it consumes, and its fuel curve, which relates the quantity of fuel consumed to the electrical power produced.

Inverter

The efficiencies of the inverter and rectifier were assumed to be 90% and 85% respectively for all sizes Considered. The simulations were done for each system switching the power between the inverter and the generator. Both devices were not allowed to operate in parallel. Initial and replacement cost for the converter is 700$, with no cost for operation and maintenance.

Figure 8. Block Diagram of a Conventional PV–Wind–Diesel–Battery System



Optimization of Renewable Hybrid Energy System USING HOMER Software

The Hybrid Optimization Model for Electric Renewable (HOMER 2.81) is used for designing standalone electric power systems that employ some combination of wind turbines, photovoltaic panels, or diesel generators to produce electricity. The cost benefit analysis of a wind turbine-solar hybrid system was done using HOMER software and comparison was also made with the cost per kilowatt of central grid or utility supply. The software requires initial information including energy resources, economical and technical constraints, energy storage requirements and system control strategies. Inputs like component type, capital, replacement, operation and maintenance costs, efficiency, operational life, etc. are also required. The goal of the optimization process is to determine the optimal value of each decision variable that interests the modeller. A decision variable is a variable over which the system designer has control and for which HOMER can consider multiple possible values in its optimization process. The software executes three major tasks; simulation, optimization, sensitivity analysis. Possible decision variables in HOMER include:

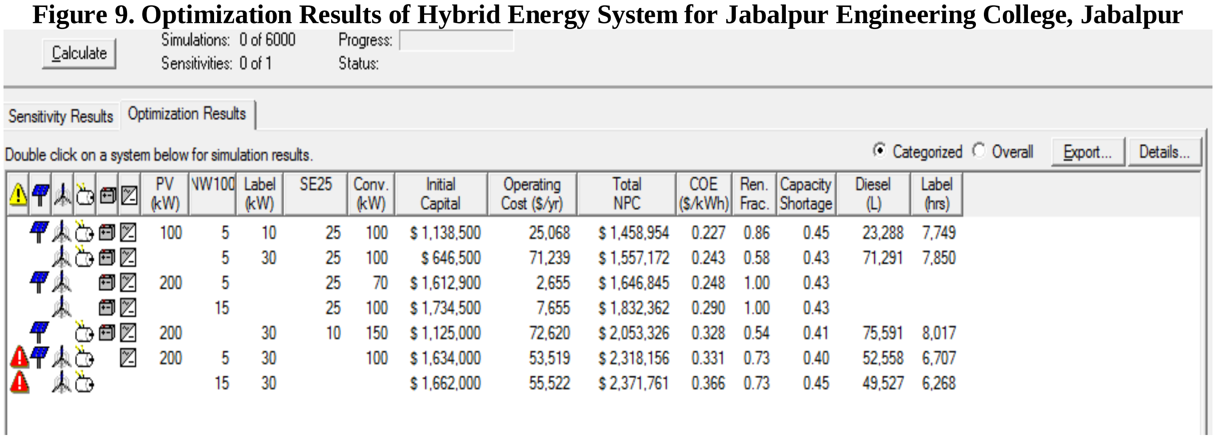
- The size of the PV array
- The number of wind turbines
- The size of each generator
- The number of batteries
- The size of the ac–dc converter

RESULTS AND DISCUSSION

The above proposed hybrid system supply the power to the Jabalpur Engineering College, Jabalpur (MP) continuously throughout the year. An optimal system is defined as a solution for hybrid system configuration that is capable of meeting the load demand of Jabalpur Engineering College, Jabalpur (MP).

From the simulation result the installation of wind solar hybrid system configuration for various locations are most suitable power solutions for Grid transformer station network in Indian sites. Considering present cost analysis of a PV/Wind hybrid system is suitable for stand-alone loads around Jabalpur. From the optimization results the best optimal combination of option I energy system components are Five 100Kw Northern Power NW/100, 100 kW PV-Array and 10 kW diesel Generator, 100 KW Convertor and 25 Becon smart energy battery. Total net present cost (NPC), Capital cost and cost of energy (COE) for such a system is $1458,954, $1138,500 and 0.227$/kWh, respectively for one year. The detailed optimization results are shown in Figure 9.The net project cost is 72947700 Rs and the expenditure of conventional existing grid system is 7250000 Rs per year. Thus the simple payback period is the ratio of net project cost to the expenditure of conventional existing grid system cost per year so pay back year is 10 years.

Figure 9. Optimization Results of Hybrid Energy System for Jabalpur Engineering College, Jabalpur



Calculate Simulations: 0 of 6000 Progress:
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Sensitivity Results | Optimization Results

Double click on a system below for simulation results. Categorized Overall Export... Details...

PV (kW)	NW100	Label (kW)	SE25	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
100	5	10	25	100	$ 1,138,500	25,068	$ 1,458,954	0.227	0.86	0.45	23,288	7,749
	5	30	25	100	$ 646,500	71,239	$ 1,557,172	0.243	0.58	0.43	71,291	7,850
200	5		25	70	$ 1,612,900	2,655	$ 1,646,845	0.248	1.00	0.43		
	15		25	100	$ 1,734,500	7,655	$ 1,832,362	0.290	1.00	0.43		
200		30	10	150	$ 1,125,000	72,620	$ 2,053,326	0.328	0.54	0.41	75,591	8,017
200	5	30		100	$ 1,634,000	53,519	$ 2,318,156	0.331	0.73	0.40	52,558	6,707
	15	30			$ 1,662,000	55,522	$ 2,371,761	0.366	0.73	0.45	49,527	6,268

Option I - System architecture

PV Array	100 kW
Wind Turbine	5 Northern Power NW100/19
Generator	10 kW
Battery	25 Beacon Smart Energy 25
Inverter	100 kW
Rectifier	100 kW
Cost summary	
Total net present cost	$ 1,458,954
Levelized cost of energy	$ 0.227/kWh
Operating cost	$ 25,068/yr

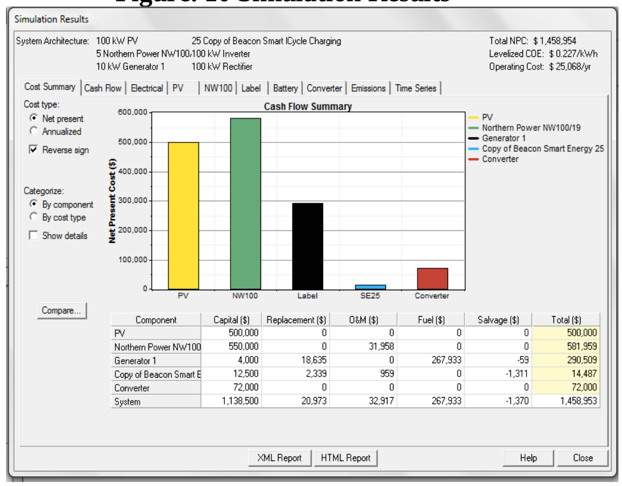

Figure. 10 Simulation Results

Option II - System architecture

PV Array	-----
Wind Turbine	5 Northern Power NW100/19
Generator	30 kW
Battery	25 Beacon Smart Energy 25
Inverter	100 kW
Rectifier	100 kW
Cost summary	
Total net present cost	$ 1,557,172
Levelized cost of energy	$ 0.243/kWh
Operating cost	$ 71,239/yr

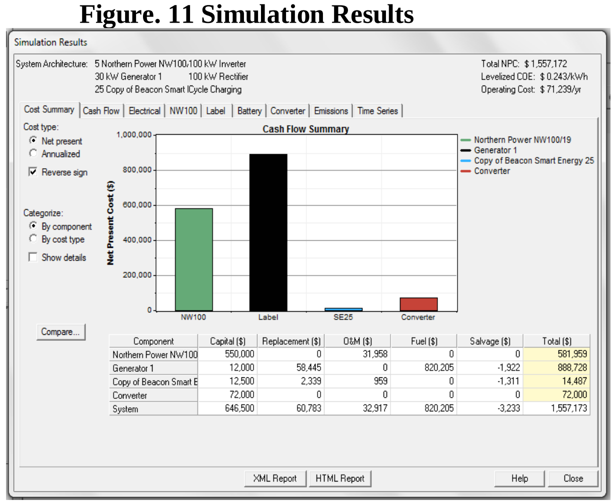

Figure. 11 Simulation Results

Option III - System architecture

PV Array	200 KW
Wind Turbine	5 Northern Power NW100/19
Generator	------
Battery	25 Beacon Smart Energy 25
Inverter	70 kW
Rectifier	70 kW
Cost summary	
Total net present cost	$ 1,646,845
Levelized cost of energy	$ 0.248/kWh
Operating cost	$ 2,655/yr

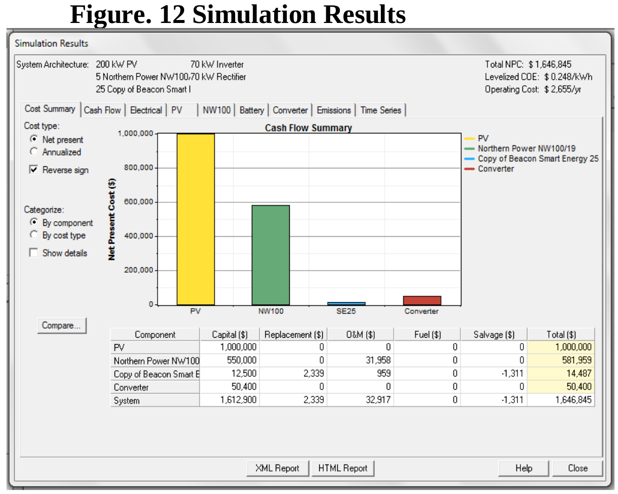

Figure. 12 Simulation Results

CO NCLUSION

Homer software was used to determine the optimum hybrid configuration of Jabalpur Engineering College, Jabalpur *(Longitude 79^o.59'and Latitude 23^o.10')*. As a result of which the Option I, is proposed for the site. The system architecture includes PV System 100KW, 5 Northern Power NW100/19, Diesel Generator 10KW, Battery 25 (Beacon Smart Energy), Inverter 100KW and Rectifier 100KW. The Net Project cost is = 72947700 Rs the payback period of the proposed hybrid renewable energy system is 10 years. The system is designed for 25 years. Thus concluded that after 10 years next 15 years we can enjoy the profits with green energy resources which is sustainable and environmental friendly. The proposed system is very good choice in the remote and village areas also. The integration of renewable energy technologies into electric power distribution systems enhances the benefits associated with fuel savings and avoidance of emissions penalties. Renewable energy technologies such as photovoltaic, and wind turbine power are environmentally beneficial sources of electric power generation. It should reduced approximate 70%-80% running cost over conventional grid system and also reduced the emission of CO_2 and other harmful gasses in environments.

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