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Real Time Load Assessment and Economic Analysis of RES System

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ABSTRACT

Renewable resources are complementary in nature so the weaknesses of one can be overcome with the strength of other. The factors such as climate condition and weather are unpredictable, more for wind than compared to solar sources. The complementary nature of wind and solar sources motivates us to hybrid wind-solar power plant concept. The major problems like environment hazards, depletion of fossil fuels can be overcome by using hybrid power station. With the help of grid interconnection, the energy can be supplied to the remote rural areas and the emission of carbon and other harmful gases can be reduced up to 80% to 90%. This paper focuses on the optimal combination of renewable energy resources that could electrify the area under study. This paper also highlights the village details, energy resources available in region under study and the predicted load assessment. The various power output equations of wind power and solar power has also been discussed. The overview of the Homer software that was used for simulation purposes has also been discussed in this work.

1. INTRODUCTION

Rural Electrification [1] is defined as the process of electrifying all the rural areas of the country. The rural areas including all small and big villages should get reliable electricity for the development. The lifestyle of the people belonging to these un-electrified villages will get access to the electricity. The people who live in unelectrified rural areas are mostly poor, but when they will get access to electricity they will start earning from the small electricity operated industries like paddy grinding machines, sheep shearing machines, weaving machines, milking plants, oil-seed machines and much more small scale plants.

Taking a look on the Indian rural areas, on records the total population of India as per census 2011 is 1.2777 billion, out of which the total rural population is about 833,087,662. Looking over the Indian rural topography it is very diverse, Healy in the northern and eastern regions, sandy in the west regions, coastal in the south side and plains in the central regions. Since the topography of India is very diverse, the energy resources also become diverse like northern and eastern regions have high hydro potential, west and plains have high solar potential, the coastal regions have high wind, wave, and tidal energy potential. In order to electrify the rural villages of India, the following technologies should be used to provide reliable electricity to these rural areas:

- Non-renewable energy systems.
- Renewable energy systems [2-5].

Electrifying rural areas by using renewable energy systems is a good and economical solution [6]. Some regions have high potential of solar, wind, biomass, tidal or wave energy at individual level in such regions we can go for individual renewable energy systems [7, 8] in which supply and demand can be easily matched [9]. Some regions are resource constraint where demand cannot be met by individual systems [10], there we can provide electricity by going with integration of renewable energy systems. Sometimes there are certain regions where there are very harsh environmental conditions, at that time we can go with hybrid renewable energy system in which overall system is grid connected [11-14] or we have one conventional system like diesel generator sets.

2. METHODOLOGY USED

The Methodology used for finding the optimal combination of renewable energy resources that would electrify the area under study is shown in the flow chart as given in Figure 1.

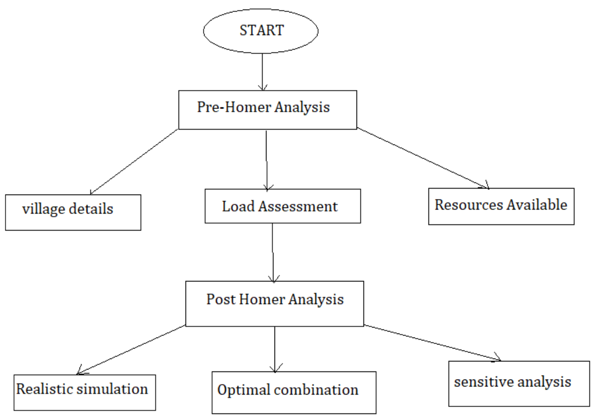

Figure 1. Flow chart showing the methodologies followed

3. VILLAGE DETAILS

Table 1 shows the details of the village for which we have designed optimized, economical and reliable scheme which would electrify this village. The village is a far flung area where access by foot is possible. It is almost 25 to 30 Kilometres far away from the nearest town where grid connectivity is present. The village can be connected to grid in near future many attempts were made for connecting this village to grid but all attempts failed in a short interval of time. The reasons for their failures were that the region is mountainous and receives heavy snowfall during the winter session. The reliable solution for electrifying this village is to develop standalone system which suits best under such harsh conditions. The rest of the details of village are given in the Table 1.

Table 1. Village details

Particulars	Detail
Village name	Kadura
District	Bandipora
State	J&K
Country	India
Longitude	74.66
Latitude	34.42
Rivers available	1
Grid electricity	0
No. of house holds	468
Total population	2,455
Primary school	1
Dispensary	1
Drinking water	available

4. LOAD ASSESSMENT

Load is different for different areas i.e. urban and rural areas. Due to the lack of industries and low lifestyle of people in rural areas the load demand is quite less. Load is not a constant variable it keeps changing with time and with seasons hence it is a random variable. Due the modernization, increase in population and expansion of industries, load demand is also increasing day by day.

In this study, the village for which we are doing load assessment is already electrified but power comes for very small duration so keeping the rural electrification standard in mind, load assessment is done and shown in table below. The load was classified as industrial, commercial, community load, irrigation and agricultural loads. Daily load profile is shown in Figure 2.

5. AVAILABLE RESOURCES

In order to maintain continuity of power in any region, the knowledge of various energy sources present in that region is very important. As the village under study is already connected to grid so during the power cuts, solar and wind sources will help in maintaining the continuity of power as solar is having good potential in that region. Due to the development in wind and solar technologies in last few decades the cost per KW production of power is reduced to 1K to 2K.

5.1 Solar

The monthly solar radiation kWh/m^2/d of selected site are shown in Table 2 below. Figure 3 shows the available solar profile. In case of solar [15-22] the power potential is obtained by using formula:

$$P = A*R*H*PR$$

R-yield factor
A-total solar panel area
P=kWh
H=kWh/m^2
PR-performance ratio, coefficient for losses (ranges between 0.5 to 0.9).

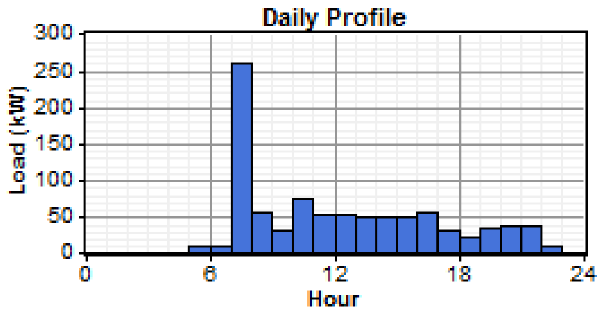

Figure 2. Daily load profile

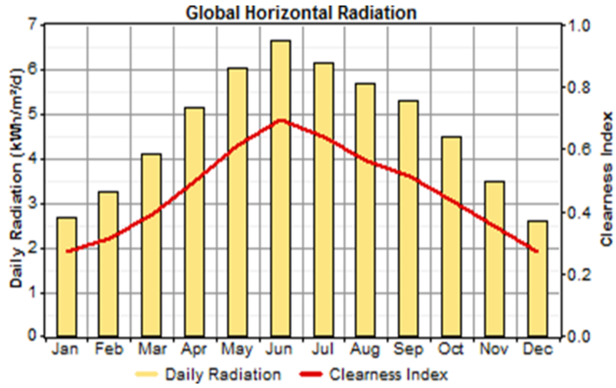

Figure 3. Solar profile at selected area

Table 2. Monthly solar radiation available

Month	Solar radiation (kWh/m^2/d)
January	2.68
February	3.23
March	4.09
April	5.13
May	6.05
June	6.64
July	6.16
August	5.67
September	5.30
October	4.48
November	4.10
December	3.48

5.2 Wind

The average monthly wind speed of selected geographical location is 4.78 m/s. Table 3 below shows the wind speed during the particular months of the selected site and the graphical representation of wind profile is shown in Figure 4. The theoretically available power in the wind can be ex pressed as:

$$P = 1/2\ \rho\ A\ v3 \qquad (1)$$

where,

P = power (W)

ρ = density of air (kg/m^3)

A = area wind passing through perpendicular to the wind (m^2)

v = wind velocity (m/s)

Table 3. Monthly wind speed available

Month	Wind speed (m/s)
January	4.5
February	4.4
March	4.4
April	4.7
May	4.6
June	4.9
July	5.1
August	5.1
September	5.0
October	5.0
November	4.9
December	4.8

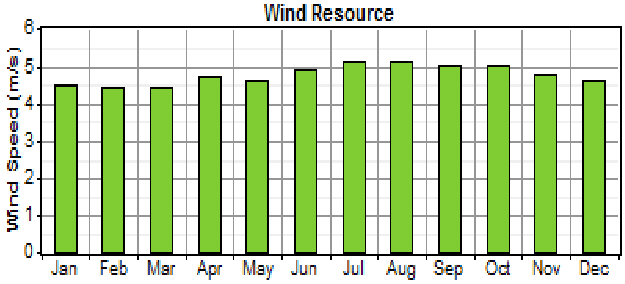

Figure 4. Wind profile at selected site

5.3 Hydro

The water discharge of the stream throughout the year was collected from the irrigation department of the district Bandipora. The head is almost ranging from 120-170 m. The turbine under consideration is Francis turbine. The classification of small hydro power plants by capacity in India is given in Table 4 and the worldwide classification is given in Table 5. The hydro plant which we are integrating is mini hydro power plant. The theoretical power output of hydro power plant is given by Eq. (2). Figure 5 show the hydro profile at a given site.

$$P_{th} = \rho.q.g.\ h \qquad (2)$$

where,

P_{th} = power theoretically available (W)

ρ = density (kg/m^3) (~ 1000 kg/m^3 for water)

q = water flow (m^3/s)

g = acceleration of gravity (9.81 m/s2)

h = falling height, head (m)

Table 4. Indian small hydro power plant classification

Class	Station capacity
Micro	Up to 100 Kw
Mini	101 to 2,000 Kw
small	2 to 25 MW

Table 5. Worldwide classification of small hydropower plants

U.K.	<5 MW
India	<25 MW
Sweden	<15 MW
Australia	<20 MW
China	<25 MW
New-Zealand	<50 MW

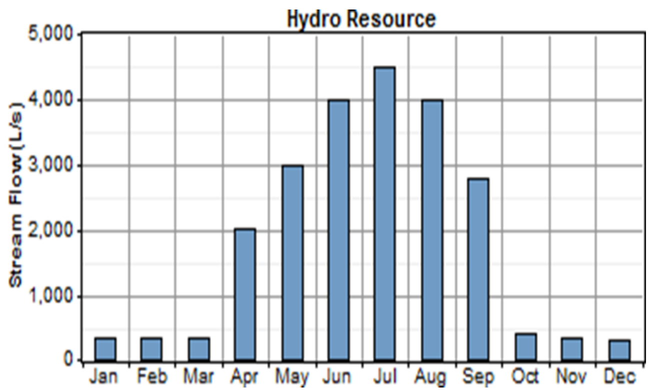

Figure 5. Hydro profile at given site

6. SIMULATION MODEL

After the survey of the site, the data collected are used for the development of the simulation model of integrated renewable energy system which will be implemented for our case study. Below Figure 6 shows the required simulation model.

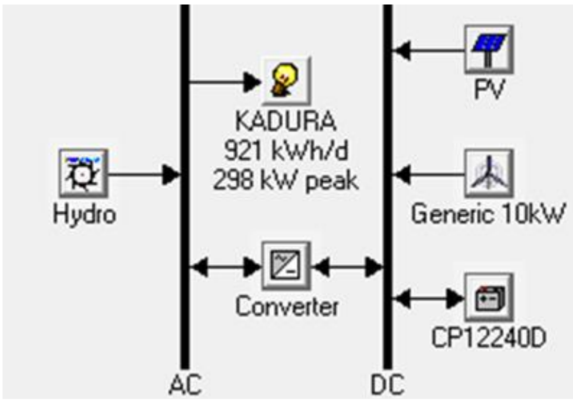

Figure 6. Simulation model

6.1 Hydro inputs

Table 6 shows the hydro turbine parameters and Table 7 shows the overall generator economics. Since the head available is medium head of about 150m, the turbine proposed for this implementation would be Francis turbine.

Table 6. Generator turbine parameters

Generator type	AC
Available head	150m
Design flow rate	210
Minimum flow ratio (%)	50
Max flow ratio (%)	150
Efficiency	75
Pipe head loss	10

Table 7. Generator economic

Capacity	234 kW
Cost/kW	2,000$
Total capital cost	480,000
Replacement cost	450,000
O&M cost ($/yr)	10
Lifetime (years)	25

6.2 PV inputs

Solar Photo Voltaic (SPV) Panels are connected in series with following economic and other input parameters given in Table 8.

Table 8. PV Inputs

Output current	DC
Lifetime (years)	20
Size (kW)	300
Ground reflectance	20
Capital cost ($)	615
Replacement cost ($)	615
O&M cost ($/yr)	15

6.3 Wind turbine details

For our simulation the wind turbine we have considered is Generic 10 KW. Table 9 shows the various economic and input wind turbine parameters.

Table 9. Wind Inputs

Quantity	30
Capital /generic 10kW	6,000$
Lifetime (years)	15
Hub height	25m
Capital cost ($)	180,000
Replacement cost ($)	175,000
O&M cost ($/yr)	100

6.4 Battery inputs

Table 10 shows the economic and various battery inputs for our simulation model.

6.5 Converter inputs

Table 11 shows the various converter Inputs for our simulation model.

Table 10. Battery inputs

Battery type Quantity	Vision CPI224OD 36
Total Capital	2,880
Replacement	2,880
O&M($/YR)	10
No. of strings	2
Batteries per string	18
Minimum battery life	5

Table 11. Converter inputs

Size (kW)	20
Capital	3,076 $
Replacement	3,076 $
O&M ($/Yr)	30
Size	20
Lifetime (years)	15
Efficiency	90

7. RESULTS AND DISCUSSION

The results that we have obtained after carrying out the data analysis and required simulation are discussed here. The optimal and economical combination that was capable of meeting the predicted load demand consists of wind, solar and hydro integrates system. The net present cost (NPC) and operational costs of the integrated system has been discussed. The cost associated with each and every single component of the integrated system has been discussed in detail in this chapter. The output power waveforms of each solar, wind and hydro have been discussed. The cost flow curves and various emissions of this integrated renewable energy system have also been discussed.

7.1 Wind and solar power graphs

Hydro power, wind power and PV power output graphs are shown in Figures 7, 8 and 9 respectively.

Figure 7 shows the output hydro power with respect to the steam flow of water in the area under consideration. The output is high in the last quarter of the year in spite of the low steam flow is because of the consideration of extra water storage due to the rain which will temporarily increase the steam flow and in turn will increase the output power of hydro plant.

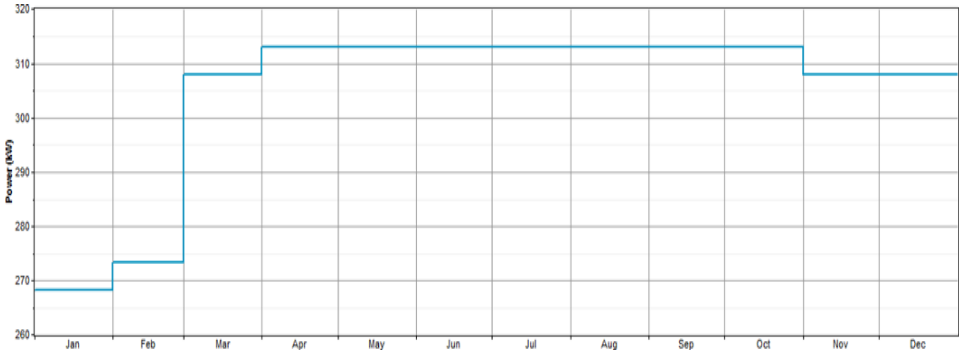

Figure 7. Hydro power

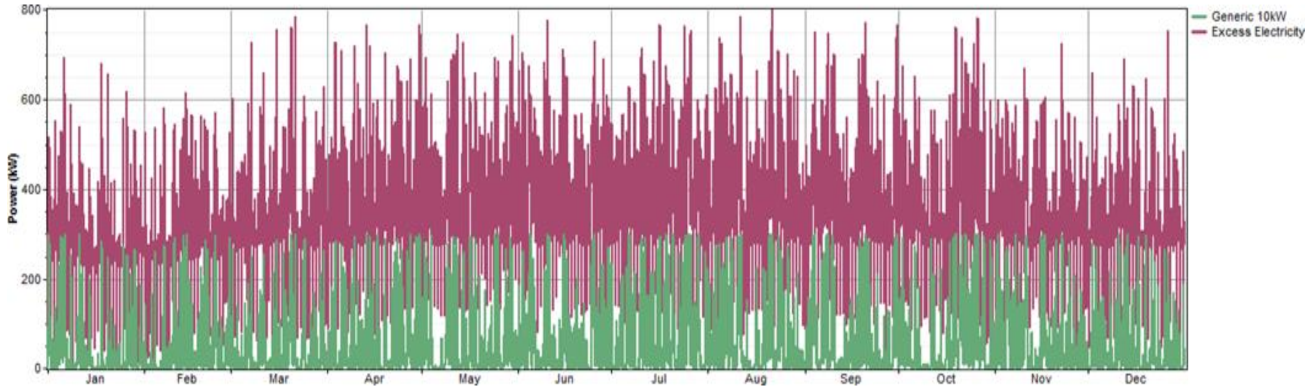

Figure 8. Wind power

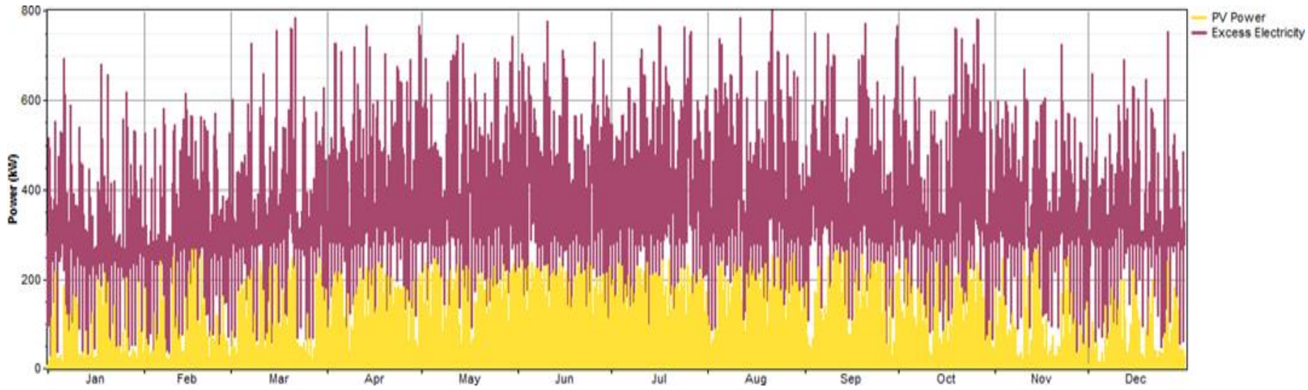

Figure 9. PV power

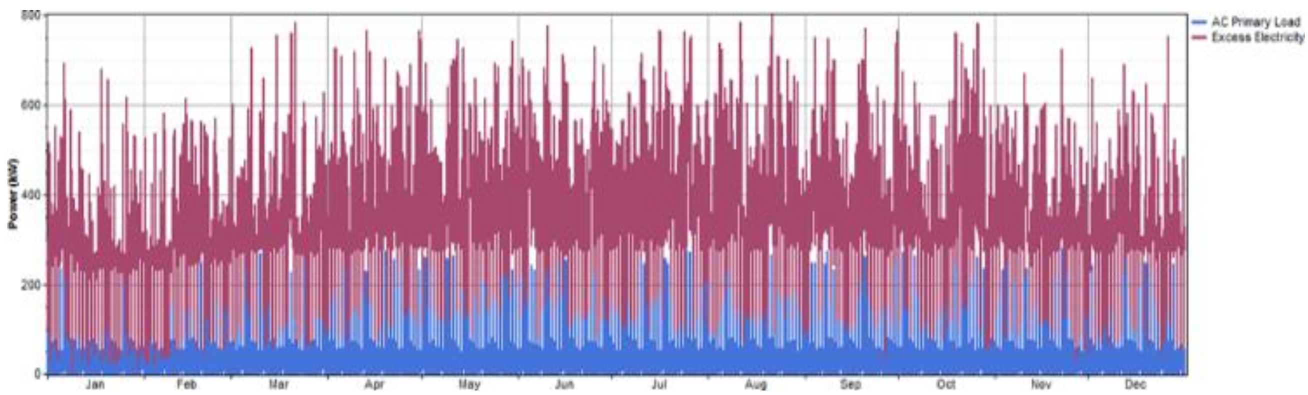

Figure 10. Excess electricity

Figure 8 shows the output power delivered by the wind system. The green curve shows the actual electricity supplied by the wind system after interconnection and rest is excess power. Figure 9 shows the output power delivered by the solar system. The yellow curve shows the actual contribution of solar power in the interconnected system to the load and rest is excess power. Figure 10 shows the excess amount of electricity after supplying the load demand. This excess power can be transferred back to grid or can be stored for the unwanted situation. For now there is no grid connected to the area under consideration so this can be done in future.

7.2 Mission and battery details

In India most of the load is met by thermal power plants which degrade the environment because of various emissions like sulphur dioxide, Nitrogen oxides, carbon dioxides, Carbon monoxide and other particulate matter. Because of these emissions global warming takes place which increases temperature on the earth's surface and results in natural disasters like floods and droughts. In our integrated renewable energy system all these emissions are zero which solves the modern power system big challenge. Table 12 shows the various emissions in our integrated scheme. As the system is based on the renewable energy hence emissions are coming out to be zero. The battery output details are mentioned in Table 13.

Figure 11 is the scatter plot the graph plotted between Incident solar (KW/m^2) and global solar (KW/m^2).

Figure 12 shows the A.C Primary load curve, the graph between power and different months of the year.

Figure 13 shows the input and output power of the inverter.

Table 12. Emissions

Pollutant	Emissions (kg/yr)
Carbon monoxide	0
Carbon dioxide	0
Unburned hydrocarbons	0
Particulate matter	0
Sulfur dioxide	0
Nitrogen oxides	0

Table 13. Battery output details

Quantity	Value
Nominal Capacity	10.4kWh
Usable nominal capacity	6.22kWh
Autonomy	0.162Hr
Lifetime throughput	3712 kWh
Battery wear cost	0.868 $/kWh
Average energy cost	0.000$/kWh

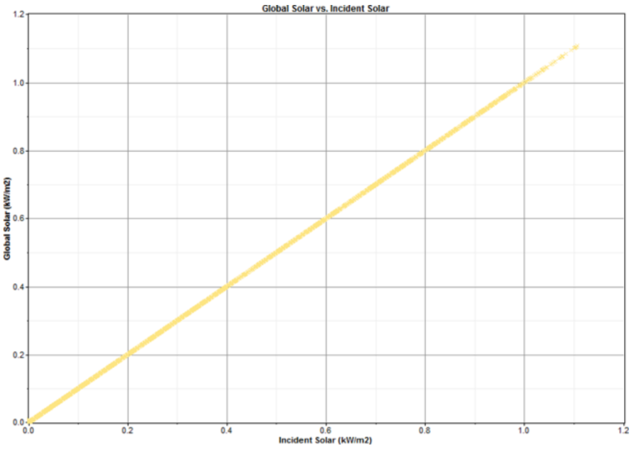

Figure 11. Scatter plot (Global Vs Incident Solar)

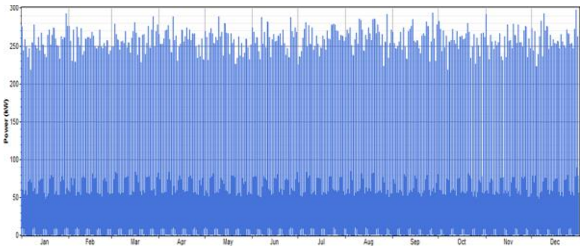

Figure 12. AC primary load

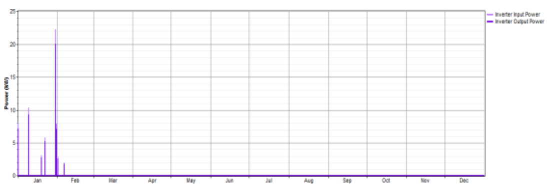

Figure 13. Inverter output and input power

7.3 Electricity share of various resources and average monthly electricity of integrated system

Figure 14 shows the monthly average electricity production by integrated renewable energy system. During the summer months the water discharge and the solar intensity is good, due to which the integral system is capable of producing extra electricity, however during the winter months the electricity production gets reduced however the integral system is capable of meeting the demand with ease. In Figure 14 hydro electricity production is represented by blue color, however solar and wind generated power are represented by yellow and green color respectively.

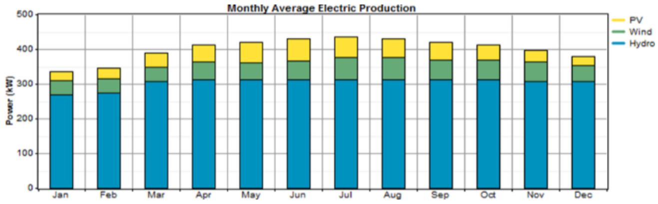

Figure 14. Monthly average electricity production by integrated system

Table 14 shows the various electricity shares of various resources. The maximum share is coming from the hydro turbines which are used to supply the base load which is available all the time, while peak load is met by combination of solar and wind power.

Table 14. Electricity share of various resources

Component	kWh/yr
PV array	389677
Wind turbines	454105
Hydro turbines	2670191
Total	3513974

7.4 Cash flow summary

As it is very clear from the cash flow summary, which about 45% of initial investment will go for hydro system, 30% initial investment will go for solar photovoltaic system and 20% will go for wind power. Although hydro is very costly in terms of initial investment but it will be supplying the entire base load throughout the year. Maintenance charges for the solar system are very less but the battery bank associated with it has less life of about 5 years. Figure 15 shows the cash flow summary of the entire integrated scheme.

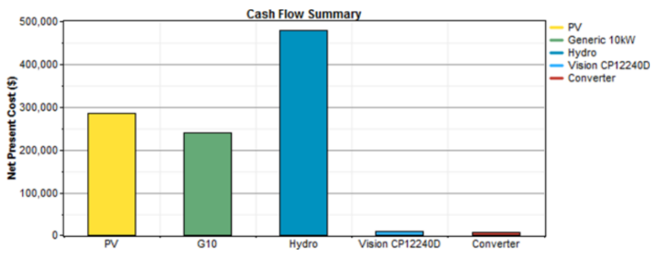

Figure 15. Cash flow summary

7.5 System architecture and overall cost summary

The optimal combination obtained is of 232 kW hydro, 30 Generic 10 Kw, 300 Kw PV, 36 VISION CPI2240D, 20 KW inverter and 20 kw rectifier. Table 15 shows the overall system architecture of the optimal combination. The total net present cost (NPC), Levelized COE (cost of electricity) and capital cost for such an integrated scheme are $1,022,932, $0.238/kWh and $850,456respectively. The operating cost per year was found to be $13,492/yr. Table 16 shows the overall cost summary of the optimal combination. Table 17 shows the individual component capital, replacement, O&M ($) & Fuel ($) costs respectively.

Table 15. System architecture

Hydro	232 kW
PV array	300 Kw
Wind	30 Generic 10 Kw
Battery	36 vision CPI 2240D
Inverter	20 kw
Rectifier	20 kw

Table 16. Overall cost summary

Total NCP	$ 1,022,932
Lavelized COE	$ 0.238/kWh
Operating cost	$ 13,492/year
Capital cost	$ 850,456

Table 17. Individual component cost

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)
PV	184500	57528	76700	0
Generic 10Kw	180000	73021	1278	0
Hydro	480000	0	128	0
Vision CPI2240D	2880	5860	192	0
Converter	3076	1284	2557	0
system	850456	137693	80855	0

8. CONCLUSION

In our case study we collected information like village details, various renewable energy resources present in the village during various time zones of the year, load assessment was also done, the data obtained was well analysed and with the aid of homer software our case study resulted in finding an optimal combination of renewable energy resources that will satisfy the predicted load demand of this remote border village consisting of about 468 number of households.

The optimal combination consists of solar, wind and hydro power that satisfies demand at a cost of 0.238/KWh. The load assessment was carried which resulted in a peak load of 298 KW and average per day load of 921 KW /day. The base load is met by hydro power whereas the less efficient system of solar and wind would be used to meet the peak loads.

The optimal combination was found after a rigorous survey done in the village under consideration. The information regarding various energy resources present with their potential was also calculated.

The architecture of the optimal combination consists of 300KW PV, 30 Generic 10KW and 232KW hydro. The total net present cost (NPC) and operating cost are $1,022,932 and $13,492/yr respectively. The individual cost assessment of each component of the simulation model was also done.

The output power of hydro, solar and wind was also discussed with various plots. The hydro, solar and wind potential profiles were also plotted for the various months of the year.

The extra energy generated during summers could electrify neighbouring un-electrified villages in combination with some other renewable energy source. The transmission network would consist of LT cables or 11 KV ACSR conductor in combination with step down transformer 11 KV/400 V.

REFERENCES

[1] Nour, M., Rohani, G. (2014). Prospects of stand-alone PV-DIESEL hybrid power generation for rural electrification in UAE. International Journal of Renewable Energy Research, 4(3): 749-758.

[2] Ellabban, O., Abu-Rub, H., Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technologies. Renewable and Sustainable Energy Reviews, 39: 748-764. https://doi.org/10.1016/j.rser.2014.07.113

[3] Misak, S., Prokop, L. (2017). Operational characteristics of renewable energy sources. Springer International, ISSN 1865-3529. https://doi.org/10.1007/978-3-319-43412-4

[4] Anoune, K., Bouya, M., Ghazouani, M., Astito, A., Abdellah, A.B. (2016). Hybrid renewable energy system to maximize the electrical power production. 2016 International Renewable and Sustainable Energy Conference (IRSEC), Marrakech, Morocco, pp. 533-539. https://doi.org/10.1109/IRSEC.2016.7983992

[5] Pattanayak, P., Panigrahi, N., Mishra, S. (2015). Overcome of energy crisis using hybrid renewable energy sources in India. IEEE 9th International Conference on Intelligent System and Control (ISCO), Coimbatore, India, pp. 1-6. https://doi.org/10.1109/ISCO.2015.7282263

[6] Omogoye, O.S., Ogundare, A.B., Akanji, I.O. (2015). Development of cost effective solar/diesel independent power plant for a remote station. Journal of Energy, 2015: 828745. https://doi.org/10.1155/2015/828745

[7] Anees, A.S. (2012). Grid integration of renewable energy sources: Challenges, issues and possible solutions. IEEE 5th India International Conference on Power Electronics (IICPE), Delhi, India, pp. 1-6. https://doi.org/10.1109/IICPE.2012.6450514

[8] Lohar, A.T., Ramteke, R.G., Patil, U.V. (2015). Grid interconnection of renewable energy sources and performance improvement of power quality at distribution level. International Journal on Recent and Innovation Trends in Computing and Communication, 3(2): 2278-8875.

[9] Montouri, L. (2017). Application of demand response strategies for the management of natural gas system under the smart grid configuration: Development of a methodology for technical, economic and environmental evolution. Universitat Politecnica de valencia.

[10] Ituarte-Villarreal, C.M., Lopez, N., Espiritu, J.F. (2012). Monkey algorithm for power system optimization. Procedia Computer Science, 12: 344-349. https://doi.org/10.1016/j.procs.2012.09.082

[11] Ani, V., Nnene, E.A. (2013). Simulation and optimization of PV/diesel hybrid power generation system for health service facilities. Electronic Journal of Energy and Environment, 1(1): 57-70. https://doi.org/10.7770/ejee-V1N1-art521

[12] Katayama, M., Ohno, T., Obara, H., Kawamura, A. (2017). Study on application of multi-level converter to realize fast current control in DC micro-grid with extremely low impedance interconnection. IEEE 12th International Conference on Power Electronics and Drive Systems (PEDS), Honolulu, HI, USA, pp. 697-702. https://doi.org/10.1109/PEDS.2017.8289205

[13] Podder, S., Biswas, M.M., Khan, M.Z.R. (2016). A modified PWM technique to improve total harmonic distortion of multilevel inverter. 9th International Conference on Electrical and Computer Engineering (ICECE), Dhaka, Bangladesh, pp. 515-518. https://doi.org/10.1109/ICECE.2016.7853970

[14] Neha, G.L., Banakara, B. (2017). Power quality enhancement in smart grid by synchronizing SPWM inverter and LC filter. 2nd IEEE International Conference on Recent trends in Electronics, Information and Communication Technology (RTEICT), Bangalore, India, pp. 633-637. https://doi.org/10.1109/RTEICT.2017.8256674

[15] Obreja, V.V.N., Codreanu, C., Nuttall. K.I. (2005). Reverse leakage current instability of power fast switching diodes operating at high junction temperature. IEEE 36th IEEE Power Electronics Specialists Conference (PESC2005), Dresden, Germany, pp. 537-540. https://doi.org/10.1109/PESC.2005.1581677

[16] Tamraker, V., Gupta, S.C., Sawle, Y. (2015). Single diode PV cell modeling and study of characteristics of single diode and two diode equivalent circuit. Electrical and Electronics Engineering: An International Journal (ELELIJ), 4(3): 13-24. https://doi.org/10.14810/elelij.2015.4302

[17] Villalva, M.G., Gazoli, J.R., Filho, E.R. (2009). Comprehensive approach to modeling and simulating PV array. IEEE Transactions on Power Electronics, 24(5): 1198-1208. https://doi.org/10.1109/TPEL.2009.2013862

[18] Bellia, H., Youcef, R., Fatima, M. (2014). A detailed modeling of photovoltaic module using MATLAB. NRIAG Journal of astronomy and Geophysics, 3(1): 53-61. https://doi.org/10.1016/j.nrjag.2014.04.001

[19] Sarkar, M.N.I. (2016). Effect of various model parameters on solar photovoltaic cell simulation. Renewable: Wind, Water and Solar, 3: 13. https://doi.org/10.1186/s40807-016-0035-3

[20] Shannan, N.M.A.A., Yahaya, N.Z., Singh, B. (2013). A comparison of single diode and two diode model of PV module. IEEE International Conference on Control System, Computing and Engineering (ICCSCE), Penang, Malaysia, pp. 210-214. https://doi.org/10.1109/ICCSCE.2013.6719960

[21] Sharma, S., Jain, K.K., Sharma, A. (2015). Solar cell: In research and application-A review. Material Science and Applications, 6(12): 1145-1155. https://doi.org/10.4236/msa.2015.612113

[22] Alapatt, G.F., Singh, R., Poole, K.F. (2012). Fundamental issues in manufacturing photovoltaic modules beyond the current generation of materials. Advances in OptoElectrinics, 2012: 782150. https://doi.org/10.1155/2012/782150