ISSN 2063-5346

# COMPUTATIONAL MODELS FOR ASSESSMENT OF RENEWABLE ENERGY POTENTIAL AND LOAD ANALYSIS

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**Article History: Received:** 02.05.2023 **Revised:** 14.06.2023 **Accepted:** 25.07.2023

**Abstract**

The primary concern of the Nations worldwide has been the growing energy demand. In view of changing energy scenario, renewable energy emerges as a feasible solution to address circumstances that do not permit centralized energy grid extensions owing to socio–economic problems. The present study has identified a remote cluster of villages located in Sringeri Taluk, Chikkamagalur district of Karnataka state in India. HOMER based Simulation approach was adopted to choose different combinations of PV-WIND-MH-HK systems based on strategies as Development side and Demand Side. The various resource combinations were investigated on the grounds of Net Present Cost (NPC) and Cost of Energy(COE). The results showed that Development side load strategy was optimal for PV-MH-HK combination with $217,191.5 and $0.166/kWh for NPC and COE values. On the contrary, Demand-side Load strategy yielded values of NPC and COE as $120,825 and $ 0.158/KWh respectively. The data indicated a poor wind potential at the area investigated, evident through omission of WIND system in optimal combination. The long term or multiyear simulations carried out for the optimal solution indicated 4.45% rise in COE owing to 4.54% drop in energy production through PV.

**Key words-** simulation, Load strategies, Optimization studies, cost of Energy, Net present cost, Multiyear simulation

**DOI:10.48047/ecb/2023.12.si5.309**

**Abbreviations**-MNRE: Ministry of Renewable Energy sources,MH:Micro-Hydro Generator,BGG:BioGas Generator,BMG:Biomass Generator,PV-Photovoltaic,DG-Diesel Generator,HOMER-Hybrid optimization of Multiple Electrical Renewables,COE:Cost of Energy,NPC:Net Present cost,IRES:Integrated Renewable Energy Systems,HK:Hydro Kinetic Generator,HH:House Hold,IMD:Indian Meteorological Department.CRF:Capital Recovery Factor:LRHP-Low rate watt High Performance.

**Nomenclature**

$Q_D$: Direct surface run off depth(mm),

I :monthly rainfall(mm)

S Maximum potential retention in a watershed(mm)

CN : curve number

Q :the rate of run off or discharge in $m^3/s$

$T_P$: is the time to peak run off(hour)

$T_C$: is the time of concentration(hour),

$L_w$: is the length of the water shed

A: is the area of the Water shed

$H_{net}$:Net Head available

$v_{CI}$: is the cut in speed

$v_R$ :is the rated speed of the turbine

$v_{CO}$: is the cut out speed

$P_R$: is maximum rating of power from the turbine

$V_{hub}$: Velocity at the hub height

$\alpha$=0.43(coefficient value for mountain, terrain)

$Z_1$,$Z_2$=Reference heights wind turbine

$R_{PV}$: rated power output from the turbine,

DF: Derating factor in %,

$I_T$: instantaneous solar radiation

$\eta_{Hydro}$ :efficiency of the Micro Hydro turbine,

$\rho_{water}$: density of water 1000Kg/$m^3$

$Q_{tur}$: discharge from the turbine.

$A_{tur}$ is the surface area of the turbine from the manufacturer is the Average velocity of the stream flow

$C_p$ is the coefficient of performance

V: Velocity of the water stream flow

$\eta_r$:,rotor efficiency

$\eta_b$: Blade efficiency of Hydrokinetic

$\eta_g$:Generator efficiency

D:Diameter of the turbine

i:Interest factor%

N: Number of years

## 1.Introduction

Availability of Energy is the primary criteria for the development of any site/location/area/city, utilizing its primary and secondary resources, commercial and Non-commercial energy resources, and Renewable and Non-renewable energy sources[1].The Government of India has established MNRE(Ministry of Renewable energy Sources) to utilize the full potential alternative energy resources. India's renewable energy potential is about 900GW, from the contribution of Wind-12%,solar-83%,Bioenergy-3% and Small Hydro-2.2%[2]. The energy demand will always show an increasing trend for all the developing and developed countries. In India, rural electrification progress has made a revolutionary development, but some of the electricity access to villages has remained as a barrier. There are a large number of socio-economic challenges that have to be overcome in providing the grid extension[3]. When rural electrification is concerned, the major challenge is to provide the grid to the rural and remote areas[4].It is found to be uneconomical to pass the grid extension to the remote hilly areas and another reason is that flora and fauna at the place for grid extension are mostly get affected[5]. The remote areas are usually found with two or more potential resources, utilizing these resources is far better than passing the extension. The alternative solution is to integrate the potential renewable energy systems to meet the demands of the rural people, especially remote area living people. The optimization process for better integration selection of the systems is to be carried out to assess the feasibility and suitability of the system[6]. An Economic and Environmental pollution study[7] is carried out for the cluster of 9 villages using HOMER tool taking the components MHG/BGG/PV/DG with Battery and obtaining the optimal COE and NPC values for all the configurations. Suitable strategy adopting DSM for standalone IRES[8] in the remote area is made taking PV/WIND/MHG/BGG/BMG configuration to assess the cost of COE and NPC using the Genetic algorithm approach. Optimal modeling of IRES for the remote area electrification[9][10] in Chamaraja Nagar District ,Karnataka is studied for obtaining the optimal sizes of components of the system. The research on simulation and optimization studies[11] of Hybrid energy systems using software tools on various platform are suggested. Different optimal sizing methodologies[12] are referred and suggested which include probabilistic methods, analytical methods, Iterative methods, and Hybrid Methods. WIND-PV-DG[13] system integration is carried out for sizing the systems to provide electrification in rural Algeria using the MATLAB/Simulink environment. A feasibility study of a standalone PV-WIND with Battery[14] is made to assess the NPC and COE with different possible system types in remote island using HOMER tool. A combination of PV/BMG with battery bank[15] for the non-connected zones are studied using the HOMER software and systems are designed and installed at Distributed energy resources Laboratory.A new approach[16] is studied for PV-WIND and energy storage systems in diesel-free isolated communities which proposes the various models handled for optimizing the cost functions. Off-grid generation options are studied[17] to deliver a load of 110KWh/day in rural villages of cameroon using the PV(18kW)-MH(14kW) and LPG generator(15KW) using HOMER. The remote area study[18–20] for the Uttarkhand District villages is performed using the PV/WIND/BMG/BGG/MH. This study gives the feasibility of integrating all the systems in remote areas by conducting the load survey in the villages. The integration of the systems require proper assessment of the resource load and demand load.The demand load is carried out by enquiring with the local people and Grama panchayat available at the location. The study on the Operation of optimal energy systems[21] by considering the Demand-side strategies are simulated as load response from the renewable systems. In this study, optimization strategy is proposed and demonstrated for the single-family residential home. Optimization of PV-WIND -DG[22] is studied for their integration in isolated communities in Brazil for results of NPC and COE.The optimal studies on remote isolated island-sandwip,Bangaldesh [23] is studied for the combination OF PV- Diesel taking the various loading parameters and adopted the Genetic Algorithm(GA) approach for the simulation of NPC and COE.The experimental studies related to off-grid areas[24] are conducted using the PV-Diesel Generator without the battery storage and found that the operation of diesel generator is to be designed for the Peak load demand of the area. The operation of the diesel contributing 60%-80% is observed from the nominal power demand. A review study on IRES[25] are the integration of renewable systems, sizing methodologies, storage technology options for storage durations, and the uncertainties of integration are mentioned by referring the various works of literature. Techno-economic study for MH-PV-WIND-BG-BM-DG is conducted[26] for five un-electrified villages using HOMER software and found best optimal configuration with the least cost of COE as $0.197/kWh.The study[27] was made on using HOMER software for seven un-electrified clusters of villages in Limkheda taluk and Dahood District in Gujarat State using HOMER tool for obtaining the value of NPC and COE.The study[28] is made on a cluster of un-electrified villages in Odisha state , obtained the results for NPC and COE using the salp swarm algorithm utilizing the MATLAB environment for its robustness and convergence efficiency for optimal solutions.The research study,[29] and [30]suggested a Demand response program(DRP) for the performance of PV/FC/Battery –WT/Battery to reduce cost and emissions and latter suggested for smart distribution system(SDS).Studies on Demand side management[31] also gives information for distributed network supply for electric vehicle operations.

From all the above literature studies, it is inferred that the integration of Renewable energy systems is feasible and sustainable for remote areas. The studies are made taking the potential resources available at the locations. The studies related to the configuration of PV-WIND-BM-BG with Diesel generator is more of concern and found less literature on the part of Integrating the Micro-Hydro and Hydro Kinetic turbine. These two renewables sources are site-sensitive and largely depend on the rainfall at the selected areas. Few literature are found integrating the Hydro Kinetic turbine as a resource. The Multi-year simulation results using HOMER are not carried out in various literature. A simulation for Development side strategy is not made in the literature. Here, an integration of MH-HK with the PV- WIND is made for optimal simulation on the un-electrified remote cluster of villages near sringeri Taluk,Karnataka state which is found to be experience with high rainfall status in the Karnataka state region. A different combination for simulation to integration of renewable energy system is carried out to obtain the best optimal solution taking two strategies. The reported research gives an insight into the study in the sections of Load demand and Resource demand assessment, Modeling of Renewable energy systems, optimization studies , Results and discussions and Multi-year simulation results.

## 2.Motivation for present study and Methodology

This study is carried out to obtain the best optimal integrated combination and solution for NPC and COE simulation using HOMER pro soft for a different combination of potential resources at the site. To size different renewable energy systems to accommodate the load demand by considering the two strategies, 1. Development side Load strategy and 2.Demand side Load strategy. This research also assess the NPC and COE using the Multiyear simulation module in HOMER Pro soft. This study involves getting the local coordinates for the site under study for watershed area assessment using the Google save location Mobile app and then elevation contours are developed using the Google earth and ArcGis software. The meteorological data are obtained from using the Meteonorm 7.3 software for solar data and wind data is recorded using the Typical Meteorological year data. The simulations are carried in the recent version of the HOMER Pro soft. Figure 1 shows the Main tool menu in HOMER Pro available for simulation.

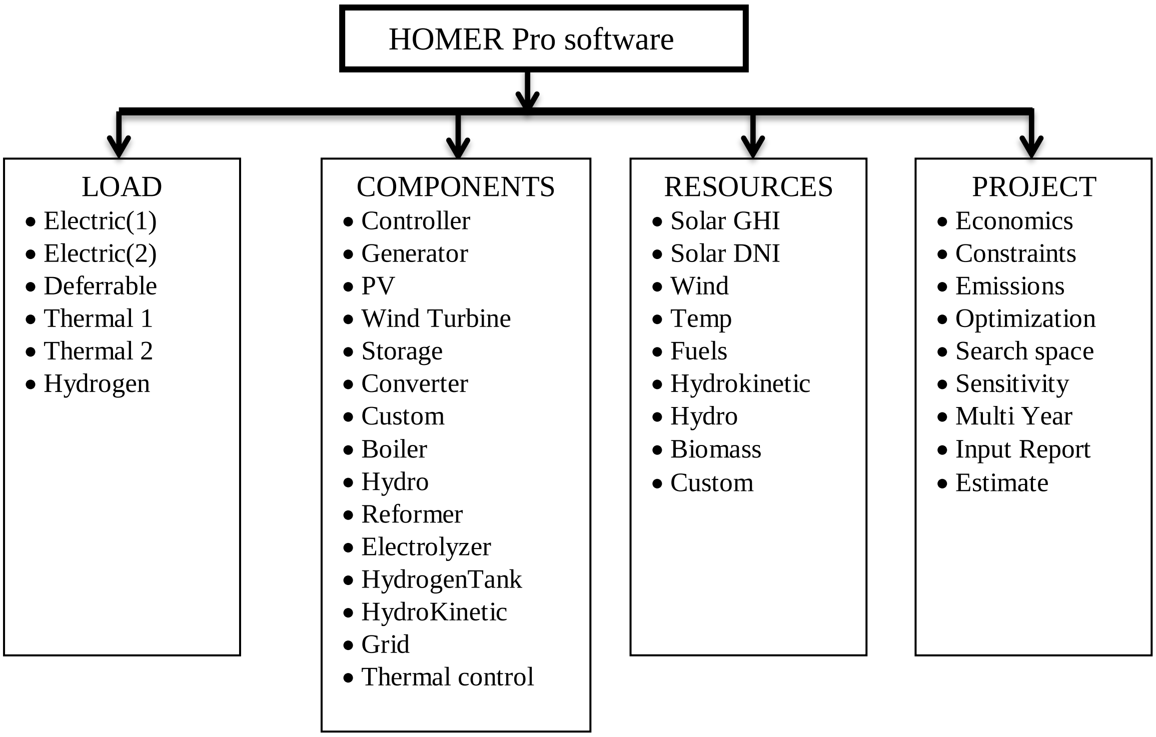



Figure 1.HOMER Pro software main menu tools for simulation.

## 3. Load Assessment of Study Area

The study area is selected from the cluster of Remote villages nearby Sringeri Taluk(Latitude 13.417 N Longitude 75.252 E),chikkamagulur District,Karnataka.The villages were first identified by grouping the villages into urban villages(which are near urban area/city),Rural villages(which are near to Rural taluks) and Remote rural villages(which are remotely residing near to Rural taluks).The electrification to urban and rural villages are already benefitted by the NJY(Nirantara Jyoti scheme) implemented by the Government of Karnataka, for the rural village Electrification. The electrification to remote villages is difficult for the Government to pass the grid lines and these grid lines are posing endanger to the flora and fauna at the remote sites. The cluster of villages are identified at the radial distance of 1-2km, having the study location at Longitude 75.152837 E, Latitude 13.470276 N.

### *3.1 Load Demand at the study area*

The load demand for the study is made by considering the two strategies of Development side Load strategy and Demand side Load strategy. The former strategy is evolved on basis of development required at the remote areas by collecting data from the Local/Grama panchayat-which is a village governance body in Indian villages and the tribal people, about the various developments required like schools, outpatient Hospital, community halls, small industrial loads(flour mills, water pumps),stationary shops(food items/groceries and others) by preparing the questionnaire and communicating with local people and Grama panchayat members who are elected by the village people for governing the village issues. on the contrary the latter uses actual demand required in the present situation, which is estimated by collecting load data from the Residential Houses.Here only Domestic Loads are considered. The Table 2 shows the Load point estimation of Domestic, community loads and commercial Loads.

**Table 1** Demography of the cluster of Remote villages

| Name of the Village | No. of House holds | population |
|---|---|---|
| Tarulli Kodige | 27 | 132 |
| Anukulli bylu | 15 | 45 |
| Bylubaru | 6 | 25 |
| shunti hakkalu | 6 | 18 |
| kote | 25 | 112 |
| Total | **79** | **332** |

Table 1 gives the demography of villages for load assessment. Hourly load demand for the year is obtained by categorizing the year into four quarters (Jan- March, April-June, July-Sept and Oct-Dec). In obtaining the hourly load demand for Development Load strategy, loads are categorized into Domestic loads, community loads and Commercial Load. But for the Demand side Load strategy, only Domestic loads are considered because It is observed the local people living are not availed of community and commercial services in the study area.

**Table 2** Load points estimation for obtaining the Hourly demand at the study site

| **Domestic loads** | |
|---|---|
| **Appliances** | **Quantity** |
| CFL LIGHT(40W) | 4 Points in each House Hold |
| LCD TV(70W) | 1 Point in each House Hold |
| Radio(25W) | 1 Point in each House Hold |
| Fan(75W) | 2 Points in each HH |
| **Community loads** | |
| **Appliances** | **Quantity** |
| CFL LIGHT(40W) | 3 points for Hospital,4 points for School Building |
| Refrigerator (1000W) | 1 Point for Hospital Usage |
| Fan(75W) | 3 points for Hospital, 4 points for School Building. |
| **Commercial Loads** | |
| **Appliances** | **Quantity** |
| CFL LIGHT(40W) | 2 shops having 1 point for 79HH |
| Street light(60W) | 1 pole for every 3 HH |
| Fan(75W) | 2 shops having 1 point for 79HH. |
| Pumping water(3.76 KW) | 3 water pumps for 79HH |
| Flour mill (5KW) | 1 Point having 5KW for 79HH |

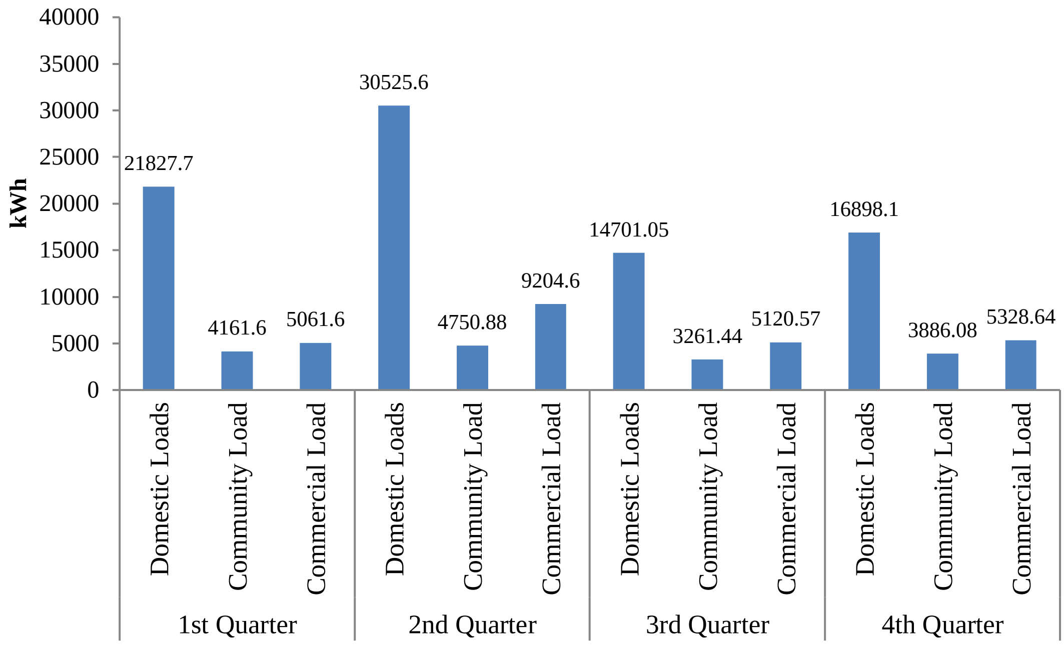



Figure 2. Annual Energy Demand estimation in each quarter for Development side strategy Load.

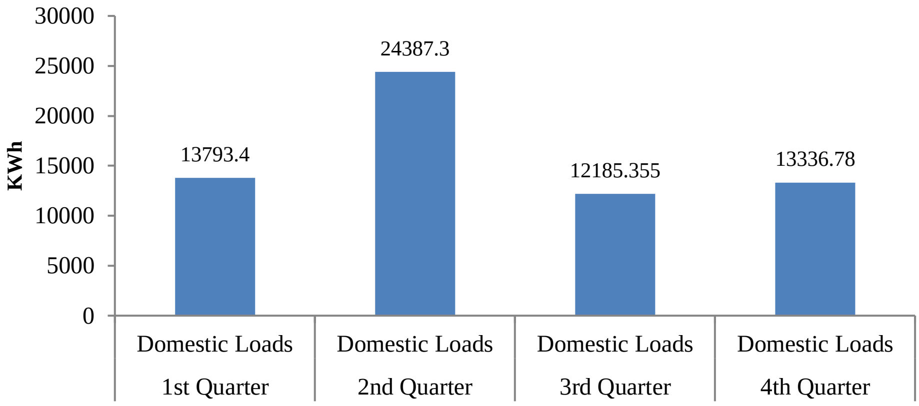



Figure 3. Annual Energy Demand Estimation in each quarter for Demand-side Management strategy.

Table 2 gives the details about the appliances and the number of points estimated in each Household (HH).The Load points are assessed by enquiring with the Local people and Grama panchayat members. Hourly Energy demand (KWh) is then calculated in each quarter of the year. The Energy demand in each hour, in each quarter, is assumed to be constant. Figure 2 and Figure 3show the energy demand in each quarter for Development side strategy and Demand-side management strategy. The load assessment is carried out based upon their life style during the various seasons and usage of their energy. The tribal people have their own kind of habitat of work. Their usage is found to be more during the second quarter(April-June). Total Annual Energy demand required for Development side strategy is 124727.86 KWh/Year with annual average of 341.72 KWh/year and Peak load of 65.08KW/day. For the Actual Total energy Demand for the cluster of villages is found to be 63702.83 KWh/year with annual average of 175.5 KWh/year and the Peak load demand of

45.04 KW/day. While calculating the load on Demand side Low rate Watt with High performance(LRHP) appliances(like LED bulbs) are considered. The Demand-side load is found to be 51% of the Development side load strategy.

## 4. Resource Load Assessment at the study area

Potential Renewable sources available at the study area are identified as Wind, solar, Micro-Hydro and Hydrokinetic resource.

### *4.1 Wind Load assessment*

The wind speed available at the location is retrieved from the typical Meteorological Year chosen for 10 years from 2008 to2018[32]. The wind data is also collected from the local IMD(Indian Meteorological Department) center at Karwar,Karnataka.The wind velocity is observed high during June-september from the data.

Figure 4 shows the Typical meteorological data for wind speed generated and mean wind speed was found to be 4.2m/s.

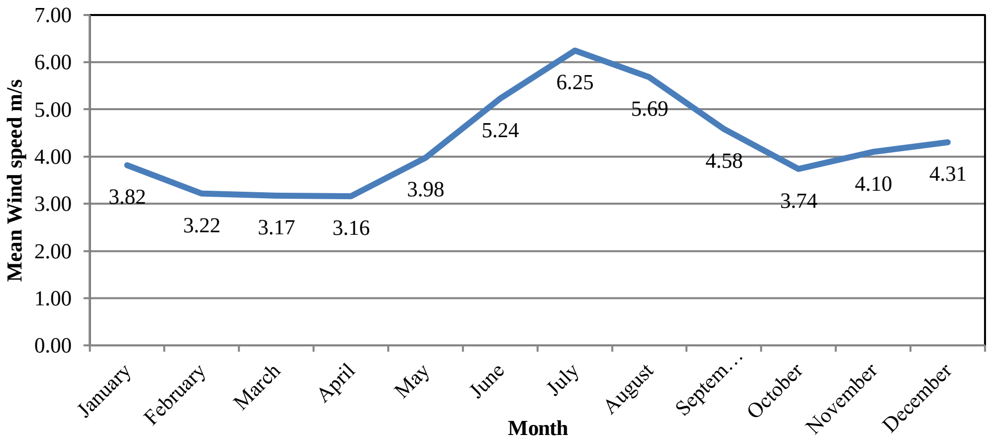



Figure.4.Mean wind speed velocity calculated from the Typical meteorological year Data

### *4.2 Solar energy load Assessment*

Solar radiation data of sringeri taluk are obtained from the Meteonorm 7.3 software application for the period of 10years by giving the geographical coordinates as input. Solar intensity kWh/m$^2$/day for each month available at the site is then calculated as shown on Figure 5. The average solar intensity in kWh/m$^2$/day for the year was found to be 5.44 KWh/ m$^2$/ day/year.The solar insolation is found be high during the summer season from February-June from the Data.

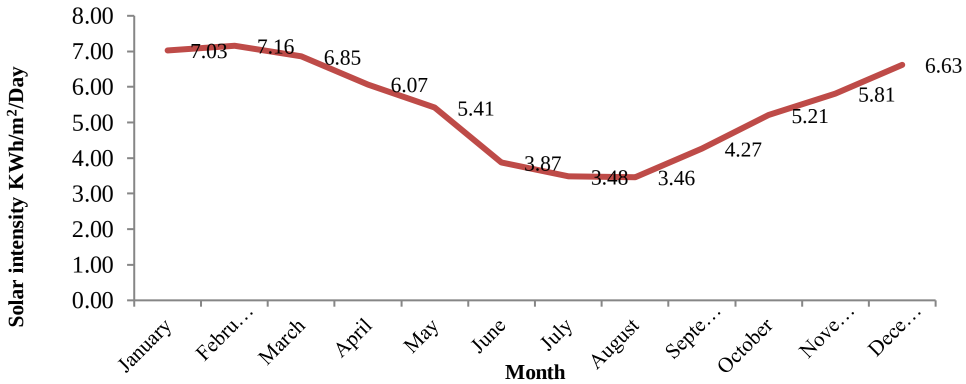



Figure 5. solar intensity KWh/m$^2$/day available at the site for all the months

### 4.3 Micro-Hydro Load Assessment

To assess the Hydro potential at the study site for Micro-Hydro turbine, the discharge to the turbine is calculated by using the Soil conservation services Curve Number Method(CN), developed by the USA in 1969 for estimating the actual run off depth based on the Rainfall data.

Actual run off depth is calculated by the Equation 1 as[33]

$$Q_D = \frac{(I-0.2S)^2}{(I+0.8S)} \text{ when } I > 0.2S \quad (1)$$

$$S = \frac{25400}{CN} - 254 \quad (2)$$

Where $Q_D$ is the direct surface run off depth(mm), I is the monthly rainfall(mm) and S is the Maximum potential retention in watershed(mm) and CN is curve number ranging from 48-58 for dense forest. The peak rate of run off or discharge are calculated by the equations as follows

$$T_P = 0.6T_C + \sqrt{T_C} \quad (3)$$

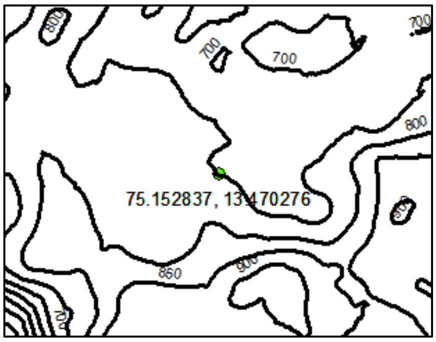
$$T_C = 0.0195\left[\sqrt{\frac{L_W^3}{H_{net}}}\right]^{0.77} \quad (4)$$

$$Q = \frac{0.0208 \times A \times Q_D}{T_P} \quad \text{---} \quad (5)$$

Where Q is the rate of runoff or discharge in $m^3/s$, $T_P$ is the time to peak run off(hour) ,$T_C$ is the time of concentration(hour),$L_w$ is the length of the water shed and A is the area of the Water shed. These are calculated from developing the watershed contours using the Google Earth and ArcGiS 10.8 software. The exact geographical coordinates of the location are obtained for the implementation of Hydro turbine site. Table 1 gives the calculated values of average Discharge values of Q taking the rainfall data of 10 years using the meteorological information from the Meteorological department at IMD, karwar District, Karnataka and from the online resource website[34].It is estimated that Average of 3379.7 litres/s for the year is available as a discharge to the Micro-Hydro turbine output.Figure 6(a) shows Elevation contours developed from the ArcGIS soft at the site and elevation is calculated as 625m and length of the watershed is 1125m.Figure 6(b) and Figure 6(c) are the watershed area contour and Topography of the study location respectively.

**Table 3** Calculation of Discharge from the Curve Number Method

| | Average Rainfall Data (mm) | | | | |
|---|---|---|---|---|---|
| Months | 2009-12 | 2013-16 | 2017-20 | CN | Avg Q ($m^3/s$) |
| January | 6.11 | 2.84 | 6.76 | 52 | 0 |
| February | 3.42 | 9.175 | 4.96 | 52 | 0 |
| March | 10.89 | 15.83 | 16.75 | 52 | 0 |
| April | 65.5 | 41.9 | 62.42 | 52 | 0.130 |
| May | 92.61 | 67.69 | 200.32 | 52 | 3.898 |
| June | 99.94 | 69.54 | 190.63 | 52 | 3.706 |
| July | 123.31 | 85.74 | 214.75 | 52 | 5.265 |
| August | 122.25 | 76.7 | 220.76 | 52 | 5.342 |
| September | 125.37 | 76.6 | 237.24 | 52 | 6.0451 |
| October | 129.41 | 71.47 | 442.15 | 52 | 15.175 |
| November | 103.07 | 32.77 | 87.19 | 52 | 0.93592 |
| December | 19.19 | 8.92 | 62.89 | 52 | 0.0570 |



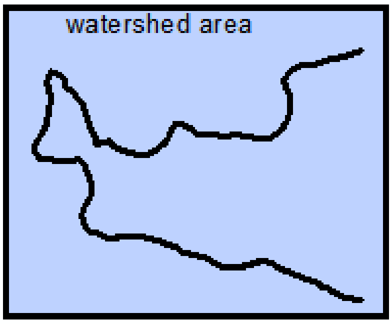




Figure.6(a) Elevation contours at the site (ArcGIS)

Figue6(b) watershed area contour

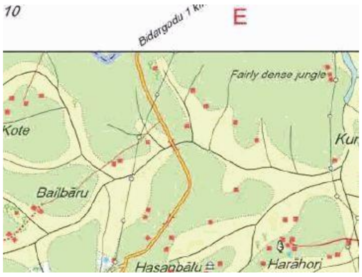



Figure 6(c) Topography of study area

### *4.4 Hydro-kinetic resource Load assessment*

The study site is identified with water stream flow suitable for generating the power using the Hydro-kinetic turbine. This requires the data for the average velocity of water streams. Average velocity of water flowing is obtained for each month using the Electro-Mechanical current meter device. To obtain the monthly data, current meter is used to get the velocity readings for mid-day of the month for 12 hours, keeping the device at 0.5m, 1m and 2m depth from the surface level of water.

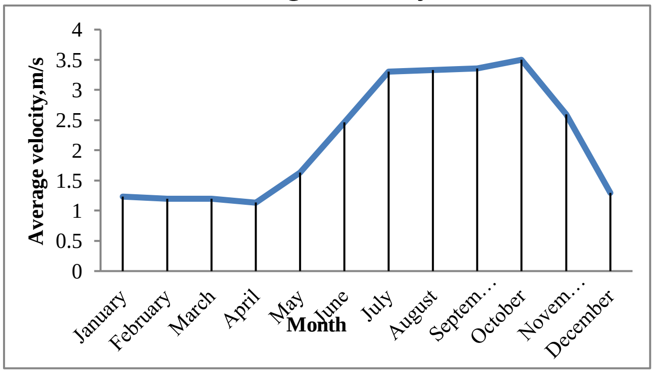



Figure7. Average water stream flow velocity in each month

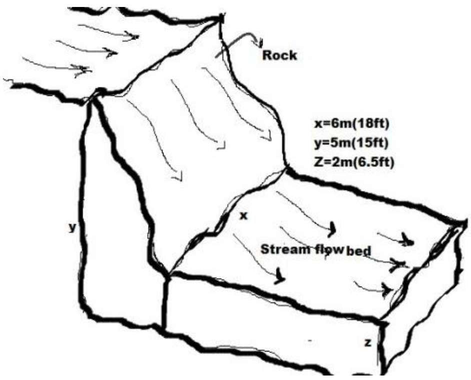



Figure 8. HK resource model

The average velocity of stream flow obtained is shown in Figure 7.This velocity is assumed to be constant throughout each month for obtaining the Hourly analysis. Figure 8 shows the details of the Hydro-kinetic resource model at the location. The average water stream velocity is high during the rainy season from June-october.

## 5. Modeling of the Energy Resources

This study is made identifying the energy resources of Wind energy, solar energy, MicroHydro and Hydro kinetic resources available at the locality.

### *5.1 Modeling of Wind power output*

The power output from the wind turbine is calculated by the Equation 1[35][36] as

$$\left.\begin{array}{ll} P_W=0 & (\text{for } v<v_{CI}) \\ P_W = P_R(v- v_{CI}) /(v_R-v_{CI}) & (\text{for } v_c \leq v \leq v_R) \\ P_W=P_R & (\text{for } v_R \leq v \leq v_{CO}) \\ P_W= 0 & (\text{for } v > v_{CO}) \end{array}\right\} \quad (1)$$

Where $v_{CI}$ is the cut in speed, $v_R$ is the rated speed of the turbine and $v_{CO}$ is the cut out speed ,$P_R$ is maximum rating of power from the turbine. The power curve from the manufacturer details are correlated for calculation of power output in HOMER optimization by taking the effect of air density ratio and multiplied by the Power output from the wind turbine at STP(standard Temperature Pressure) conditions. For the calculation of power from the turbine is taken at hub height of 30 m, which is given by the Equation 2 as

$$V_{hub}=V*(Z_2/Z_1)\hat{}\alpha \quad (2)$$

Where $Z_2$=30m, $Z_1$=10m and $\alpha$=0.43(coefficient value for mountain, terrain) Power calculations are obtained for each hour data for 8760 hours

### *5.2 Modeling of Photovoltaic systems*

Power calculations for the PV output are carried out using the Equation 3 [37]

$$P_{PV}= R_{PV}\, DF(\%) \left[\frac{I_T}{I_{STC}}\right] \quad (3)$$

Where $R_{PV}$ is the rated power output from the turbine, DF is the Derating factor in %,$I_T$ is the instantaneous solar radiation and $I_{STC}$ is the solar radiation at the standard Test conditions.

### *5.3 Modeling of Micro Hydro system*

Power output from the Hydro turbine is obtained from the Equation 4 [38] as

$$P_{MH} = \frac{\eta_{Hydro} * \rho_{water} * H_{net} * Q_{tur}}{1000} \quad \text{KW} \quad (4)$$

Where $\eta_{Hydro}$ is the efficiency of the Micro Hydro turbine,$\rho_{water}$ is the density of water 1000kg/m$^3$,$H_{net}$ is the net head available to the turbine and $Q_{tur}$ is the discharge from the turbine. The discharge to turbine is calculated from the soil conservation curve method as explained in the resource load assessment section.

### *5.4 Modeling of Hydro-Kinetic turbine*

Hydrokinetic turbines are placed under water which may be fixed or floating type against the stream water flow, normally these are placed at a minimum depth of 1m from the surface level of water..The power output from the Hydro-kinetic turbine is calculated by the Equation 5[39] as

$$P_{HK} = 0.5 * \rho_{water} * A_{tur} * V^3 * C_p \quad (5)$$

Where $A_{tur}$ is the surface area of the turbine from the manufacturer is the Average velocity of the stream flow and $C_p$ is the coefficient of performance of the turbine taken value of 0.59(Betz Limit).

Equation 5 is modified by taking the rotor efficiency( $\eta_r$ ),Blade efficiency ($\eta_b$ ) and Generator efficiency($\eta_g$), taking the values of 0.6 for rotor efficiency, blade efficiency and generator efficiency values equal to 0.9, We get

$$P_{HK} = 0.5 * \rho_{water} * A_{tur} * V^3 * C_p * \eta_r * \eta_b * \eta_g \quad (6)$$

Substituting $A_{tur}=\Pi D^2/4$, the equation gives

$$P_{HK} = 0.112 * D^2 * V^3 \quad (7)$$

In HOMER, Power curve from the manufacturer is taken as reference, the values are interpolated to the manufacturer details.

## 6. Optimization Simulation studies

In this study, optimization for the Economic analysis for different combinations of renewable energy sources is carried out using HOMER pro Optimizer tool. HOMER performs the sizing operations for the feasibility analysis. The NPC(Net Present cost) and COE(Cost of Energy) are the two parameters considered for analyzing the feasibility and suitability of the systems. Each simulation is provided with Load data by taking some suitable sensitive parameters as sensitivity analysis.Net present cost is the Present cost involving all the cost components deducting all the revenues it earns all throughout its Project Lifetime.

In economic analysis, NPC is calculated by Equation 7[35] as

$$NPC = \frac{C_{Totalyear}}{CRF}$$

$$C_{Totalyear} = C_{FCyear} + C_{RCyear} + C_{OMyear} \quad (8)$$

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

Cost of Energy(COE) is the annualized Total cost of producing the Energy generation to the Total energy served by the Renewable energy systems given by Equation 9 as

$$COE = \frac{C_{Totalyear}}{E_{served}} \quad (9)$$

HOMER does not Rank the Renewable Integration system based on the COE .In determining the cost components of the Renewable systems, HOMER analyzes the cost considering the Fixed cost, Replacement cost, and Operation and Maintenance cost. Therefore, the capital cost of the system per KW is assessed by taking various costs involved, the distribution of various costs are obtained by manufacturing details and with the Engineers associated with the installation of Renewable energy systems. Figure 9 shows the percentage of distribution of various costs involved for installation of Renewable energy system per KW or MW.

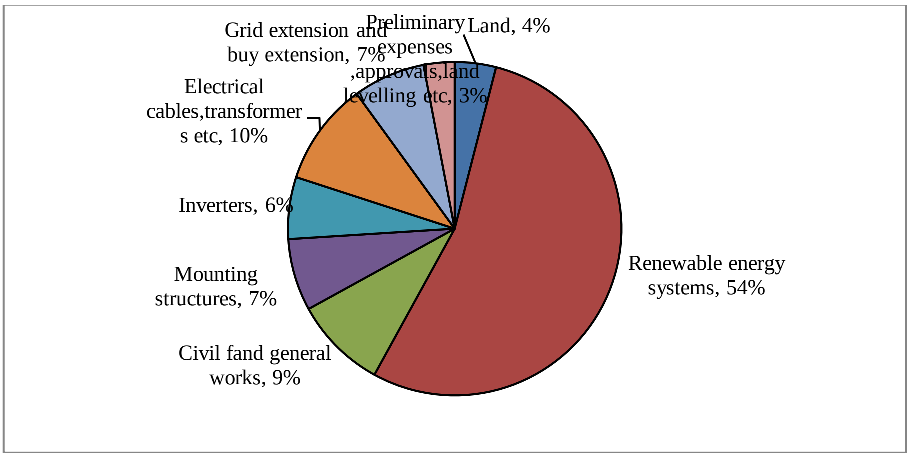



Figure 9. Percentage distribution of various costs installing RE system.

It shows from the Figure 9 that, 54% of the capital cost is involved for Renewable Energy systems and other 46% is accounted for costs of supporting activities required at the installation of the system. The optimal Simulation method followed is shown in the Figure 10.With the available Resources at the Location, integrating the different combinations of systems are performed considering as only the Potential resources available at the study area. Each combination simulation is being performed with different sensitive parameters concerning scaling factor, Renewable energy fraction, and other variables for the systems. HOMER gives the feasibility of the combination with the values of Net present cost and cost of Energy. The load input for the Development side strategy and Demand side strategy for each run of the combining the Integrated renewable system. In all the simulations Battery and Inverter capacity and cost are considered same. Thus, all the individual run combinations give the values for NPC and COE. Then the best possible combination for sustainability is selected on the optimization results.

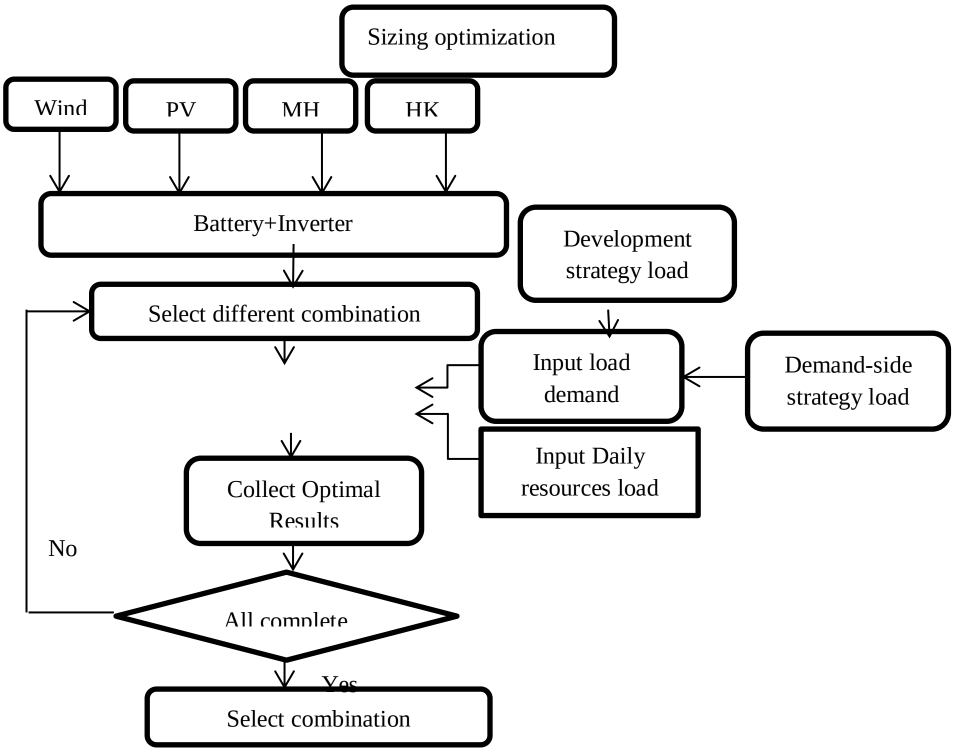



Figure10. Flow chart for the Optimization studies

## 7. Results and Discussion

Simulations for the different possible combinations are performed by considering the size of Battery(1KWh) Lead Acid and converter size varying between 10KW to 50KW.The Load demand for Development side strategy is explained in the load demand assessment section ,which is found to be of Annual Average 341.68KWh/day with a peak Demand of 65.08 KW.The Demand side load strategy is having annual average of 175.5KWh/day with a Peak demand of 45.04 KW. Hourly Assessment of load demand is carried out by taking the four quarters of a year. Hourly demand of load is assumed to be constant for the particular quarter and time. For the two strategies, seven possible combinations are considered as an optimal integration renewable system. This involves integration of PV-BATT/PV-WIND-BATT/WIND-BATT/MH-HK-BATT/WIND-MH-HK-BATT/PV-MH-HK-BATTand PV-WIND-MH-HK-BATT. Table 4 gives details of the costs of systems considered for simulation.

**Table 4** various costs of systems considered for simulation in HOMER

| Systems | Capital cost($) | Replacement cost($) | O&M cost($) |
|---|---|---|---|
| PV-1KW | $2,500.00 | $2,500.00 | $10.00 |
| BATTERY-1KWh(LA) | $300.00 | $300.00 | $10.00 |
| CONVERTER | $300.00 | $300.00 | $0.00 |
| WIND-95KW | $4,75,000.00 | $4,00,000.00 | $4,000.00 |
| MH-49KW | $52,266.00 | $50,000.00 | $1,045.00 |
| HK-40KW | $14,000 | $14,000.00 | $280.00 |

In HOMER simulation, the costs of renewable energy systems are divided under three categories, which consist of capital cost, Replacement cost and Operating and Maintenance cost. The other costs involved with renewable system are not included. Various other costs associated are mentioned in the Figure 9 are taken as reference and made include in the capital cost of the systems. The costs calculated do not involve in other direct and indirect taxes and are according to the price value in Indian country. It is also observed that the costs tend to change with the demand for the respective renewable energy system, like in the cases of PV panels and wind turbines. Micro-Hydro and Hydro Kinetic are site specific and demand for there is less when compared with other systems. The cost of converter and Battery are depends on the type used. Lithium-Ions batteries cost are more compared with lead acid battery and thus it increases the Net present cost and COE.

**Table 5** Simulation results based on Two strategies

| Simulations Results based on Development Strategy- Annual Average -341.68KWh/day--65.08 KW-Peak Demand | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **S.N** | **Renewable systems** | **PV (KW)** | **WIND (Nos)** | **MH (KW)** | **HK (Nos)** | **CONVERTER (KW)** | **BATTERY, 1KWh(Nos)** | **NPC($)** | **COE ($/KWh)** |
| 1 | **PV-BATTERY** | 116 | | | | 48.7 | 729 | $987.814 | $0.685 |
| 2 | **PV-WIND(95KW)-BATTERY** | 115 | 1 | | | 44.0 | 643 | $1.01M | $0.693 |
| 3 | **WIND (95KW)-BATTERY** | | 14 | | | 46.3 | 318 | $2.6M | $1.76 |
| 4 | **MH-HK(40KW)-BATTERY** | | | 57.7 | 2 | 10.7 | 46 | $166,816 | $0.153 |
| 5 | **WIND(95KW)-MH)-HK(40KW)** | | 1 | 57.7 | 2 | 10.9 | 32 | $784,769 | $0.692 |
| 6 | **PV-MH-HK(40 KW)-BATTERY** | 1.8 | | 49.4 | 2 | 26.6 | 129 | $217,191.5 | $0.166 |
| 7 | **PV-WIND(95KW)-MH-HK(40 KW)-BATTERY** | 1.78 | 1 | 49.4 | 2 | 33.2 | 151 | $817,281 | $0.589 |
| **Simulation Results Based on Demand Side Strategy- Annual average -175.5 KWh/Day ;45.04 KW --Peak demand** | | | | | | | | | |
| **S.N** | **Renewable systems** | **PV (KW)** | **WIND (Nos)** | **MH (KW)** | **HK (Nos)** | **CONVERTER (KW)** | **BATTERY, 1KWh(Nos)** | **NPC($)** | **COE ($/KWh)** |
| 1 | **PV-BATTERY** | 76 | | | | 43.3 | 476 | $626,489 | $0.8203 |
| 2 | **PV-WIND(95KW)-BATTERY** | 11.7 | 1 | | | 35.3 | 245 | $818,623 | $1.07 |
| 3 | **WIND (95KW)-BATTERY** | | 2 | | | 25.2 | 168 | $1,309,300 | $1.9 |
| 4 | **MH-HK(40KW)-BATTERY** | | | 57.7 | 2 | 1.72 | 8 | $120,841 | $0.154 |
| 5 | **WIND(95KW)-MH-HK(40KW)** | | 1 | 57.7 | 2 | 0.807 | 2 | $697,170 | $0.875 |
| 6 | **PV-MH-HK(40 KW)-BATTERY** | 1 | | 57.7 | 2 | 1.74 | 5 | $120,825 | $0.158 |
| 7 | **PV-WIND(95KW)-MH-HK(40 KW)-BATTERY** | 0.4 | 1 | 57.7 | 2 | 0.173 | 1 | $697,049 | $0.876 |

**Table 6** Energy consumptions(Kwh)/year of PV-MH-HK in Demand side strategy Load

| Component | Production (KWh/yr) | Percent |
|---|---|---|
| Generic flat plate PV | 8114.3 | 1.2 |
| GenericHydro Kinetic(40KW) | 407068.2 | 60.2 |
| Hydro | 261010.5 | 38.6 |
| Total | 676,193 | 100 |

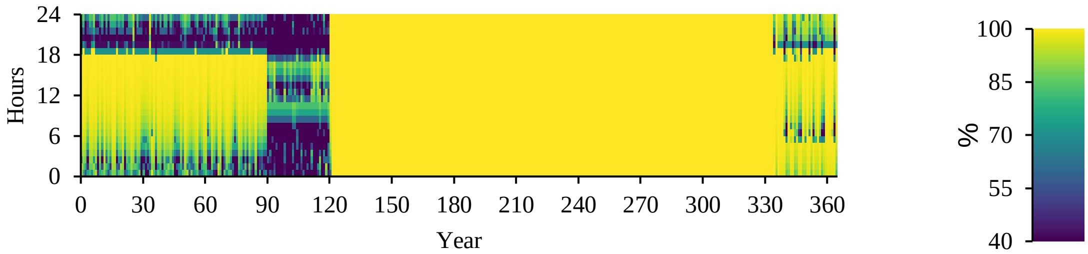



Figure 11.State of charge% Generic Lead acid Battery(1KWh) for PV-MH-HK Demand side load

Table 6 shows the energy consumptions of PV,MH,HK systems when simulated for Demand side Load strategy similarly the same trend has been observed in the case of Development side strategy. The contributions of MH and HK is more with respect to PV system. This shows that the location has a more potential in Hydro energy resource that can be utilized to full extent. Figure 11 shows the simulation result to the number of hours of Battery operation during the year. It shows that batteries are operated for maximum hours during the Second quarter of the year.

Table 5 shows the simulation details of possible integrated systems for the study area considering the two load strategies. In the case of Development side Load strategy, MH-HK –Battery integrated system can give Least cost NPC of $166,816 and COE of $/KWh 0.153 with 46 Battery Numbers. The next best possible integrated system is PV-MH-HK-Battery with NPC of $217,191.5 and COE of $0.166.The cost of NPC and COE is found to be high if it is proposed for only Wind –Battery system. In case of Demand side strategy, the value of Least NPC is $120,841 and the COE is $0.154, it is found to be almost same for MH-HK-Battery and PV-MH-HK-Battery integrated system. The number of Batteries required is 8 and 5 for these integrated systems. The NPC is increased by 27.5% and 44.3% for MH-HK and PV-MH-HK-Battery systems respectively when compared to the Development side strategy load Management. But, the COE remains almost the same for these two cases of the integrated system. The size of the converter in KW required is observed to be less with these two combinations. The inclusion of the wind turbine in any of the combinations gives more value of NPC and COE. This shows that the wind is not able to deliver the expected energy demand at the site. For the wind data available, it is found to be not suitable for a sustainable resource. Micro-Hydro and Hydrokinetic alone can contribute to the delivery of the energy demand. The carbon emissions are zero for the Global emissions demand. It is also observed from the results that the contribution of MH and HK together is more than 80% in generating the Energy in KWh/year. This shows that the Hydro potential is more sustainable in these areas. This study area is near to Augumbe forest reserve where more rainfall occurs through the year as the data is collected from the nearest rain gauge station. Thus it is suggested that keeping the above results into consideration, the PV-MH-HK with battery is more suitable for the location.

**Table 7** Present study comparison with other relevant studies on Remote areas in India

| Configuration | NPC($) | COE($/KWh) | Peak Load(KW) | Reference | Remarks |
|---|---|---|---|---|---|
| PV-MHP-Battery | 4,67,644 | 0.106 | 108.6 | [35] | HOMER tool used to study the Effect of different batteries is analyzed with and without Dieselgenerator.Hydrokinetic resource is not considered. |
| MH-BM-BG-WT-BT | 6,05,376 | 0.087 | 170 | [40] | Cluster of villages in remote area are analyzed.Hydrokinetic resource is not considered |
| PV-WT-BM-BG | 141142 | 0.069 | - | [27] | HOMER tool used HK resource is not considered |
| PV-BM-Battery | ---- | 0.21779 | 64 | [28] | MATLAB metaheuristic algorithms study .HK resource is not considered. |

## 8.Multiyear simulation results

Multi-year simulation module in the HOMER software provides futuristic values of various parameters integrated into the system. This module takes the values of PV degradation of production, annual increase in the fixed mainatainence cost and annual increase of electrical load requirement. The simulation results on various parameters like PV production kWh/year, AC primary load, Battery losses (kWh/year), converter losses (kWh/year), unmet electrical load (%) and capacity shortage (%) are noted 10 year simulation output. Table 8 shows the Multi-year simulation for the optimal result obtained.

**Table 8** Multi-year simulation of optimal result for Development side strategy

| PV-MH-HK-BATT SYSTEM PV-10KW BATT-300,CONV-40.0KW,WIND-1(275 KWh/day) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **PV production KWh/year** | **LCOE(PV) $/KWh** | **AC Primary Load KWh/year** | **Battery Losses KWh/year** | **Rectifier / Converter Losses KWh/year** | **Unmet Electrical Load in %** | **Capacity shortage in %** |
| 1 | 794 | 0.146 | 92,426 | 1883 | 476/374 | 7.93 | 10.5 |
| 2 | 791 | 0.144 | 93,865 | 1912 | 484/385 | 8.35 | 10.8 |
| 3 | 784 | 0.145 | 95,312 | 1934 | 491/391 | 8.74 | 11.4 |
| 4 | 781 | 0.146 | 96,775 | 1955 | 497/392 | 9.14 | 11.6 |
| 5 | 772 | 0.152 | 98,2561 | 1978 | 502/395 | 9.54 | 12.7 |
| 6 | 773 | 0.152 | 99,717 | 1994 | 506/404 | 10.1 | 12.5 |
| 7 | 772 | 0.152 | 101,195 | 2004 | 509/401 | 10.2 | 13.5 |
| 8 | 765 | 0.152 | 102,684 | 2012 | 511/402 | 10.2 | 13.6 |
| 9 | 766 | 0.152 | 104,175 | 2015 | 513/405 | 11.3 | 14.5 |
| 10 | 754 | 0.154 | 105,712 | 2025 | 515/405 | 11.7 | 14.6 |

**Table 9** Multi-year simulation of optimal result for Demand side Load strategy

| PV-MH-HK-BATT SYSTEM -PV-0.5 KW, BATT-5, CONV-1 KW | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **PV production KWh/year** | **LCOE(PV) $/KWh** | **AC Primary Load KWh/year** | **Battery Losses KWh/year** | **Rectifier / Converter Losses KWh/year** | **Unmet Electrical Load in %** | **Capacity shortage in %** |
| 1 | 795 | 0.146 | 58,717 | 31.3 | 6.06/7.81 | 8.06 | 10.8 |
| 2 | 795 | 0.146 | 59,657 | 32.2 | 6.06/7.81 | 8.44 | 11.2 |
| 3 | 782 | 0.147 | 60,605 | 32.2 | 6.14/8.02 | 8.81 | 11.4 |
| 4 | 784 | 0.148 | 61,560 | 32.6 | 6.12/8.06 | 9.14 | 12.3 |
| 5 | 776 | 0.151 | 62,527 | 33.1 | 6.10/8.13 | 9.55 | 12.7 |
| 6 | 7754 | 0.152 | 63,506 | 33.2 | 6.07/8.15 | 9.96 | 13.2 |
| 7 | 777 | 0.153 | 64,497 | 33.6 | 6.09/8.26 | 10.34 | 13.4 |
| 8 | 761 | 0.153 | 65,499 | 33.7 | 6.11/8.41 | 10.71 | 13.8 |
| 9 | 760 | 0.155 | 66,510 | 33.8 | 6.01/8.42 | 11.21 | 14.5 |
| 10 | 758 | 0.155 | 67,533 | 34.1 | 5.94/8.45 | 11.41 | 14.5 |

From **Error! Reference source not found.**8 , % change of PV production (decrease) – 4.3%, COE (%)-4.74%,AC primary Load-14.35%, Battery Losses-7.498%, converter/Rectifier Losses-8.17%/7.37%, unmet electrical load-3.88%,capacity shortage-4.5%.From Table 9,% change of PV production (decrease) – 4.4%, COE (%)-5.44%,AC primary Load-15.01%, Battery Losses-8.28%, converter/Rectifier Losses-0.825%/8.38%, unmet electrical load-3.43%,capacity shortage-4.0 %.The Multi-year simulations gives the degradation of PV systems is around 4.4% to 8% in all the cases studied,AC primary load is increased from 12.33% to 18% for the cases,the battery losses is around 3.9% to 19% and the unmet load is increased in the range of 1.3% to 6% in all the cases studied.

## Conclusions

This paper presents the simulation studies for a different combination of the integrated renewable energy system for obtaining the least NPC and COE. The potential resources available in the study area are first identified as PV-WIND-MH-HK. The seven different combinations are simulated for obtaining the optimal value of NPC and COE considering the Developing side Load strategy and Demand-side Load strategy which gives 14 combinations of simulation studies. It is found that Demand side Load strategy is 51% of Development side Load strategy for the annual Energy Demand Estimation. In all the simulations, Battery system should be included as a it provides a continuous un interrupted power supply. In the Development side Load strategy, the best optimal solution is found to be of MH-HK(40KW) with a NPC of of $166,816 and COE is $0.153.The second optimal solution is with the combination of PV-MH-HK with NPC of $217,191.5 and COE is $0.166.From the feasible and sustainable point of view , the PV-MH-HK is found to be better for the location considering

rainfall situations. For the Demand side load strategy, it is found that same two combinations hold good as the best possible solution. Here, NPC and COE values obtained are almost same having values $120,481(MH-HK)-$120,824(PV-MH-HK) and $ 0.154(MH-HK)-$0.158(PV-MH-HK). The optimal values were obtained by considering sensitivity parameters in HOMER pro soft. Integration with WIND turbine system gives more value of NPC and COE. It can be identified the generation from the WIND turbine is not a feasible solution at the location.
Further, the Multiyear simulation results carried out for the best optimal solution for 10 years gives the parameters effect is well within the lower range.From all the observations, it is clear that the site is having a good potential for Hydro resources and is more feasible and sustainable with zero emissions.

**Acknowledgments**
The author wishes to thank the Local people and the Grama Panchayat for providing useful information about the local resources.

**Author contributions**
Naveen R: Conceptualization, organizing,Methodology, Software, Naveen R.: Data curation, Investigation, Writing- Original draft preparation. Prashanth P Revankar: Visualization, Supervision: Prashanth P Revankar: Software, Validation,Writing- Reviewing and Editing.

**Competing Interests**
There are no competing interests reported by the Authors

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