Electricity Distribution Planning for an Eco-Village with Distributed Renewable Generation

[a]Gurusthal Reven Sidda, [b]Biswarup Mukherjee,[c]Muhammad Salman Shahid
[a] Master Student, Institut National Polytechnique de Grenoble ENSE[3], Grenoble, France, 38000
[b] Master Student, Institut National Polytechnique de Grenoble ENSE[3], Grenoble, France, 38000
[c] Master Student, Institut National Polytechnique de Grenoble ENSE[3], Grenoble, France, 38000

Abstract

Eco-village is a term widely used for such rural areas that utilises indigenous renewable resources for attaining energy self-sufficiency with extremely low GHG emission impact through a closed-loop regenerative system. It is significant for enabling island mode owing to disturbance in national grid, export of excess energy within national grid and ensuring circular economy. In this paper we have considered a small village Luxettipet of Adilabad district in Telangana, India, with the main focus on the economic aspects of possible energy mix. The estimation of generated electricity is done for renewable resources like solar, biogas, wind and hydro energy, while load of the village is taken into account on the basis of previous annual energy consumption data. The population growth rate is extrapolated by 10%in the next 25 years and the energy consumption has been considered accordingly. Techno-economic analysis of different possible energy solutions has been performed and is compared with the conventional energy system using HOMER ENERGY software. By performing techno-economic analysis, we observed that the investment and operational costs for different energy resources play a crucial role for electricity pricing. This paper will also lead to future grid planning of Luxettipet and other similar villages to overcome rural electricity crisis.

KEYWORDS—Homer, Grid, Solar energy, Bio energy, Hydro energy, Cost

I. Introduction

The development of an agro-industrial country highly depends upon optimal and reliable energy distribution to both rural and urban areas. This development can be significantly achieved by implementing indigenous distributed generation in both urban and rural sector. India has a great potential for exploiting renewable distributed generation at rural level with abundance of un-exploitedbio-mass, solar and wind resources.

In this paper, we have taken a case study of Luxettipet, India to make it eco-friendly and sustainable while ensuring the energy security and energy balance of the village. The village has a population of 11,322 persons with 2768 households [1]. The village has abundant solar and wind energy whereas the village is on the bank of Godavari River which is suitable for hydro-power to meet local as well as neighbourhood demand.

Homer**:**HOMER (Hybrid Optimization of Multiple Electric Renewable), the micro power optimization model, simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. While designing the power system, multiple decisions are taken regarding system configuration e.g. selection, type and size of components. The availability of energy resources and choice of technology with diverse market costs make these decisions more complex. HOMER ENERGY algorithm for optimization and sensitivity analysis makes it easier to evaluate various energy generation system configurations.

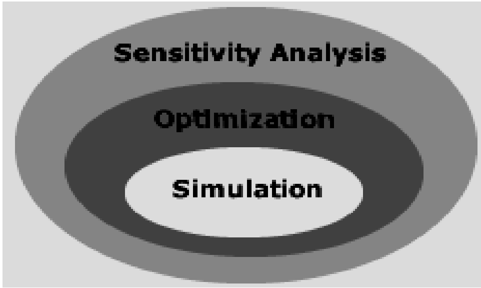

Figure 1:HomerStep Analysis

The understanding of HOMER three core capabilitiesi.e.*simulation*, *optimization*, and *sensitivity analysis* and their interaction with each other is required for optimal results.

Simulation: At its core, HOMER is a simulation model. It simulates a viable system for all possible combinations of resources and loads that are required to consider. Depending on the problem, HOMER may simulate hundreds or even thousands of power resources combinations.

Optimization: The optimization step follows all simulations. The simulated systems are sorted and filtered according to user defined criteria for cost-effective solutions. HOMER also offers the choice of minimum fossil fuel usage despite its being an economic optimization model.

Sensitivity Analysis: This is an optional step that allows you to model the impact of variables that are beyond your control, such as wind speed, fuel costs, etc. and see how the optimal system changes with these variations.

II. Solar Energy

Earth receives more solar energy in an hour than the world's population uses in a whole year. The total solar energy flux intercepted by the earth on any particular day is 4.2×10^{15} kWh (equivalent to burning 15 Btoe/hr). In 2014, the total annual global energy consumption was 1.1×10^{5}TWh (equivalent to 9.42 Btoe) while in India, the annual energy consumption was 6.46×10^{3}TWh (equivalent to 0.55 Btoe)[2].

Solar panels, also known as modules, contain photovoltaic cells made of silicon that convert sunlight into electrical energy. Solar photovoltaic cells consist of a positive and a negative film of silicon placed under a thin slice of glass. As the photons of the sunlight beat down upon these cells, they knock the electrons off the silicon. These negatively charged free electrons are preferentially attracted to one side of the silicon cell, which creates an electric voltage. This current is gathered by connecting solar panels in series to form a solar photovoltaic array. Depending upon the size of installation, multiple strings of solar photovoltaic array cables terminate in one electrical box, called a fused array combiner. Contained within the combiner box are fuses designed to protect the individual module cables, as well as the connections that deliver power to the inverter. The electricity produced at this stage is DC (direct current) and must be converted to AC (alternating current) for suitable utilization in residential, commercial, industrial and tertiary sector.

Month	Clearness index	Daily radiation (kWh/m^2/day)
January	0.636	4.870
February	0.657	5.670
March	0.653	6.370
April	0.630	6.650
May	0.587	6.380
June	0.440	4.800
July	0.378	4.100
August	0.375	3.970
September	0.463	4.600
October	0.559	4.960
November	0.627	4.900
December	0.644	4.720
Average	0.636	5.17

Table 1: Monthly Averaged solar radiation Incident on a Horizontal Surface (kWh/m^2/day)

Table 1demonstrates monthly solar radiation on a Horizontal Surface (kWh/m^2/day) by taking an average of solar radiation data of 22 years provided by NASA[3] for Luxettipet village. This data serves as a resource for the solar energy used in the HOMER simulation.

III. Hydro Energy

Hydro-electricity is fulfilling 17.5% of global electricity demand, majorly99% in Norway, 57% in Canada, 55% in Switzerland, 40% in Sweden, 7% in USA [4].It is not a major option for the future in the developed countries because most major sites in these countries having potential for harnessing gravity in this way are either being exploited already or are unavailable for other reasons such as environmental considerations.

Godavari River flows nearby Luxettipet village and offers a good source of hydro-electricity production. The average annual flow rate of Godavari River is 110 billion m^3 (approximately 3.48 mega-litre/year)[5]. Rainy season brings huge water flow so the potential of energy production is at its peak during rainy season. Hydro energy is available in many forms; potential energy from high heads of water retained in dams, kinetic energy from current flow in rivers and tidal barrages, and kinetic energy also from the movement of waves on relatively static water masses. Many ingenious ways have been developed for harnessing this energy but most involve directing the water flow through a turbine to generate electricity.

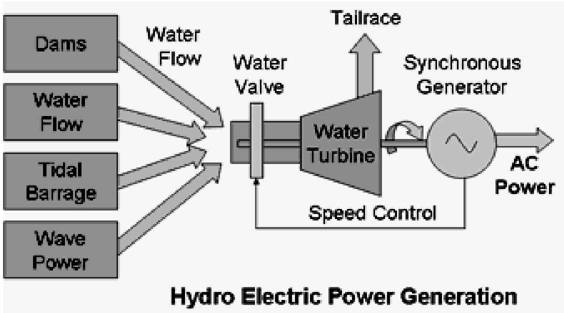

Figure 2: Block diagram ofHydro-Electric Production

Equation 1 and 2 will give the total mechanical and electrical output from the hydro energy .The general cost of the hydro energy for 50MW or more than that will be around ?89975.1.

$$\text{Torque } T = \rho.Q.\left(r_{in}.V_{in} - r_{out}.v_{out}\right)\text{---}1$$

$$\text{Power } P = \omega.T$$

$$\omega.T = \omega.\rho.Q.(r_{in}.q_{in}.\cos\beta_{in} - r_{out}.q_{out}.\cos\beta_{out})\text{---}2$$

Following is the assumption of average monthly flow rate based on average annual flow rate.

Month	Litres / month
January	1000
February	1000
March	1000
April	1000
May	1000
June	145336
July	145336
August	145336
September	145336
October	10000
November	10000
December	1000
Average	50612

Table 2: Monthly Averaged flow rate litres/month

IV. Bio Generation

Biogas produced during anaerobic process is called bio-digestion. Anaerobic digestion is a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen. The process is used for industrial or domestic purposes to produce fuels.

This technique is performed in the bio-digesters where the organic material is mixed with water where the reaction to produce bio-gas executes between 20°C and 30°C.Biogas consists of varying proportion of burning fuel CH_4 (40-70%),CO_2 (30-60%) and remaining is residue(H_2 and H_2S).Other bi-products include acetic acid and ammonia. Large quantity of manure is produced in cattle farms which serve as excellent organic material containing a large amount of energy. However, bio-digestion is not limited to cattle manure. Fruit& vegetable skin and saw mill waste can also be used. This biogas can be used directly as fuel, in CHP gas engines or upgraded to natural gas-quality bio-methane. The nutrient-rich digest also produced can be used as fertilizer. The implementation of bio-electricity generation can be incentivized by the central governments to acquire clean energy through circular economy of energy.

Electricity Production: Bio-Energy can be converted into electric energy and excess can be sold to the power company.

Direct use of gas - Biogas can also be used for vehicles and farming machines compatible to run at natural gas.

Mixed solution - It is also possible to opt for a mixed solution i.e. to produce electricity and utilize the rest of the gas directly.

The amount of energy produced from the manure of different farming animals is different. A cow produces about 26.24 kg of wet manure/day, from which 1.04 m^3 of biogas can be extracted. Pig produces 4.21kg of wet manure per day, which results in production of 0.33 m^3 of biogas. A farmed chicken produces only 0.08 kg/day which yields 0.0032 m^3 of biogas. Although the amount of biogas produced per chicken seems little, the number of animals of a poultry breeding farm is much higher than that of other farm, which offsets the difference. For a methane concentration of 60%, the energy generated from biogas is 6kWh_e/m^3[6].

V. Island Mode

Simulation:In this scenario, no grid is connected with the village electrical distribution system as shown in Figure 3.

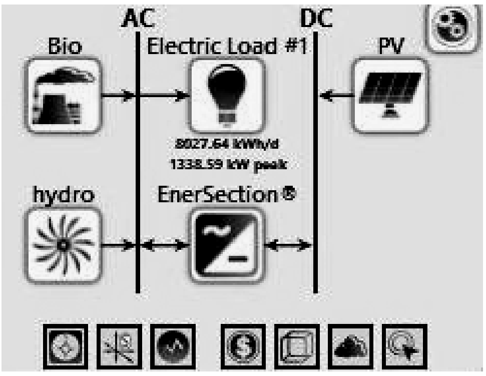

Figure 3: Architecture for HOMER Simulation without Grid Connection

In this paper we are considering bio-energy generation from animal waste as the raw material is readily available with minimal logistics cost.In addition to that, the village has abundant solar energy with an annual global irradiation of 2000 kWh/m^2[7]. The graph of daily load profile depicts a random utilization of energy in the village with no clear load pattern as it can be observed in urban load centres. For an approximate 2768households in Luxettipet[1], we take an assumption that there are 700 cows in the village. The total electricity production is around 182kW/h, the cost of 1kW electrical power will be around ₹581198.55.

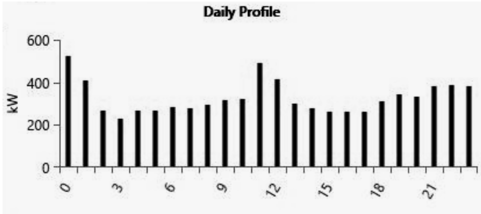

Figure 4: Plot of Daily Load Profile

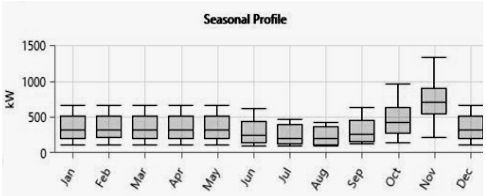

Figure 5: Plot of Seasonal Load Profile

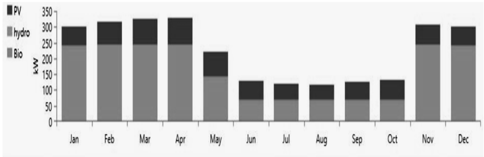

Figure 6: Plot of Monthly Average Electricity Production by Different Sources

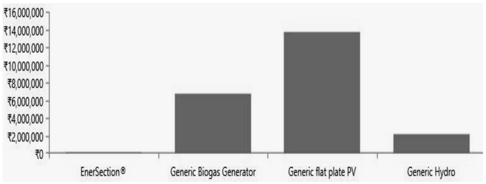

Figure 7: Component wise Net Cost Summary for Different Sources

Architecture							Cost			
				PV (kW)	Bio (kW)	hydro (kW)	COE (₹)	NPC (₹)	Operating cost (₹)	Initial capital (₹)
				382	400	504	₹1.02	₹22.8M	₹461,239	₹16.9M
				382	400	504	₹1.02	₹22.8M	₹461,239	₹16.9M
				383	400	504	₹1.02	₹22.8M	₹461,220	₹16.9M
				383	400	504	₹1.02	₹22.8M	₹461,220	₹16.9M
				383	400	504	₹1.02	₹22.8M	₹461,260	₹16.9M
				383	400	504	₹1.02	₹22.8M	₹461,260	₹16.9M
				384	400	504	₹1.02	₹22.9M	₹461,291	₹16.9M
				384	400	504	₹1.02	₹22.9M	₹461,291	₹16.9M
				385	400	504	₹1.02	₹22.9M	₹461,243	₹17.0M
				385	400	504	₹1.02	₹22.9M	₹461,243	₹17.0M
				385	400	504	₹1.02	₹22.9M	₹461,373	₹17.0M

Figure 8: Table Showing Optimal Combinations of Different Sources by HOMER and Cost of Electricity in INR

Analysis of Simulation Results:The most optimized results are considered for analysis and are tabulated in Table 3.

PV (KW)	Bio (KW)	Hydro (KW)	COE (INR)	Operating Cost (INR)	Initial Cost (INR)
382	400	504	1.02	461239	16.9M
382	400	504	1.02	461239	16.9M
383	400	504	1.02	461220	16.9M
383	400	504	1.02	461220	16.9M
383	400	504	1.02	461260	16.9M

383	400	504	1.02	461260	16.9M
384	400	504	1.02	461291	16.9M
384	400	504	1.02	461291	16.9M
385	400	504	1.02	461243	17.0M
385	400	504	1.02	461243	17.0M
385	400	504	1.02	461373	17.0M

Table 3: Obtained Optimal Solutions by HOMER

The simulation result shows that less amount of energy is consumed during summer. The generation is mainly from biogas and PV sources along with fixed production of Hydro power. With an increase in PV power production, both initial cost and operating cost increases as also the cost summary predicts that the capital cost of PV installation is very high compared to hydro and biogas generator. It is suggested to use bio-energy resource and hydro resource at its maximum as it has very low running cost.

VI. GridConnected Mode

Simulation: In this scenario, both grid and distributed generation at local level are connected with the village electrical distribution system as shown in Figure 3

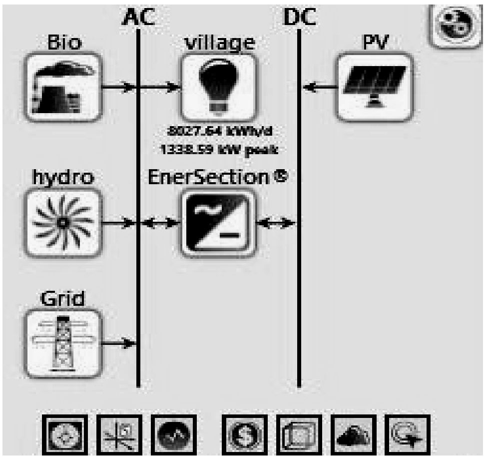

Figure 9: HOMER Architecture with Grid Connected

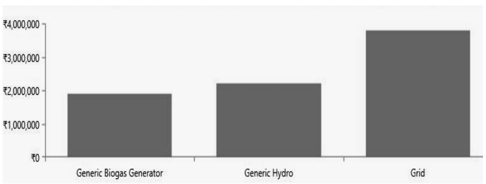

Figure 10: Component Wise Net Cost Summery For Different Sources When Grid Is Connected

					Architecture			
					PV (kW)	Bio (kW)	Grid (kW)	hydro (kW)
						400	999,999	504
						400	999,999	504
						400	999,999	504
						400	999,999	504
					1.30	400	999,999	504
					1.30	400	999,999	504
					2.60	400	999,999	504
					2.60	400	999,999	504
					5.21	400	999,999	504
					5.21	400	999,999	504
					10.4	400	999,999	504

Figure 11: Table Showing Optimal Combinations of Different Sources by HOMER When Grid Is Connected To Our System

Analysis of Simulation Results:The most optimized results are considered for analysis and are tabulated in Table 4.

PV (KW)	Bio (KW)	Hydro (KW)	Grid (KW)	COE (INR)	Operating Cost(INR)
0	400	504	999999	0.208	380518
0	400	504	999999	0.208	380518
0	400	504	999999	0.208	380518
0	400	504	999999	0.208	380336
1.30	400	504	999999	0.209	380336
1.30	400	504	999999	0.209	380154
2.60	400	504	999999	0.211	380154
2.60	400	504	999999	0.211	380154
5.21	400	504	999999	0.213	379789
5.21	400	504	999999	0.213	379789
10.4	400	504	999999	0.218	379060

Table 4: Obtained Optimal Solutions by Homer

VII. Conclusion

From the simulation result it is evident that the cost of electricity is reduced when the system is connected to the Power Grid. Since the capital cost for PV and Bio energy is very high, HOMER simulation shows some optimal configurations where large amount of electrical power is consumed from the grid where we need only maintenance cost. The simulation result also reflects that optimal solution is highly dependent on the capital cost or the investment cost. Again with the larger PV consumption the price of the electricity increases along with the operating cost.

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