Development of a Polygeneration System for a Rural Community

M R Kamesh1*, Girishkumar G S2, Aneessa Kajampady3

1Associate Professor, Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru.
2Assistant Professor, Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru.
3Student 8th Semester, Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru.

*E-mail: kamesh mr@yahoo.com

Abstract: Energy plays a very important role in the economic development of a country. Almost 85% of the primary energy comes from fossil fuels. Meanwhile, it is necessary to reduce carbon footprints to protect environment from the way of production and consumption of energy. To overcome this, adoption of a poly-generation system is the most effective way. It can be said as one of the most effective method to enhance energy efficiency, reduce energy consumption and control environmental pollution. It is the combination of several renewable energy using systems in a way that the output of one system becomes the input for another. Also, a number of utility outputs are obtained. This way, the amount of useful energy in the given amount of input is harnessed to a maximum extent, thus maintaining a very high energy efficiency. In this present work, our objective is to propose a techno-economical and techno-feasible polygeneration system for the selected three villages by using Homer Pro software. For this number of renewable energy systems like solar PV, biomass, hydrokinetic systems, wind turbine, hydrogen etc. are combined in an optimal way suitable for 3 different villages in south India. This is done by taking into account the availability of resources in the corresponding geographic area and also the utility products/outputs and deliverables on demand with the aid of an energy software called Homer Pro.

Keywords: Renewable energy; Poly-generation system, Deliverables; Economic feasibility.

1. Introduction
Replenishment of the available resources is a far reaching goal in today’s world. Availability of resources in the form of fossil fuels is very carbon intensive and does not meet the climate change goals. Regardless of the energy source human’s demand of electricity needs are increasing even beyond the capabilities of conventional sources. While many developing countries have started venturing into non-conventional sources of energy, alternate resources of energy are being accepted widely and swiftly everywhere. This has shown a sustainable form of energy consumption for the coming days to reduce carbon footprints. These non-conventional energy sources include solar, biomass, wind and hydropower. These are widespread around us. Optimum utilization of these resources in electricity generation and meeting other requirements has shown a steady pace. But
renewable energy sources face difficulties like being unsteady and interrupted availability being subjected to climatic and geographical conditions. These irregularities and shortcomings can be compensated by developing a poly-generation system which can sustain the entire availability of electricity. This can be done by including the various resources available in rural areas, thus reducing the dependency on the conventional grid by maximizing the usage of resources like solar (PV), wind and biomass. This localized grid will stand as a replacement for a particular resource (during its deficiency) ensuring steady electricity supply to the community. [1]Kuntal Jana et al., proposed poly generation for a grid independent Indian village. The proposed model was optimized financially and on reliability basis. Green energy powered, grain alcohol generating unit and vapour absorption freezing units were the different modules considered. MoS2 was used in ethanol production unit as a catalyst. [2]Avishek Ray, Kuntal Jana et al., proposed a system in which the results showed, that numerous energy utility supply is possible through dispersed polygeneration system and gain in carbon credits significantly as compared to conventional genset. [3] Kuntal Jana et al., proposed a polygeneration system using agricultural waste in which agro based wastes crop residues were taken as input. Gasification, power generation, process steam generation, vapour absorption refrigeration, ethanol production, etc., were the different units used. Utility outputs reported were CCHP and grain alcohol. The proposed model was analysed for economic feasibility and hence it is deduced that this model can be technologically and economically feasible for rural areas. [4] Rachit Srivastava et al., have developed a hybrid system, that uses renewables as well as conventional prime movers as well as battery storage system using HOMER software. [5] Y Zhu, B Shao et al., developed an optimized model of distributed CCHP systems. Good reduction in carbon emissions were observed. [6] Hossain et al developed a polygeneration system that can function with the aid of bio-oils. Prototypes were used to check the feasibility and efficiencies of the system. The output of the system includes exhaust gases for cooking purposes and system’s waste heat for distillation process. [7] Pavlos Nikolaidis et al have done a comparative study of the various hydrogen production processes regarding conventional and renewable sources. The feasibility, economic aspects, technical aspects of fourteen various types of hydrogen production processes were explained in detail. Techniques regarding hydrogen storage and proper transportation are also discussed. [8] Karim Farhat et al have developed a fossil fuel based Polygeneration energy system. Coal is used as the primary energy input, thereby producing electricity and fertilizers as outputs. Economic analysis of the developed system is also done. [9] George Kyriakarakos et al., have developed a polygeneration microgrids based on the overall energy flows in to a building. [10] Pedro J. Mag et al., proposed a CCHP system that can be applied to any industry, domestic or any commercial establishments using the above components.

1.1 About Polygeneration System
Polygeneration is the combination of several renewable energy producing systems in a way that the output of one system becomes the input for another. Also, a number of utility outputs are obtained. This way, the amount of useful energy in the given amount of input is harnessed to a maximum extent, thus maintaining a very high energy efficiency. A well-proposed poly generation system works excellently in the areas with abundance of renewable sources and may even help achieve total independency from the power grid. This is a generic concept of integrating heat generation within primary energy systems with simultaneously producing multiple outputs. Many necessary utilities can be gained by adding components to this system. Traditionally the utility generation was limited to co-generation and tri-generation types. With the idea of providing even greater number of deliverables has led to polygeneration system.
1.2 About Homer Pro
The application tool incorporated for this work is the trial version of a software known as HOMER ENERGY. This software has the ability to design, develop, evaluate technically and financially any type of poly-generation system. The developed system will have capabilities such as off-grid, on-grid power systems for remote, stand-alone and distributed generation applications.

1.3 Steps for simulating poly generation systems in HomerPro
i. Defining the load profile.
ii. Resources to be incorporated
iii. Power systems
iv. Calculations and analysis

2. Methodology
Selection of Village with high abundance in renewable energy. Three villages from Karnataka, Kerala and Tamil Nadu are chosen. Collecting data about the village. Finding the type of resources with high intensity. Evaluation of Electrical, Thermal and Hydrogen loads in each villages. Choosing suitable components to be included in system. Simulating the model in Homer Energy software. Selection of the best suited and economic feasible system among available configurations. Optimization of the available systems.

2.1. Strategy for selection of villages
This work focuses on proposing a polygeneration system and analysis of the same for a village. For this to be done the prime aspect is to choose a suitable village with abundant resource and one where the dependency on the main electric grid is more. By utilizing different energy sources, conversion techniques and components, the villages can be made a self-sustainable. Although there are basically six renewable sources of energy Solar, wind, Hydroelectric, Geothermal, Biomass and Tidal (ocean energy). But in India due to many reasons geothermal and tidal are less employed, so in our work the main focus is on the remaining four sources. Based on our location, accessibility to the data, and to ensure successful implementation in in near future we finalized to propose the system for three villages totally from three states viz Karnataka, Kerala, Tamil Nadu. The villages chosen are Attigatta from Karnataka, Mlappara from Kerala and Thellanthi from Tamilnadu. These villages had adequate amount of energy sources and each village had one or two resources which surpassed others by a large margin.

3. Resources availability

| Energy source | Parameter                  | Unit          |
|---------------|----------------------------|---------------|
| Solar         | Global Horizontal Irradiance (GHI) | kWh/m²/day   |
| Wind          | Wind speed                 | m/s           |
| Hydroelectric | Flow speed                 | m/s           |
| Biomass       | Quantity                   | tons          |

Attigatta: Attigatta is a village in Chitradurga district from Karnataka situated about 768 m above sea level with a total population of 1179 with average 233 households. The resources which are available in Attigatta are biomass, solar, wind and Hydro energy. After choosing a district, the taluk and village is chosen based on biomass per year and location of river nearby which is Attigatta village in Hosadurga taluk due to proximity of Vedavathi river which the counterparts in the taluk don’t have aforementioned parameters.
Mlappara: Mlappara comes under Idukki district which being in Western Ghats region has high forest density. Resources which are available in Attigatta are biomass, solar, and hydro energy.

Thellanthi: Resources which are available in Thellanthi are biomass, solar, and wind.
4. Various Load profiles for the polygeneration system

*Electrical load:* The primary power production by the polygeneration is for electricity deliverable. For this we have setup the gensets to satisfy the base load. The electric demand is being assumed as same and equal in terms of units for a single house hold but it varies from village to village basis.

![Power Demand across the villages in both seasons](image1)

*Figure 4.1:* Electric Power Demand across all villages (Season Wise)

*Thermal Load:* Hydronics is used for obtaining heating effect in an enclosed space using a fluid (which is in a significantly higher temperature than the room) that transfers heat to the room from a heat source (or a thermal storage system). Most commonly used fluids are water, glycol and mineral oils. Space heating application is the deliverable from this heat energy conversion. The hydronic radiators can be a single module room; or may be integrated with and be running along floors and walls.

![Temperature variations observed in a cold winter night](image2)

*Figure 4.2:* Temperature variation village wise in winter season

*Hydrogen Load:* The proposed polygeneration has four outputs, of which Hydrogen is one. The aim of choosing hydrogen was to use the unused biomass in each village for the production which is achieved by Methanol Reforming process. For more refined production of better quality of hydrogen, electrolysers could have been incorporated. But due to the less volume of capacity and the cost of installation. Though the component was present, we limited to go with reformer.
Figure 4.3: Biomass required for hydrogen production

These loads are satisfied by the system built according to their feasibilities. The deliverables mainly are electricity, hot water, hydrogen, space heating and fertilizers (slag part of biomass conversion). Hence, the developed system utilizes the maximum capability of the renewable energy in place. Operating and maintenance costs for the components have been added for the results.

5. Results and Discussion

5.1: Attigatta results simulated by Homer Pro showcase the component costs included:

Figure 5.1.1: Attigatta simulation results
Figure 5.1.1 shows the maximum costs is included for the boiler and the reformer part as the cost of the input for their working is biodiesel. So extra costs are incurred. Fig. 5.1.2 shows the cashflow for the entire time period of negative type and salvages of positive is gained after 25 years. It also has calculated that hydrokinetic and other components using renewable inputs produce the profit after 25 period of polygeneration system installation.

5.2: Mlappara results simulated by Homer Pro showcase the component costs included:

![Mlappara simulation results](image)

**Figure 5.2.1: Mlappara simulation results**
Due to the excess of availability in biomass reformer is in much need for this polygeneration system. Thus resource costs are high for the converted methanol. As from Figure 5.2.1 G1001 is highly used so might need a replacement. H₂ production typically found high in this system. By increase in capital costs for the reformer. From the cashflow we can understand that reformer costs are having a negative cash intake. However from Figure 5.2.2 the biogas genset G1001 shows a positive cash inflow after 25 years. Hence salvages have started up after 25 years.

5.3: Thellanti results simulated by Homer Pro showcase the component costs included:

Figure 5.3.1: Thellanti simulation results
As shown from Figure 5.3.1, the maximum costs are included for the boiler and thereformer part as the cost of the input for their working is biodiesel. So extra costs are incurred. After boiler and reformer, hydrogen tank has max costs in terms of capital investment. Figure 5.3.2 shows the cashflow for the entire time period of negative type and salvages of positive is gained after 25 years. It also has calculated that Wind turbine and other components using renewable inputs produce the profit after 25 period of polygeneration system installation.

![Cashflow diagram](image)

**Figure 5.3.2: Cashflow diagram**

![Polygeneration system](image)

**Figure 5.3.3: Proposed polygeneration system**
From the proposed polygeneration system the following are the output utilities are obtained:

i. Electricity from PV panels and Wind turbine
ii. Biogas from biomass produced by gasifier
iii. Hydrogen from methanol by hydrogen reforming method
iv. Thermal load for space heating from boiler unit
v. Hot water for domestic usage
vi. Fertilizer

Conclusion

Seasonal availability of resources and energy has been evaluated. A Polygeneration System for the set of villages has been designed from the available resources. This system minimizes the non-utilised portion of the resource as the by-product of one constituent system serves as an input resource to another. Specific energy requirements are met by using locally available resources for rural community. This ensures that there is little or no usable elements in the final waste and hence, a very high value of resource utilisation efficiency is achieved. This system also provides a lot of desirable utility outputs other than electricity. Grid Independency from conventional grid system for the village has been shown to be possible. Techno economic feasibility for the components used in the system has been performed. With the much needed resource feasibility, the thermos-economic feasibility has also been conducted for the components.

Scope for future work

i. Further research may be proposing more sustainable poly generation systems and its prototypes based on analytical results along with feasibility as well.
ii. Employing latest device as storage systems to get long lasting storage capacity in poly generation systems as renewable energy sources are intermittent.

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