MULTI-OBJECTIVE OPTIMIZATION OF HYBRID RENEWABLE ENERGY SYSTEM

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MULTI-OBJECTIVE OPTIMIZATION OF HYBRID RENEWABLE ENERGY SYSTEM

Major Project Report

Submitted in fulfillment of the requirements

For the Degree of

Master of Technology in Mechanical Engineering

(Thermal Engineering)

By

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MAY 2021

Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Thermal Engineering at Nirma University and has not been submitted elsewhere for a degree or diploma.

2. Due acknowledgment has been made in the text to all other material used.

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I, **Danish Siddiqui**, Roll. No. **19MMET14**, give undertaking that the Major Project entitled **"Multi-Objective Optimization of Hybrid Renewable Energy System"** submitted by me, towards the fulfillment of the requirements for the degree of Master of Technology in **Mechanical Engineering (Thermal Engineering)** of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that the Major Project Report entitled "**Multi-Objective Optimization of Hybrid Renewable Energy System**" submitted by **Mr. Danish Siddiqui (19MMET14)**, towards the fulfillment of the requirements for the award of Degree of **Master of Technology in Mechanical Engineering (Thermal Engineering)** of School of Engineering, Institute of Technology, Nirma University, Ahmedabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination. The result embodied in this major project, to the best of our knowledge, has not been submitted to any other University or Institution for award of any degree.

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Abstract

Access to electricity is the basic need for any community to uplift the standard of living by the virtue of improvement of healthcare, education, and the local economy. However, most of the rural areas do not have access to electricity and providing in such areas by the increasing scope of the electrical grid often proves expensive and, in some cases, it is not possible. Renewable energy aims to offer energy at a reasonable and acceptable price. However, its power generation is inconsistent. The Hybrid Renewable Energy system aims to address this problem, as it combines two or more sources of renewable energy and aims to deliver a constant and continuous stream of power. The combination of HRES can be selected according to the needs, feasibility, and availability.

It had been observed that not much research work was carried out with Biomass gasifier in HRES, moreover, even where it had been incorporated it was optimized in single objective. This Research Project thus aimed to work in this area and carry Multi-objective optimization using MOEA. The multi-objectives that can be applied to HRES are economical, social, environmental and reliability. The objectives considered are economical and social i.e., Minimizing the LCOE (Levelized Cost of Energy while Maximizing the HDI (Human Development Index). In the present work, the 'Solar PV - Wind Turbine - Biomass Gasifier' type of HRES has been selected for Billimora, Gujarat location which is connected to the Grid. The simulation is done using MATLAB and the Genetic-Algorithm search technique has been implemented for optimization, i.e. to find the optimal configuration of individual RER, minimizing the LCOE and maximizing the HDI.

Using reference data for factors such as Load Demand, Solar irradiation, Wind velocity and Biofuel availability for the selected location; the individual year-round power generation requirement had been calculated to meet the hourly Load demand, based on which the GA will return the optimal configuration for Solar PV, Wind Turbine and Biomass Gasifier. The simulation is done in such a way that Bio-mass Gasifier will be only recruited if the hourly demand is not met by Solar PV, Wind Turbine which is a cheap and more reliable form of energy. As it is further connected to the grid; The surplus energy generated is sold to the grid while if the Load demand is not met by all RER combined, the deficit energy is purchased from the grid to satisfy the load demand.

The Results indicates that the optimal configuration for HRES is the capacity of Solar PV - 13.9 MW, Wind Turbine - 11.7 MW and Biomass Gasifier - 2.1 MW. Moreover, it returns LCOE as 6.3802 ₹/kWh and HDI as 0.7046 which falls under the high Human development range. The total annual Load demand for the location is 111650 MWh; out of which the contribution of Solar Energy is 28.14 %, Wind Energy contributes 22.39 %, Biomass gasifier contributes 13.25 %; while the rest of Energy is purchased from the grid which is 38.76%. The surplus energy generated, sold to the Grid is 1298 MWh. The plant load factor (PLF) of Solar PV, Wind turbine and Biomass gasifier is 0.2575, 0.2444 and 0.7751 respectively.

Keywords: HRES, MOEA, GA, LCOE, HDI, Pareto, Solar PV-Wind Turbine-Biomass Gasifier

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Abbreviations

ASC	**Annualized System Cost**
ALCC	**Annualized Life Cycle Cost**
CRF	**Capital Recovery Factor**
CUF	**Capital Utilization Factor**
DG	**Diesel Generator**
EA	**Evolutionary algorithm**
GA	**Genetic Algorithm**
GHG	**Green house gases**
HDI	**Human Development Index**
HRES	**Hybrid renewable energy system**
LCOE	**Levelized Cost of Energy**
MOEA	**Multi-objective evolutionary algorithms**
MOP	**Multi-objective programming**
MPPT	**Maximum power point tracking**
NPC	**Net Present cost**
PSO	**Particle swarm optimization**
RER	**Renewable energy resources**

Chapter 1

Introduction

This chapter contains brief about current energy scenario, renewable energies, role of HRES in overcoming the limitations of RER and its applications. Moreover, various techniques involved for the optimization of HRES are also discussed.

1.1 Overview

Availability and accessibility of a good and trustworthy source of electricity is a prime requisite for any public, community or livelihood as it can lead to dramatic improvement in their living standards. Feasible source of energy leads to development and improvisation of hospitals, education, infrastructure and thereby improving the economy. Renewable energies is crucial components of sustainable development. Thus, Renewable energy serves our society by providing feasible energy service at suitable cost. Additionally this cost of service tends to have a positive effect on environment, local economy and the society in general.[13].

The increasing depletion of conventional petroleum energy along with cost have led to need for research and advancement in the area of renewable energy technologies. Hybrid Renewable Energy System (HRES) is getting recognized lately, mainly due to power generation applications in remote areas. Vast area of India lies in rural setting, with desert, inaccessible terrains, higher mountains, deep forests scattered around; thereby making the accessibility of conventional electrical energy through grid system a challenging and unfeasible approach. Therefore, HRES is one of the best options to address such issues [10].

1.2 Scope of Hybrid Renewable Energy System

The implementation of 'Hybrid Renewable Energy System' (HRES) has potential to provide a greener energy, reliable as well as sustainable and reliable energy system for remote and isolated locations. There has been a steep increment in consumption of HRES and therefore related optimization for such hybrid systems is necessary to address the problem. Therefore, using multi-objective optimization technique to overcome this subject has caught the attention of researchers, more so in recent years[8].

1.3 Hybrid Renewable Energy System

A system comprising of two or more renewable energy systems used together in order to provide better balance in energy supply and increased efficiency in the system; is termed as a hybrid energy system. Hybrid systems have an edge over single renewable energy system as they overcome the limitations like fuel flexibility, feasibility, efficiency, reliability, emissions and even economics in some cases.

Thus, in case of hybrid renewable energy system, incorporation of highly-efficient devices such as advanced materials, fuel cells, cooling systems along with heat and power can increase efficiency of the system as well as conserve energy when compared to renewable technologies used individually. It can further be accomplished by bringing into use redundant technologies along with better energy storage mechanism for achieving optimum reliability. Some hybrid renewable energy systems put into use both of the above[13], which can results in simultaneously improving the quality and accessibility of the energy system.

Thus, the HRES is used to design a system producing lower emissions when comparing it to traditional fossil fuel technologies by incorporating two or more renewable energy systems. While, HRES can also be designed in order to achieve the described attributes at optimal cost which is the key to feasibility and acceptance in the market.

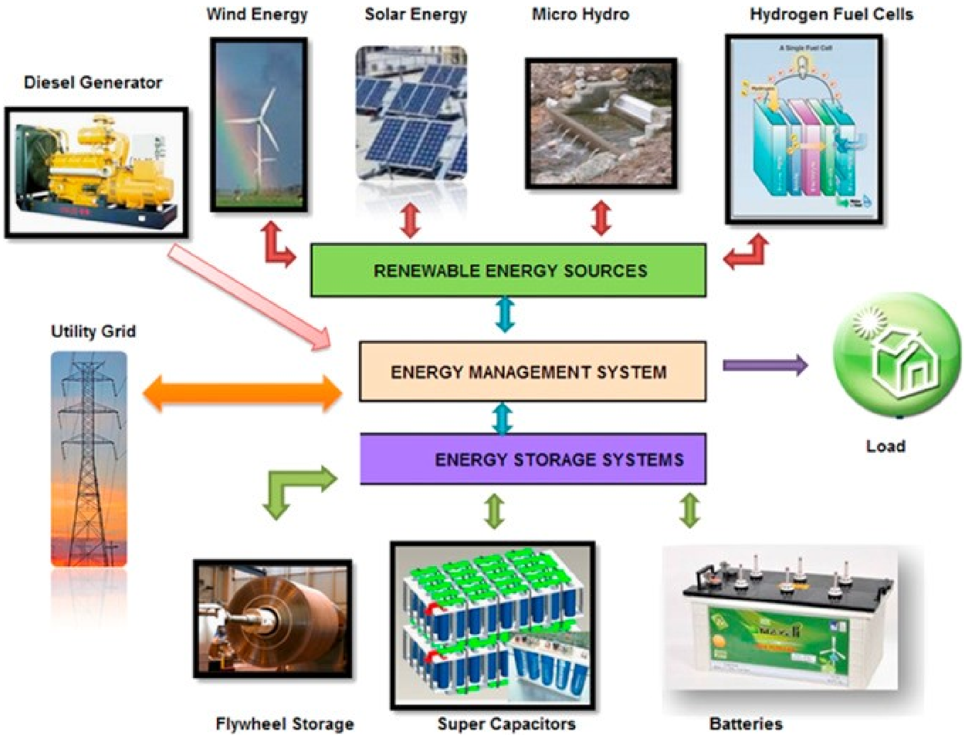

Figure 1.1: General structure of a Hybrid Renewable Energy System

In order to achieve a continuous stream of electrical supply, the power output of the RE system can thus be connected to a battery storage or battery bank which can recharge itself and further add to the load. But in case where the (AC) load is present then an inverter is need to be connected to AC load for conversion of the (DC) supply from the battery to (AC). Here, particularly the wind generator aids in starting the voltage transition among modules. However, when challenged with voltage compatibility; 'battery charger controller' and 'inverter' should be taken into consideration which is subjected to voltage standard and focuses on it[13].

1.4 Types of HRES

There are various of HRES used in order to meet the load demand which is selected by considering various factors and according to one's needs. Selection of an optimum and efficient HRES can be achieved by combination of one or more renewable energy sources along with traditional renewable energy sources. Few efficient and tested HRES configurations are as follows:

1. Solar -Wind Turbine- Diesel Generator HRES
2. Solar - Wind Turbine-Fuel cells HRES
3. Wind Turbine- Battery storage HRES
4. Biomass Gasifier- Wind Turbine-Diesel Generator HRES
5. Solar PV- Wind Turbine-Biomass Gasifier-Fuel cells HRES,etc.

1.5 Advantages of HRES

The ever fluctuating price rise in petroleum products has shifted the focus towards HRES, which is increasingly becoming popular because of relative ease generating power in rural areas along with recent advancements in field of renewable energy technologies[13].

A HRES generally is the sole system that efficiently combines, incorporates and leverages several available sources with ease[13].]. HRES is used for extensive applications such as telecommunications, border crossings, isolated habitat, clinics, etc[16]. Power which is made from generators, need constant supply of fuel and regular maintenance. Also, undesirable noise pollution and inefficiently poor performance at partial load are some of the drawbacks that make such power generation an unattractive option[13].

HRES addresses the boundaries in terms of economics, emissions, reliability, and ease of fuel use by incorporation of the highly-efficient devices such as storage resources like fuel cells, cooling systems, latest materials, etc. These factors together increases efficiency along with conserving energy for HRES when compared with traditional technologies[14].

Also, hybrid energy renewable systems have improved economical feasibility, negligible fossil fuel usages for all the Renewable Energy Resources, along with having very little or almost zero greenhouse gas emission. Renewable energies such as solar, hydropower and other RER proves safe for the environment and at the same time it has satisfactory potential of power generation. Thus, the combination of these sources with energy storage as HRES has remarkable financial returns[14].

While designing an optimum HRES its very important to consider and incorporate together; a good feasibility studies, simulation and integration of many hybrid RER[14] and energy storage systems.

1.6 Types of Optimization Techniques

Optimization algorithms are ways of computing maxima or minima of mathematical functions. Optimization techniques help solve complex problems, increase efficiency, etc. It could be of Single or Multi-objective Optimization. Different objectives can be considered when optimizing a HRES's design. There are mainly 3 distinct types of search technique and 4 distinct types of objectives which are as follows.

1.6.1 Search Techniques

1. Calculus based techniques
2. Guided Random Search Techniques or Metaheuristics
3. Enumerative Techniques

This techniques can be further classified which are mentioned in following figure.

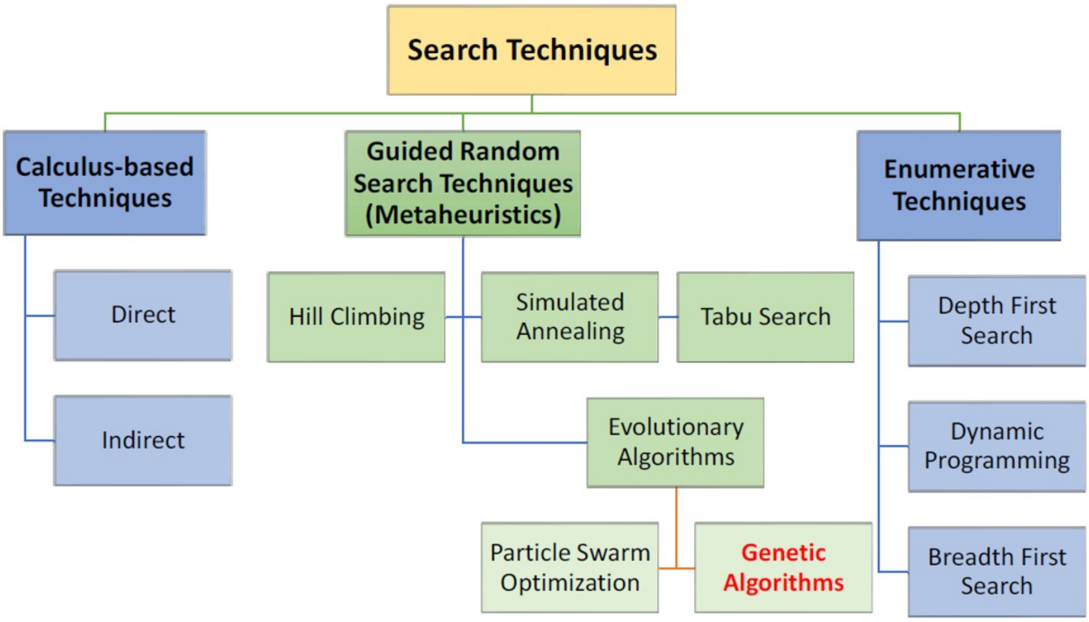

Figure 1.2: Various types of Search techniques

1.6.2 Types of Objectives

There are various types of objectives that be considered to optimize Hybrid Renewable Energy System. It is mainly of four types which are as follows:

1. Economical – e.g. NPC, LCOE
2. Environmental – e.g. C02 emissions
3. Social – e.g. HDI
4. Reliability – e.g. LPSP

1.7 Motivation

Advancement in technological innovations has led to implementation of Hybrid Renewable Energy Systems as use of RER is not enough as its availability is intermittent. Further, HRES needs to optimize to meet the needs. Various objectives are considered while optimizing the HRES. As this research focused on applying MOEA for optimization; the objectives considered are of Economical and Social aspects. Thus Minimizing the LCOE while Maximizing HDI.

1.8 Organization of the Thesis

The thesis consists of eight chapters in total.The framework for the thesis is described as follows:
The **present** chapter gives brief description of the current energy scenario, role of hybrid renewable energy system and its advantages. Various optimization techniques are briefly discussed along with motivation behind the present work carried out.
Chapter 2 gives an overall review of background and research carried out in Hybrid Renewable Energy Systems using various optimization search techniques. Also the literature summary are briefly discussed. Moreover, based on the research gap and current research trend; the objective of the current study is highlighted.
Chapter 3 provides details about the methodology adopted in the study alongwith brief history and background of the same.

Moreover,detailed description of various components involved in selected Evolutionary algorithm GA has been discussed. The method for calculating the HDI, power for RER to obtain ALCC, etc. has been discussed.

Chapter 4 consists of results of simulation work carried out on MATLAB using GA for Solar PV-Wind Turbine-Biomass Gasifier HRES at Billimora, Gujarat. Moreover, other characteristics related to HRES such as Individual RER contribution, Energy interaction with the Grid, Plant Load Factor, etc are mentioned and discussed in brief.

Chapter 5 provides conclusions from the study and results obtained from the MATLAB simulation, also bried summary from the previous chapters and also been discussed. Moreover, how could this study contribute and future scope of the work is also been discussed.

Chapter 2

Literature Review

This chapter describes the need for the research carried out in the field of renewable energy system. Also, the solution; how actually HRES could address its limitation and reasons for implementation of the same.

This chapter gives an overall review of research carried out in the field of Hybrid Renewable Energy System and various optimzation techniques used to optimize it. HRES designed in order to improve social aspects as in by maximizing HDI can be found in this chapter. Also a brief summary of the literature review is also been mentioned.

2.1 Background

It has become quite important for the engineers to find out new ways for improving the utilization of the various renewable energy sources such as solar, wind, tidal, geothermal, ocean thermal and biomass; so as to make it more sustainable, cost-effective and environment friendly substitutes that can make it more attractive over conventional energy sources. However, these renewable energy resources are not available at equal intensity throughout the year which calls for good research work in the area of 'Hybrid Renewable Energy Systems' HRES[8].

For any country or a community to develop, access to a good and cost effective source of electricity is a primary need. As per 'United Nations Development Program' (UNDP), the report states that more than a quarter of the people around the globe, especially those living in rural areas have absolutely no access to electricity[2].

Rural areas are often located far away from the electrical grid and sometimes even located in such an hard to access terrains, for example hilly areas or dense forests, where installing the grid line can result to be expensive and unfeasible due to obvious reasons[2].

2.1.1 Role of HRES in addressing the lacuna

HRES has been brought into implementation as a greener alternative to conventional systems and also a more consistent power generation system for isolated areas. As a result, there is a noticeable increase in usage of HRES in a couple of years. Thus, subsequently, optimization problem solving such HRES systems has become all the more necessary. In the recent years, researchers have become quite involved in using MOEA techniques to address the above problems[8].

Thus, there is high potential for RERs such as wind, solar, and bio energies to be used as a reliable and efficient alternative as they are ever-present, plentiful, free, clean, and easily accessible with certain modifications to the conventional approach.

However, although renewable energy is economical and provides green and clean energy; its availability is intermittent. So, some additional backup power is needed to overcome this issue.

Hence, storage devices (batteries) and diesel generators can also be used as a secondary system to overcome the discontinuous nature of wind and solar energy resulting from seasonal and climatic fluctuations. RE in the form of HMGS offers a suitable cost-beneficial and optimal solution in order to utilize the localized renewable energy resources.

2.1.2 Reason for implementation of HRES

HRES are widely used in power generation applications located in rural, remoter and isolated areas primarily due to innovation in the field of RE technologies and successive rise in cost of petroleum products[13]. For many applications such as telecommunications, border crossings, isolated habitat, clinics, etc. HRES is used. Generally, A HRES easily merges and combines several available sources. In case of hybrid systems, limitations in terms of fuel flexibility, efficiency, reliability, emissions and / or economics can be addressed to make it more efficient. By making use of available heat, power, and various highly-efficient devices[13] it can increase overall efficiency and conserve energy. HRES can be configured to maximize the use of RE resources, which can result into a system with lesser emissions compared to traditional technologies.

Also, HRES can be intended and configured so as to achieve desired attributes at the lowest suitable cost. HRES proves beneficial to economy as it uses much lesser or negligible fossil fuel consumption for all renewables, and has less GHG emission[14].

2.2 Review of Literature

Various literatures related to Hybrid Renwable Energy Systems are as follows:

(Singh et al., 2016a)[24] The authors have presented a study of hybrid renewable energy system (HRES) consisting of Solar PV-Wind turbine system alongwith Biomass gasifier and Battery storage in order to satisfy the electricity demand of a small area in Punjab. The study also highlights optimal sizing of components through demonstrating the application of 'ABC algorithm' type of Optimization technique. The researchers have employed a methodology such as to design a stand-alone using 'PV-wind-biomass-battery' HRES for meeting the electricity requirement of village in Patiala, Punjab, India. It also features energy storages system by the means of batteries where ABC Algorithm has been used to optimize the HRES[24].

(Dufo-López et al., 2016)[7] it presents MOEA for the optimization of standaloneHRES consisting Solar PV-Wind Turbine-Diesel Generator-Battery bank to minimise NPC and maximise HDI and JC[29]. Such optimization is generally performed by taking into consideration solely the minimization of cost viz. NPC or LCOE, as well as the emissions and the unmet load in some cases. It can be considered pioneer where maximisation of HDI and JC is as part of optimization is taken into account. While HDI is dependent upon the consumption of power, so the surplus energy that HRES can transmit further to the grid which can contribute in propelling the HDI index into positive direction. Generally, the three objectives are often opposed, so a Pareto front is a good option to obtain a set of possible solutions in which no solution is better than another one for all three objectives. It is basically shown as an example in the optimization of HRES to supply electricity to relatively small population residing in Sahrawi refugee camps of Tindouf, Algeria[29][7].

(Bajpai & Dash, 2012)[1] presents a study on the development unit sizing, optimization, energy management and modelling of various HRES components. Developments in research on modelling of HRES, backup storage systems such as Fuel Cells, batteries, super capacitors, Diesel Generator, techniques for proper energy management are discussed precisely. Here, the attempt has been made to summarize the complete review of the research in this area over the past decade[1].

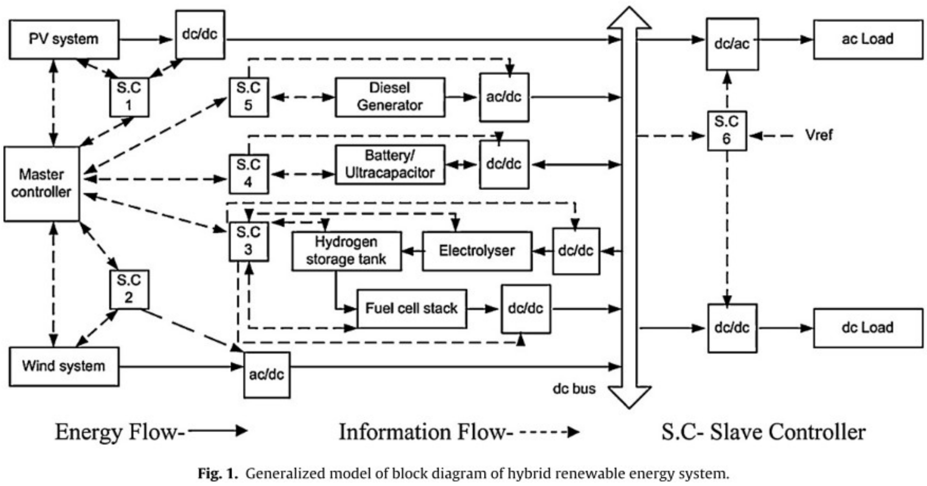

Figure 2.1: Components of hybrid renewable energy system

(Fadaee & Radzi, 2012)[10] have presented a study which gives a fair overview of the various applied MOEA methods for HRES. The method was proposed to aid the current and prospective research work in the above direction. The result shows that the preferred methods that are generally implemented are GA and PSO as there vast number of studies about optimization of the many objectives during a HRES by such algorithms or search techniques[14][10].

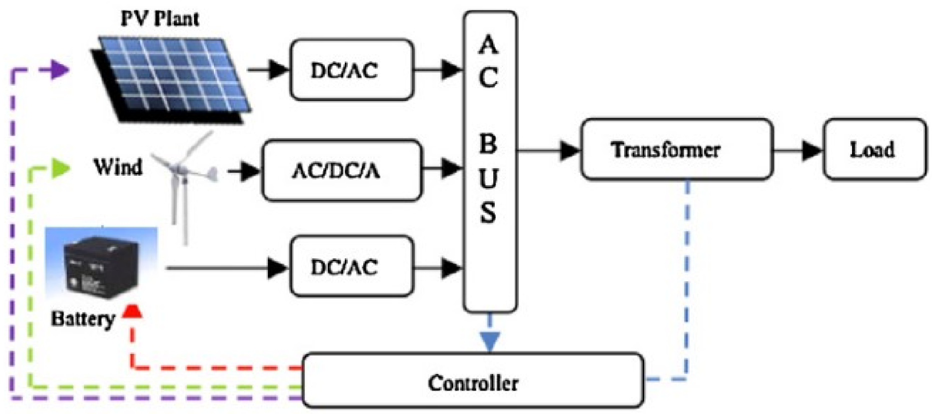

Figure 2.2: Block diagram of a conventional PV–wind–battery system

2.3 Summary of the Literature

Optimization Technique	Authors	Year	Type of HRES	Objective
Genetic Algorithm (GA)	Rui Wang et al.	2020	PV-WT	Multi-Objective
	Myeong Jin Ko et al.	2015	PV-WT-BAT	Multi-Objective
	Dufo-López et al.	2011	PV-DG	Cost
	M. Kalantar et al.	2010	PV-WT-MicroTurbine-BAT	Sizing, Cost
	Koutroulis et al.	2010	PV–WT (Stand-alone)	Sizing
	Zhou W et al.	2010	PV-WT-BAT	Sizing, Configuration
	B. Ould. Bilal et al.	2009	PV-WT-BAT	Sizing
	Dufo-López et al.	2008	PV–DG–BAT–hydrogen	Control-Strategy
	Mousavi Badejani M et al.	2007	PV-WT	Sizing, Location
Particle Swarm Optimization (PSO)	Xiao Xu, et al.	2019	PV-wind-Hydropower station with Pumped-storage Installation	Multi-Objective

	U. Boonbumroong, et al.	2010	Stand-alone Hybrid System (Thailand)	Cost Minimization
	A.Kashefi Kaviani et al.	2009	PV-WT-Hydrogen system	Cost Minimization
	Hakimi et al.	2009	Stand-alone Hybrid System (Iran)	Cost Minimization
	Moghaddam	2009	Hybrid RE back-up Micro turbine–Fuel cell–battery	Multi-Objective
Operational Optimization	R. Bravo et al.	2019	Solar PP with Thermochemical energy storage	Multi-Objective
Probabilistic simulation	Justo José Roberts et al.	2018	PV–wind–battery–Diesel	Multi-Objective
Hybrid ACO-ABC Algorithm	M. Kefayat et al.	2015	DER(fuel cell, gas turbine, micro-turbine)	Location, Sizing
Exact methods	Fallahi N et al.	2012	PV-wind-Tidal power plant	Multi-Objective
LP Iterative procedure	C. Nogueira et al.	2014	PV-wind-battery	Sizing
Mixed Integer Nonlinear Optimization	Sajjad Abedi et al.	2011	PV-wind-fuel cell	Cost Minimization

Table 2.2: Summary of the Literature review

2.4 Research Gap

From the various Research papers, I have found out that most of the optimization techniques that are applied to HRESs are Evolutionary Algorithm (EA); also in most cases with a single objective for purpose of minimizing the cost.

Even where Multi-objective optimization technique is implemented; it is mostly done on PV-Wind or PV-Wind-Diesel or PV-Wind-Diesel-Battery and so on, types of HRESs. However, not much work has been done in the area while considering Multi-Objective Optimization technique implementation on Biomass Gasifier plant or Hydro-Power kind of HRESs.

Thus, the present research work is done in order to focus on these un-explored segments and therefore we have decided to choose the Solar PV-Wind Turbine-Biomass gasifier kind of HRES.

2.5 Objective of the Research project

In this Major Research Project, Our goal is to be implementing the Genetic Algorithm (GA) search technique on PV–Wind–BioGas kind of HRES in order perform Multi-Objective optimization and provide an optimal configuration for its required capacity and sizing analysis. Here the HRES is connected to PowerGrid for Billimora, Gujarat location. Simulation is carried out on MATLAB to optimize the selected PV-Wind-Bio HRES in multiple objective as in minimizing the cost (LCOE) while maximizing the Human Development Index (HDI).

Chapter 3

Methodology

As discussed earlier there are several types of optimization techniques and algorithms which are can be selected according to the need or requirement. It's clearly evident that Genetic Algorithm and Particle Swarm Optimization are widely used when applied to a HRES. Thus, we adopted the Genetic Algorithm, which is an Evolutionary algorithm which falls under the branch of Guided random search technique or also known as Metaheuristics.

3.1 Evolutionary Algorithms

Evolutionary algorithms (EAs) mimic natural evolutionary principles to constitute search and optimization procedures. EAs are different from classical search and optimization procedures in a variety of ways. Also there existed some common challenges with most traditional direct and gradient-based techniques, which are stated as following:

- The conjunction to an optimal solution depends on the selected initial solution.
- Most algorithms tends to halt at the suboptimal solution.
- A algorithm which might be efficient in solving one optimization problem may not necessarily be efficient in solving another optimization problem.
- They are not as efficient in handling problems which contains a discrete search space.

3.1.1 Genetic Algorithm

Genetic algorithms (GAs) have been expansively used over the last decade as search and optimization techniques in various problem domains in the field that includes the sciences, commerce and also engineering. The main reason behind their success is their broad applications along with the ease of use and global accessibility. Genetic Algorithms refer to branch of computational models inspired by Darwin's theory which describes survival of the fittest publish in journal of Biological evolution.

The concept behind it is Natural Selection organizing principle for optimization and populations of individuals. The Genetic Algorithms simulates the Natural selection process in order to optimize more effectively. An evolutionary process is used to evaluate the problems which results in best or the fittest solution or the survivor. As it is inspired by Natural evolution, Gas involves direct manipulation of the coding achieved by the crossover and mutation operations.

GAs begin the search from many points and it contains the population of feasible solutions to a given problem. It does not need auxiliary information like gradients at points. They search it by virtue of sampling.

3.1.2 Structure of Genetic Algorithm

1. Population – It is a subset of all the possible (encoded) solutions to the given problem.

2. Chromosomes – A chromosome is one such solution to the given problem.

3. Gene – A gene is one element position of a chromosome.

4. Fitness Function – It is a function which takes the solution as input and produces suitable optimal solutions as the output. While in few cases, the fitness function and the objective function might be the same, while in rest it may be different which is all depended upon the type of problem it is required to solve.

5. Genetic Operators – It modifies the genetic composition of the children by the means of performing crossover, selection, mutation, etc.

A basic structure of Genetic Algorihtm model is shown in following figure:

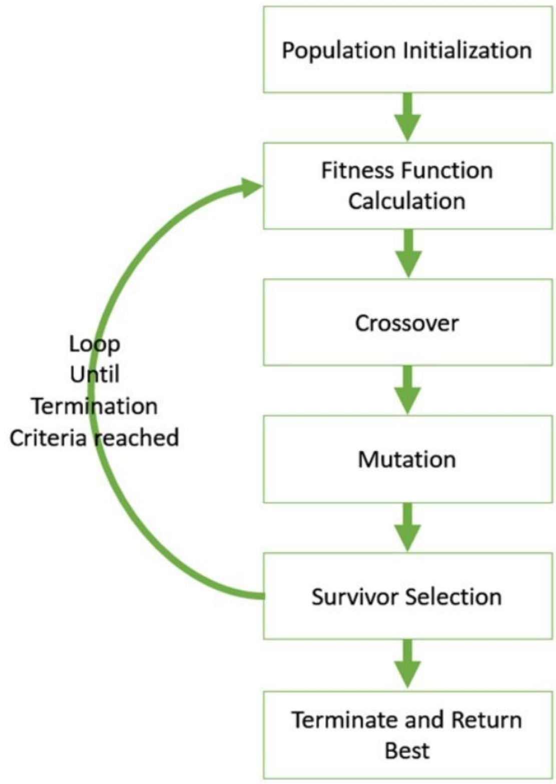

Figure 3.1: Structure of Genetic Algorithm

3.2 Multiobjective Optimization Evolutionary Algorithm

Multi-objective optimization is a powerful mathematical toolbox widely used in engineering disciplines to solve problems with multiple conflicting design objectives. In general in such optimization performed using the MOEA where no solution optimizing occurs while all objective functions at the same time exists but instead in Pareto optimal solutions, which can be considered "efficient' in terms of considering all objective functions, it has been introduced in such a way that it may have many Pareto solutions. Hence, there is a need to decide a final solution Thus, it requires to decide a final optimal solution amongst the Pareto optimal solutions taking into the consideration into account the balance among objective functions which is coined as "trade-off" analysis.

Since, the objective containing several constraints might not properly represent the problem being face; hence, 'Multi-objective programming' is needed to formulate problems that have more than one objective. In it is only concerned with the minimization of the vector of the objective function f(x) which is a subject of a no. of constraints or the bounds. Multi objective programming problems can be formulated as follows:

$$f(x) \equiv (f1(x), f2(x), ..., fn(x)) \ \ over\ x \in X$$

In general, there may be many Pareto solutions. The final decision is made among them taking the total balance over all criteria into account.

3.2.1 Pareto Front

A Pareto front is a set of points in parameter space which is the space of decision variables that has noninferior fitness function values. For each point on the Pareto front, one can improve one fitness function only by degrading another.

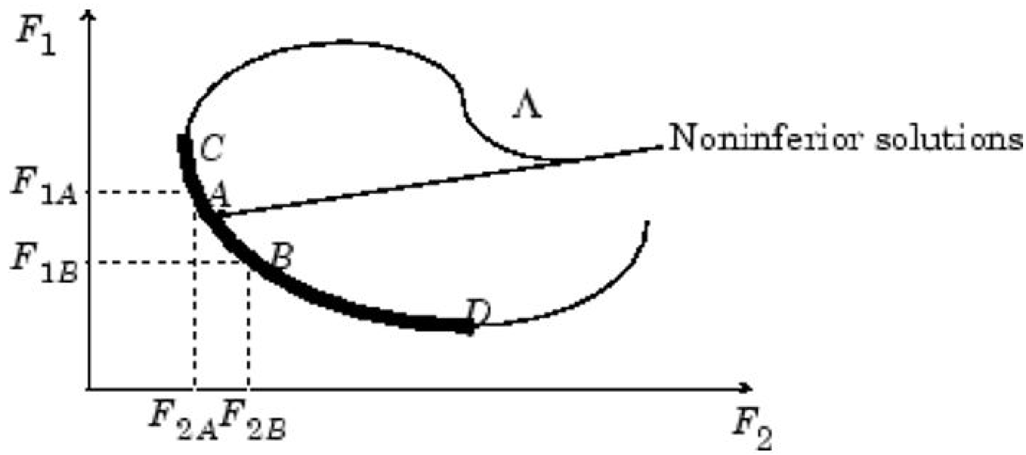

Figure 3.2: Pareto front set of solutions

In other words, MOEA has pareto front which plots its objectives on it. It could be 2D or 3D depending upon the type of problem whose solutions are plotted on its axis. Here, in our study as it had two objectives i.e. minimize LCOE and maximize HDI; where the first objective HDI is plotted on x-axis and the second objective LCOE is plotted on the y-axis as shown in the results chapter.

3.3 Multi-objective GA Algorithm

gamultiobj is MATLAB's optimization tool which uses a controlled, elitist genetic algorithm that is an alternative to NSGA-II. It always gives preference to individuals who has better fitness value or rank. Moreover, it also chooses individuals which can help in efficiently increasing the diversity of the population even though it might have a lower fitness value[11].Further, it uses an algorithm that is designed to plot the points on the Pareto front[17].

3.3.1 Problem Formulation

MATLAB's Multi-objective GA aims to generate set of Pareto optima for a Multi-objective minimization. The designer may require to set bounds, other constraints on variables. GA further helps in searching the Pareto optima locally. Moreover, if one has an initial population it can either be specified either else let the solver create one automatically in GA function.

3.3.2 Multi-objective GA Terminology

Most of the definition for Multi-objective GA is similar to single-objective GA apart from few additional termininologies.

- Dominance — It can be said that Dominance exists for a point x and y when:

  $f_i(x) \leq f_i(y)$ for all i.

  $f_j(x) < f_j(y)$for some j.

- Rank — It can defined as the iterative definition of the rank of an individual for feasible individuals.

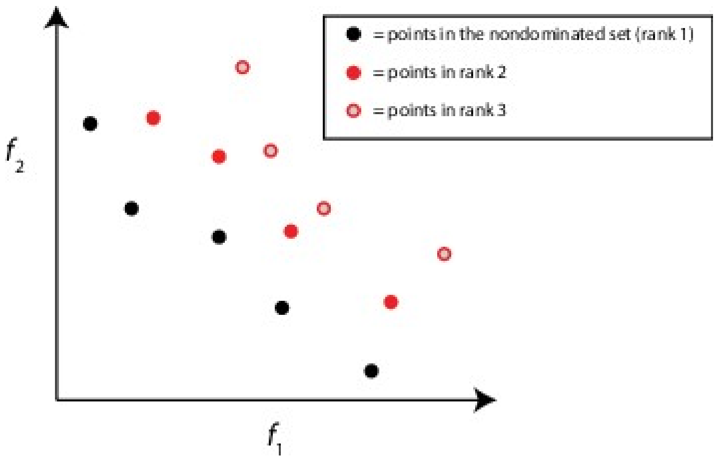

Figure 3.3: Rank representation for set of points in gamultiobj

It helps in determining parents in GA. There is a higher probability of selection for individuals with a lower rank because here the lesser rank is generally considered better. All the infeasible individuals would have a poor rank as compared with any feasible individual present. Also, inside the infeasible population, sorting of rank is done by measuring infeasibility and the most ranked feasible members[17].

- Crowding Distance — It can be defined as the measure of the closeness of an individual corresponding to its nearest neighbours. The Multi-objective GA can automatically measure it by searching within individuals having same rank in objective function search space[17].

- • GA sets its distance at the extreme positions while for the rest of the individuals, what it does is that it calculates distance as a sum over the dimensions of the standardized absolute distances amongst individual's sorted neighbors. Moreover, for the dimension m and sorted and the scaled individual (i) can be given by[17]:

$$distance(i) = sum_m(x(m, i+1) - x(m, i-1))$$

- Spread — It can defined as the measure of the movement of the Pareto set. For calculating the spread, Multi-objective GA first assesses σ which is the normal deviation of the distance measured for the points which are plotted on Pareto front within finite distance. Later, it assesses μ , known as the sum function indices over the objective function of difference between the present min value Pareto point and min point for that particular index in the previous iteration. Thus, spread can be found out by:

$$spread = (\mu + \sigma)/(\mu + k * \sigma)$$

Spread is relatively minor when the extreme objective function values whose change is negligible between the iterations, in other words when μ is small. While on the other hand, after points on the Pareto front are spread uniformly where σ is small; Multi-objective GA uses it in a stopping condition which means the Iterations break when there is neglible change of the spread and thus the final spread is comparatively less as compared to average of recent spreads[11]

3.3.3 Initialization

Creation of an initial population is the first step in the Multi-objective GA. The algorithm is designed such a way that it can itself generate the population, alternatively if desirable; the user can give a complete or fractional initial population by means of the "Initial Population Matrix" feature available in toolbox. The count of individuals in the population is established to the value of "Population Size". Moreover, it can evaluate the objective function along with the constraints for population which it later practices them for further generating scores of population. The algorithm can generate a population that is feasible w.r.t bound, linear constraints; though its limitation it may not necessarily be feasible if the constraints are non-linear.[11]

3.3.4 Iterations

The Iterations for Multi-objective GA proceeds in follows manner:

1. Select parents for the following generation using the selection function on the existing population.
2. Generate offsprings from the current selected parents by performing mutation and crossover.
3. Give score to offsprings by computing the objective function values, feasibility.
4. Merge the existing population and offsprings into one matrix thus creating extended population.
5. Evaluate the rank, crowding distance for each individuals in extended population.
6. Exclude the extended population for getting Population Size individuals by keeping the suitable nos. of individuals of each rank[11].

3.4 Specification of proposed HRES

The various key features and specifications for the selected type of Hybrid Renewable Energy System; alongwith the types of objective and optimization technique implemented for a particular location has been discussed as under:

Title: Multi-Objective optimization of Hybrid Renewable Energy System
Type of Hybrid Renewable Energy System:
Solar PV – Wind Turbine – Biomass Gasifier
Type of connection: Connected to Power/Electrical Grid
Optimization/Search Technique: Genetic Algorithm
Variant: Non-dominated Sorting Genetic Algorithm-II (NSGA-II)
Simulation Software: MATLAB
Location: Billimora – Gujarat (INDIA)
Coordinates: 20.7702° N, 72.9824° E
Objective: Minimize LCOE, Maximize HDI
I/P variables: I (W/m2), V (m/s), T (°C), Load (kWh)
O/P variables: Capacity of Solar PV (kWh), Capacity of Wind Turbine (kWh), Capacity of Biomass Gasifier (kWh), HDI

3.5 Preference of HRES

There were vast number of options for selection of the type of Hybrid Renewable Energy Systems according to one's need, feasibility, availability of resources and budget.

The preferred HRES that we selected is SOLAR PV-WIND TURBINE-BIOMASS GASIFIER for a small village located in Navsari district; Billimora, Gujarat. Its coordinates are 20.75 Latitude and 72.95 Longitude. The schematic diagram of proposed HRES is shown in Figure 3.4

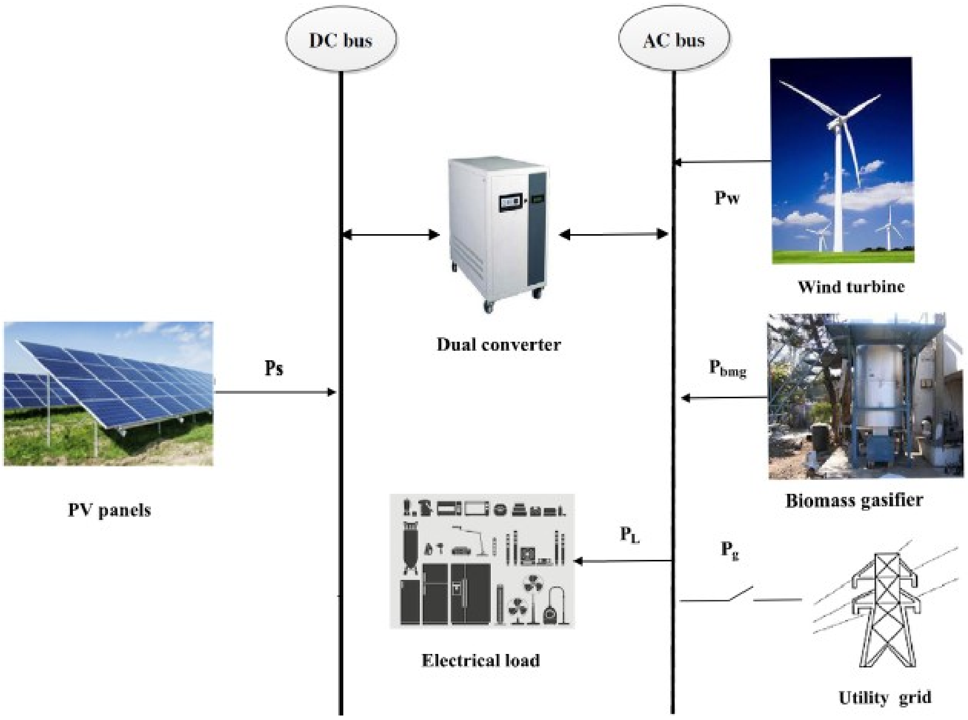

Figure 3.4: Components of Proposed HRES System

Where,
P_S = Power generated by the Solar Photovoltaic
P_W = Power generated by the Wind Turbine
P_{BMG} = Power generated by the Biomass Gasifier
P_L =Load demand for prescribed location

3.6 Flow process chart of the proposed HRES

The operational strategy for proposed HRES is shown in the following flow process chart based on which the coding for simulation is done in MATLAB with related set constraints.

The process begins with first of all calculating the power for Solar PV (P_S), Wind Turbine (P_W) and maximum Biomass Gasifer (P_{BMG}). Later, it compares it with the hourly Load Demand (P_L) to determine the optimal configuration of Solar, Wind and Biomass.

The simulation is done in such a way that it primarily tries to fulfil the load demand by Solar and Wind itself. If the energy generated by Solar PV and Wind Turbine exceeds the load demand, the surplus energy is sold to the grid directly. However, if load demand is not satisfied, only then it recruits energy from the Biomass gasifier. The remaining required energy is fulfilled by the Biomass gasifier and even still if load demand is not met; the deficit energy is purchased from the Grid.

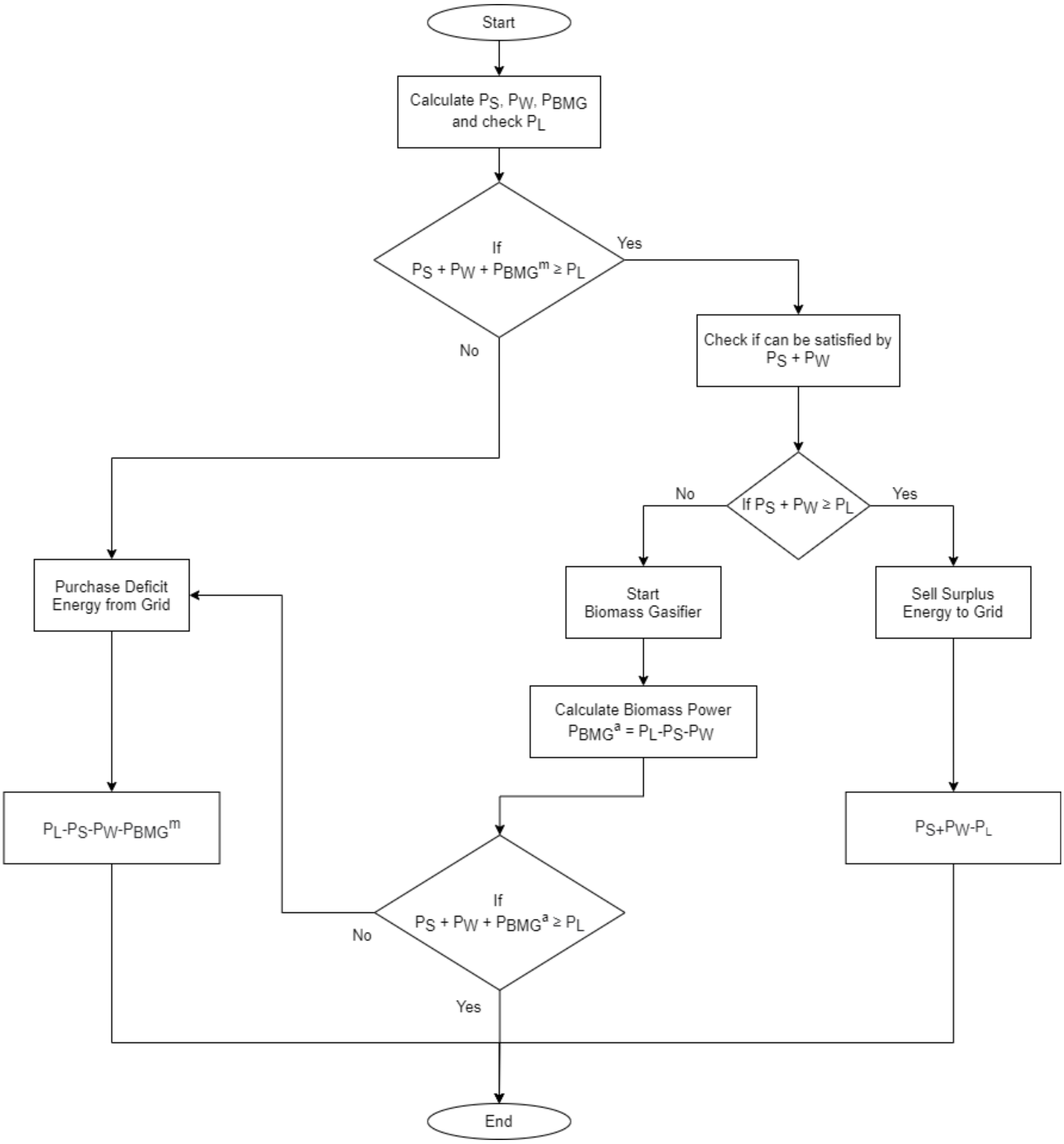

Figure 3.5: Flow chart of the operational strategy for the proposed HRES

3.7 Load and Power Generation Calculation

The simulation for the HRES optimization is done using MATLAB platform. The power generations for various individual RERs of HRES are been calculated as mentioned under, which may fulfill the hourly Load demand of the Billimora location year round; based on that GA would return us the optimal configuration of sizing for Solar PV-Wind Turbine-Biomass Gasifier HRES.

3.7.1 Solar Photo-voltaic Power generation

The power generation output (Ps) for the Solar PV always depends on the solar irradiation which is unpredictable can be further given by the expression:

$$Ps(t) = P_r^s floss \frac{G_h(t)}{G_s}$$

where P_r^s represents rating of the solar PV panel, $floss$ is the derating or loss factor of the solar PV panel because of shadow, dirt and temp etc, $G_h(t)$ is the hourly solar radiation incident at surface of solar PV panel (W/m^2)and Gs is the standard incident radiation[24] ($1000W/m^2$).

3.7.2 Wind Power generation

The power generated by a wind turbine can be calculated as:

$$P_{wt}(t) = \begin{cases} 0 & V(t) \leqslant V_{cin} \text{ or } V(t) \geqslant V_{cout} \\ P_r^w & V_{rat} \leqslant V(t) \leqslant V_{cout} \\ P_r^w \frac{V(t)-V_{cin}}{V_{rat}-V_{cin}} & V_{cin} \leqslant V(t) \leqslant V_{rat} \end{cases}$$

where P_r^w is the rating of a single wind turbine, V_{cin} is the cut in speed, V_{rat} is the rated wind speed, $Vcout$ is the furlong speed and $V(t)$ is the wind speed at desired height[31] which in our case is 50m. The wind speed at the hub height depends upon site and geographical location and it is different from reference height which can be given by:

$$V(t) = V_r(t) \left(\frac{H_{WT}}{H_r}\right)^{\gamma}$$

where $V(t)$ is the wind speed at height H_{WT}, $V_r(t)$ is the wind speed at reference height H_r, and γ is friction coefficient. Typical value of friction coefficient γ is 1/7 for low roughness, surface and well exposed site[24].

3.7.3 Biomass Gasifier Power generation

In Biomass gasifier the solid bio wastes are turned in to fuel gaseous in nature which is further used for the purpose of power generation. During the incomplete combustion process, a combustible gas called producer gas is generated which is in composition of 20%H2, 20%CO and around 2%CH4 and some inert gases. This combination of producer gas is used to power generation. The output electricity Ebmg of a biomass gasifier, annually, is calculated as[24]:

$$E_{bmg} = P_{bmg}(8760 * CUF)$$

Where P_{bmg} is the rating of biomass gasifier system and CUF is the capacity utilization factor. In the case of a biomass based energy system, few parameters such as the calorific value of biomass, availability of biomass (Ton/yr) and usage hours of biomass gasifier play an important role. The maximum rating of biomass gasifier installed in a particular area can be defined as follows[24]:

$$P_{bmg}^{m} = \frac{\text{Total biomass available (Ton/yr)}*1000 * CV_{bm} * \eta_{bmg}}{365 * 860 * \text{Operating hours/day}}$$

Here $Pbmg$ is the max capacity that can be generated at any particular hour, but we don't need to run it at max capacity. Thus, a further constraint was added such that Biomass Gasifier should only be recruited when Load demand is not met by Solar PV+Wind Turbine; apart from it, Biomass Gasifier should not be used. Perhaps, if still load demand is not met then only it should be taken from the grid.

Constraint added for the actual P_{bmg} calculation is $Pbmg = min(Pl–Pw–Ps, Pbmg)$.

3.8 HDI

Human Development Index (HDI) is a statistical composite index which is primarily used as a technique to measure a nation's or state's overall achievement. It considers the social, economic dimensions to calculate the same. Such dimensions of a country are depending upon various factors which can be such as education, life expectancy, health and standard of their living or the per capita income.

The HDI is the geometric mean of normalized indices for each of the three dimensions.

Dimension	**Indicator**	**Min**	**Max**
Health	Life expectancy	20	85
Education	Expected years of schooling	0	18
	Mean years of schooling	0	15
Standard of living	Gross national income per capita (2011 PPP $)	100	75000

Table 3.1: Dimensions, Indicator and Range of HDI

Thus, creating an overall score between 0 and 1 for HDI.

Human Development Level	**HDI Score**	**No. of Countries**
Very High Human Development	0.800 and above	51
High Human Development	0.700-0.799	54
Medium Human Development	0.550-0.699	42
Low Human Development	Below 0.550	41

Table 3.2: HDI score and level criteria

HDI is depended upon the consumption of electricity, such that the surplus power generated and thereby be supplied to the hybrid system, as a result it can increase the HDI[29]. The equation for determining HDI is as follows:

$$= 0.0978 \ln \left(E_{\text{load\_annual\_per\_capita}} \right) - 0.0319$$

Where the extended formula for HDI can be determined as:

$$= 0.0978 \ln \left[\left(E_{load} + \min \left(K_{excess} \cdot E_{excess}, K_{load} \cdot E_{load} \right) \right) / Npersons \right] - 0.0319$$

Where,

Eload = annual Total load (Pload = 111649592 kWh)

Eexcess = annual excess energy of the system (Surplus energy = 1297800 kWh/yr)

Kexcess = factor to obtain the max surplus energy that must be utilized by other loads.

Kload = factor to gain the annual AC load which can no exceed the max surplus energy and thus can be utilized by other new loads

Np = the number of persons living in the community supplied by the system (60000)

Thus, for example, if we consider that 20% of the excess energy can be used by new AC extra loads but we consider that these AC extra loads cannot be higher than 50% of the expected AC load, then Fmax_E_excess = 0.2 and Fmax_E_load = 0.5

Chapter 4

Results & Discussion

4.1 Multi-Objective Optimization

As discussed in 3.2.1 a Pareto Front representation is used to plot the various solutions of the function for a Multi-Objective optimization. As, the study consisted of 2 objectives, the solutions are plotted on a 2D graph. Here, first objective LCOE is plotted on x-axis while the y-axis represents the inverse HDI. As the objectives were minimizing LCOE and maximizing HDI; and the gamultiobj optimization used from the MATLAB optimization is only concerned with the minimization of the vector $F(x)$. Thus, both the function needs to me minimized first and then inverse the HDI to get actual maximized value. In order to maximize the HDI there few methods as minimizing $-f, 1/f$ or $1/(1+f)$. It is based on trial and error so one must make sure, if it falls in desired range. The final maximized value for HDI is returned in the MATLAB command window. Moreover, gamultiobj is a variant of NSGA-II which is a well known, fast sorting and elite multi-objective algorithm, it sorts the Non-dominated areas and hence it only shows the plots of dominated solutions for the particular given function.

The results of the both the objectives are shown in Figure 4.1.

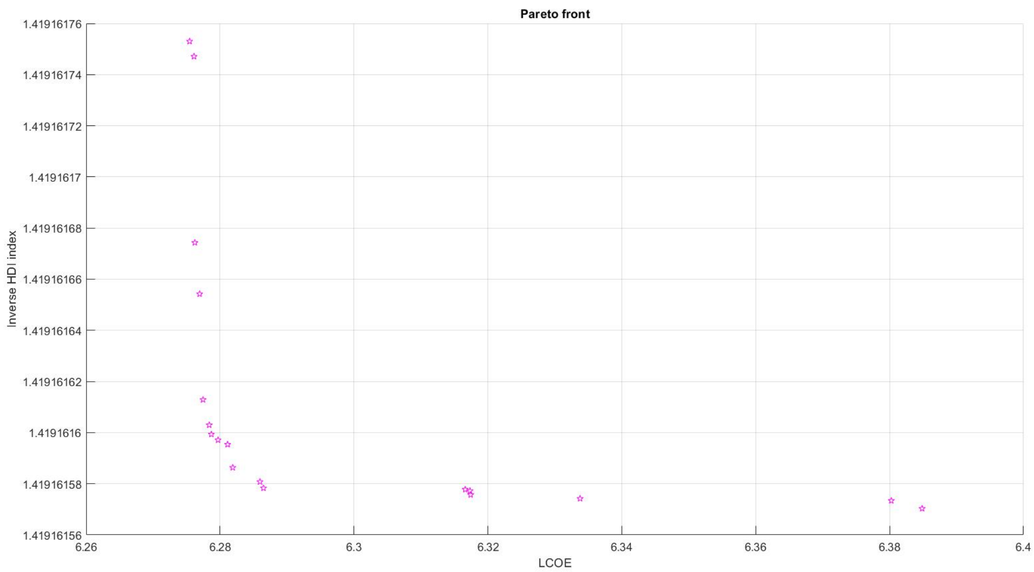

Figure 4.1: Genetic Algorithm fitness function value Pareto Front 2D plot

The final optimal value obtained for both the objectives after minimizing the LCOE and maximizing the HDI are as follows:

Levelized Cost of Energy (LCOE)	6.3802 ₹/kWh
Human Development Index (HDI)	0.7046

Table 4.1: Optimal value for Objectives LCOE and HDI

4.2 Optimal HRES Configuration

To set up the Hybrid Renewable Energy System, it is crucial to know the optimal and exact required configuration for each of the RER to generate Energy accordingly to meet the Load demand at any particular through out the year. The GA returns following optimal HRES configuration for Solar, Wind and Biomass gasifier respectively in Table 4.1.

Capacity of Solar PV	13930.69 kW
Capacity of Wind Turbine	11678.76 kW
Capacity of Biomass Gasifier	2179.38 kW

Table 4.2: Optimal HRES Configuration for RER

4.3 Annualized Life Cycle Cost

Annualized Life cycle cost (ALCC) is an approach that assesses the total cost of an asset over its life cycle including initial capital costs, maintenance costs, operating costs and the asset's residual value at the end of its life. It is an important factor for comparing the alternatives and deciding on a particular process for completing a project. There are different components taken into consideration to find ALCC. It can be calculated as $ALCC = Capital + Replacement cost + Maintenance cost + Energy\ cost – Salvage$

The ALCC for various components of HRES and Total cumulative cost breakdown is given as in Table 4.2.

Solar Cost	₹ 5,29,61000
Wind Cost	₹ 8,27,83000
Biogasifier Cost	₹ 27,31,00000
Inverter Cost	₹ 1,26,76000
Grid Cost	₹ 29,91,10000
Total Annual Cost	₹ 72,06,30000

Table 4.3: Annualized Life Cycle Cost

4.4 Annual Energy Interaction

The Total energy production by each Individual RE for Solar, Wind and Bio alongwith Total annual load for selected location is shown in the following Table 4.3. Moreover, the total Energy sales and Energy purchased from the grid is also mentioned.

Total Solar Energy Generated	31425000 kWh
Total Wind Energy Generated	24999000 kWh
Total Biogasifier Energy Generated	14798000 kWh
Grid Purchased	43286000 kWh
Grid Sales	1297800 kWh
Total Annual Load	111649592 kWh

Table 4.4: Annual Energy Interaction

4.5 HRES Individual Contribution

The breakdown for total contribution of each component of HRES to fulfill the the Load demand is given in the following Table 4.4.

Solar Contribution	28.1461%
Wind Contribution	22.3906 %
Biogasifier Contribution	13.2540 %
Grid purchase	38.7695 %
Grid sales	1.1624 %

Table 4.5: HRES Individual Contribution

4.6 Plant Load Factor

Plant Load Factor(PLF) is defined as the ratio of the energy generated by the power plant and the actual installed capacity of the same[1]. It allows to examine the reliability of various power plants. It basically measures how often a plant is running at maximum power. A plant with a capacity factor of 100% means it's producing power all of the time.

A lesser PLF is generally considered bad for power plant as it signifies that the installed plant can not use its full potential and operate at its optimal power generation capacity while, a higher PLF would create a comparatively greater total output as a result it will further reduce the cost per unit of energy generated which signifies that the higher the PLF would be the lesser will be cost of generation per unit. Also the surplus energy generated would improve the revenue of the plant by improving the same[1].

The PLF for Solar PV, Wind Turbine and Biomass Gasifier is given in following Table 4.5.

Solar PLF	0.2575
Wind PLF	0.2444
Biogasifier PLF	0.7751

Table 4.6: Plant Load Factor

4.7 Graphs

4.7.1 Load, Total Energy Generated and Grid Purchased

The total energy interaction by Load demand, Total Energy generated by RER and Total energy purchased from the Grid is been plotted in the following graph shown in Figure 4.2. Here, it represents the Load demand, Total energy generated and purchased from the Grid separately. As the load demand is first partially fulfilled by the RER and the deficit is taken from the Grid. The representation of each line is described in the graph legend.

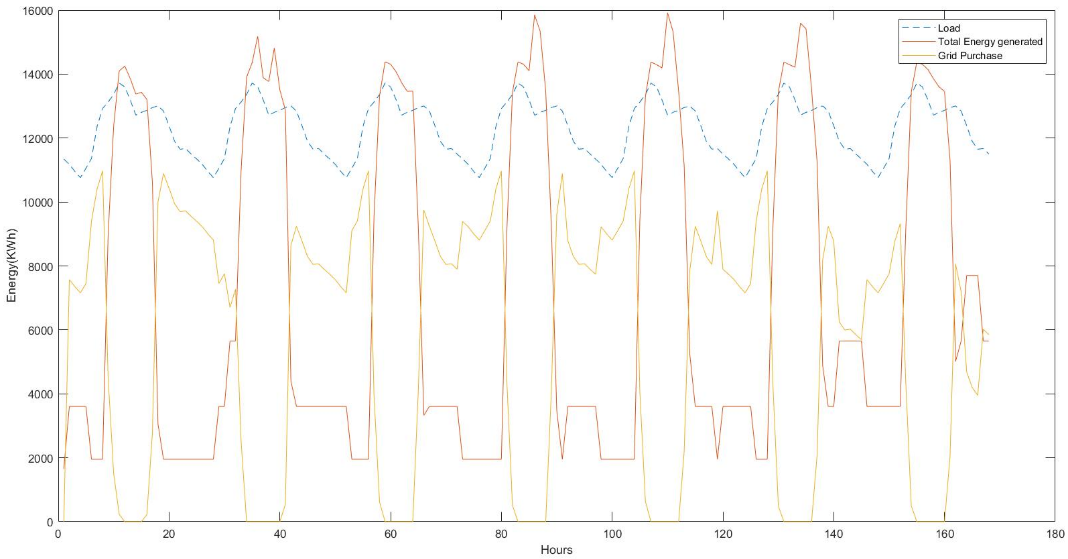

Figure 4.2: Load demand, Total Energy Generated and Grid Purchase

4.7.2 Load, Total Power Generated + Grid Purchase

The load demand and cumulative Total power generated by RER along with Grid purchase are shown in Figure 4.3. This graph ensures that the Load is met at each and every time. The load curve is always under the red curve which represents the sum of Total Energy generated and Grid purchase; Thus, the load demand is always met.

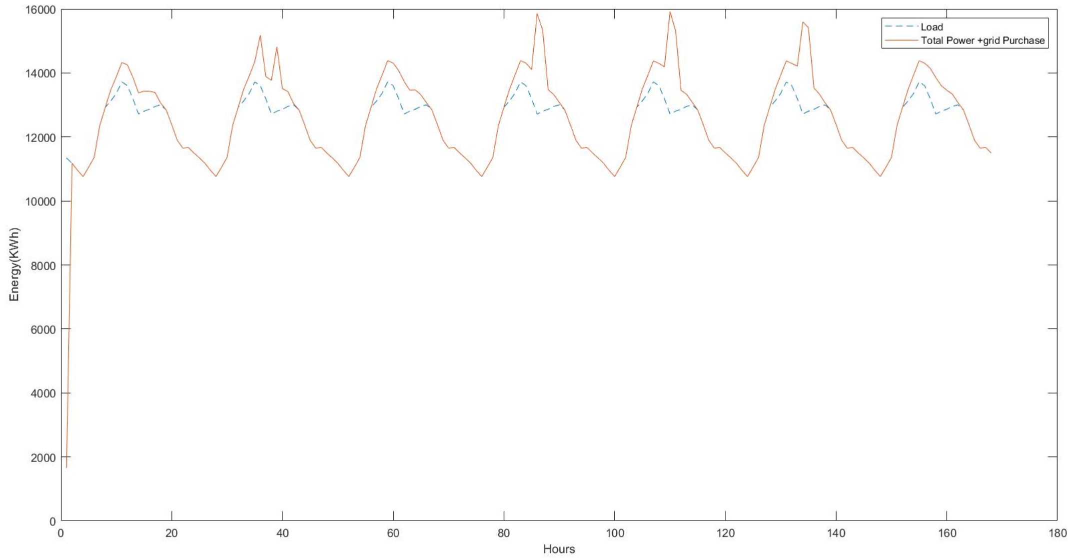

Figure 4.3: Load Demand and Total Energy (Generated & Purchased)

4.7.3 Grid Sales and Grid Purchase

The comparison between the energy sold to the grid and energy purchased from the grid is shown in the following graphs. Here, the energy sales are comparatively low as it was solely designed to meet the load demand by Solar and Wind, and only recruit Biomass gasifier when they can not be fulfilled by solar and wind. The deficit amount of energy after incorporating all RER is purchased from the grid which is represented by the red curve. The Figure 4.4. shows weekly interaction of Energy sales and purchases while an annual profile is shown in Figure 4.5.

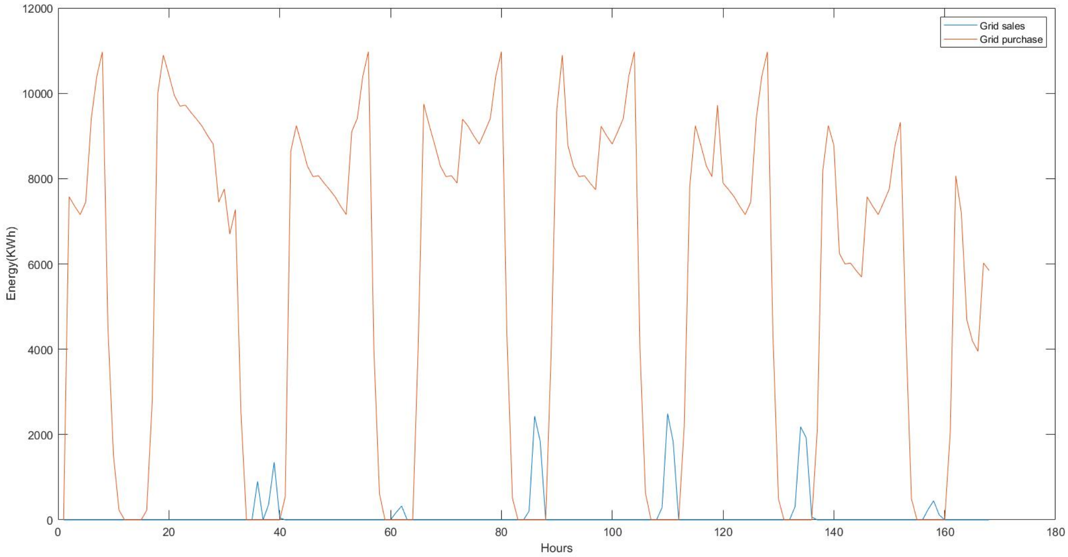

Figure 4.4: Grid sales and Grid purchase comparison

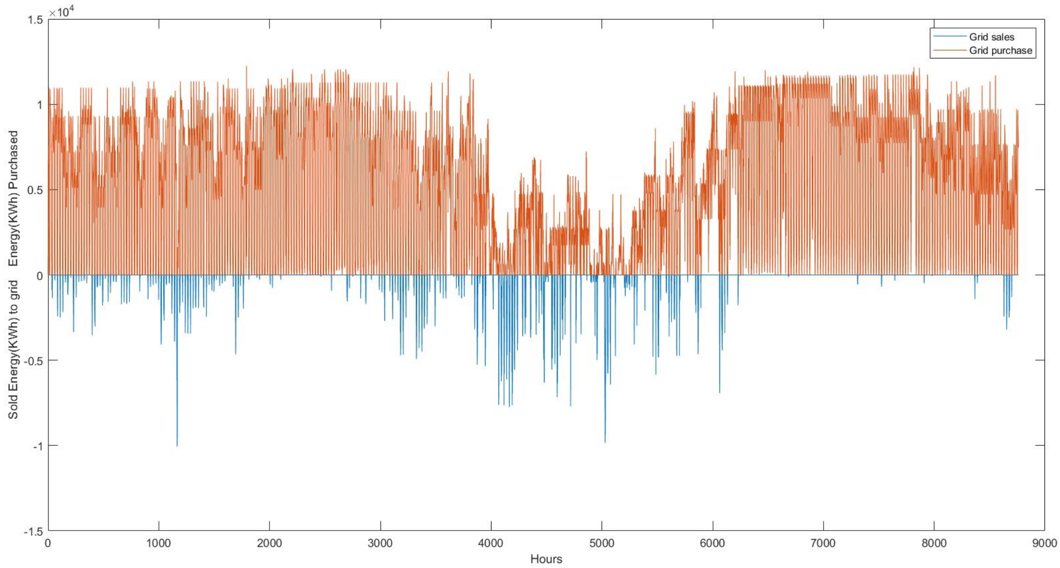

Figure 4.5: Annual Grid Sales & Grid Purchase

4.7.4 Load and Energy generated from Solar, Wind, Bio

Here, the energy generated by each RE i.e Solar, Wind and Bio is represented. All RER are individually trying to fulfil the load demand. Moreover, in some cases, the peak is above the load demand, which represents that surplus energy generated is sold to the grid. The energy interaction is shown in Figure 4.6.

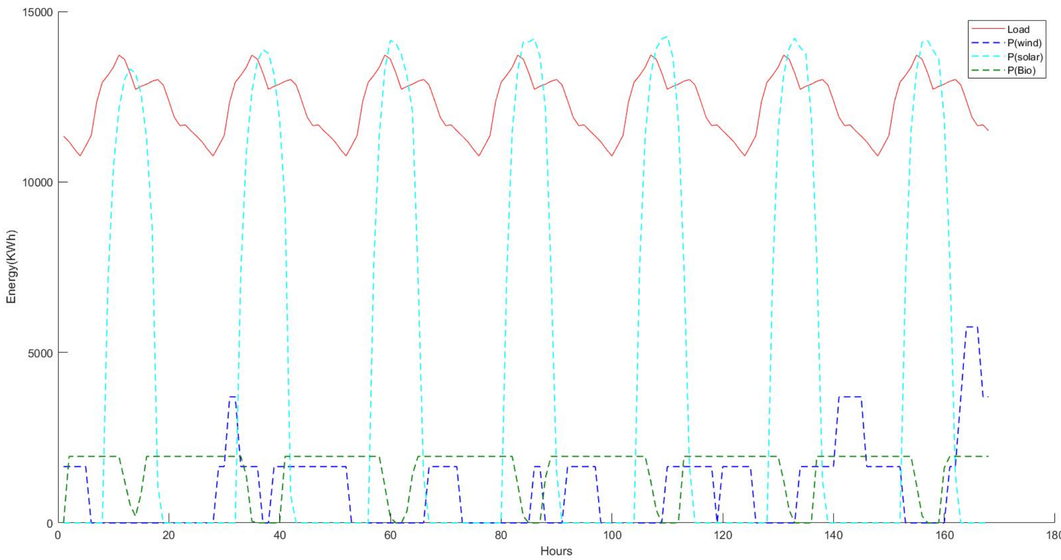

Figure 4.6: Individual Power Generated by RER & Load Demand

4.7.5 Solar Energy Production

The Power generation for Solar PV is calculated as shown in the subsection 3.7.1. The power generation of Solar energy is depended on the Solar Irradiation for that particular location. The data for Solar Irradiation can be obtained from NSRDB NREL website. The total annual energy generated by the Solar PV is 31425 MWh, contributing 28.14% towards the load demand for Billimora. The optimal size for Solar PV power plant obtained from GA is 13.9MW and the Plant Load factor is 0.2575.

The annual power generation from Solar energy for 8760 hours is shown in Figure 4.7.

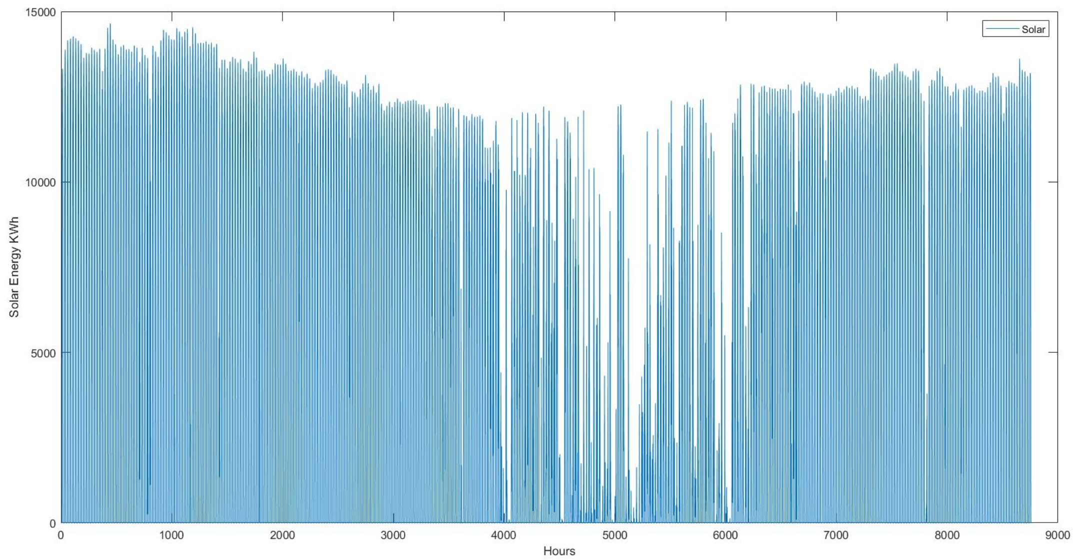

Figure 4.7: Solar Power Generation

4.7.6 Wind Energy Production

The Power generation for Wind Turbine is calculated as shown in the subsection 3.7.2. The power generation of Wind energy is depends on the Wind velocity for that particular location. The data for wind velocity can be obtained from NSRDB NREL website. The total annual energy generated by the Wind turbine is 25000 MWh, contributing 22.4 % towards the load demand for Billimora. The optimal capacity for Wind Turbine obtained from GA is 11.7MW and Plant Load factor (PLF) is 0.2444. The capacity of each selected Wind Turbine is 1MW, thus 12 units of 1MW turbines can be installed for a safe side.

The annual power generation from Wind energy for 8760 hours is shown in Figure 4.8.

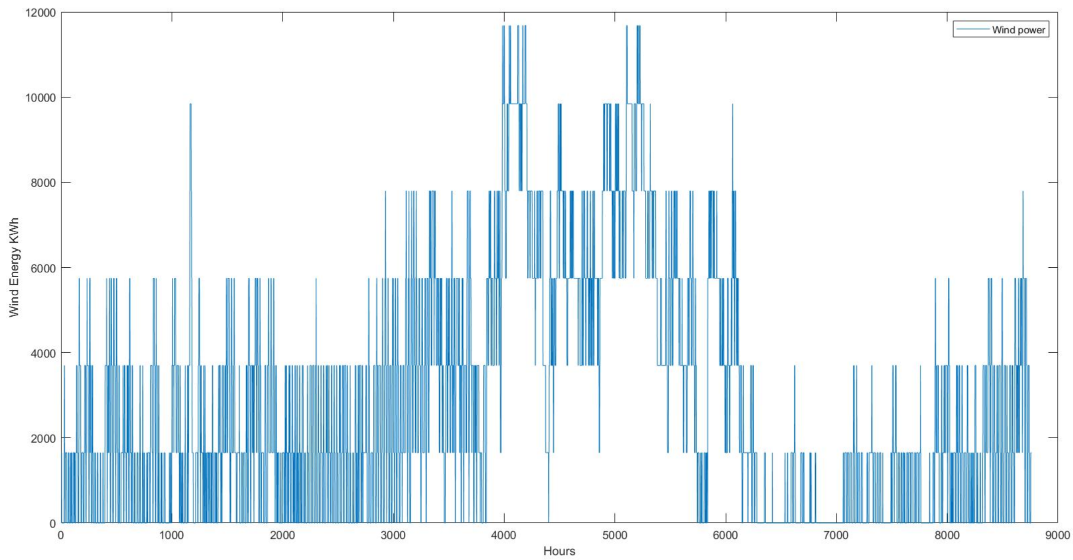

Figure 4.8: Wind Power Generation

4.7.7 Biomass Gasifier Energy Production

The power generation for Biomass gasifier can be calculated as shown in subsection 3.7.3. The maximum power that Biomass Gasifier could generate is 14798 MWh while the optimal size for Biomass Gasifier generation, obtained from GA is 2.1MW. However, the Biomass Gasifier is not always active. It is generating power only when it can't be satisfied solely by Solar + Wind as shown in the operational flow chart in Figure 3.5. The Plant Load factor (PLF) for Biomass gasifier is 0.7751.

The annual power generated by Biomass gasifier for 8760 hours is shown in following Figure 4.9.

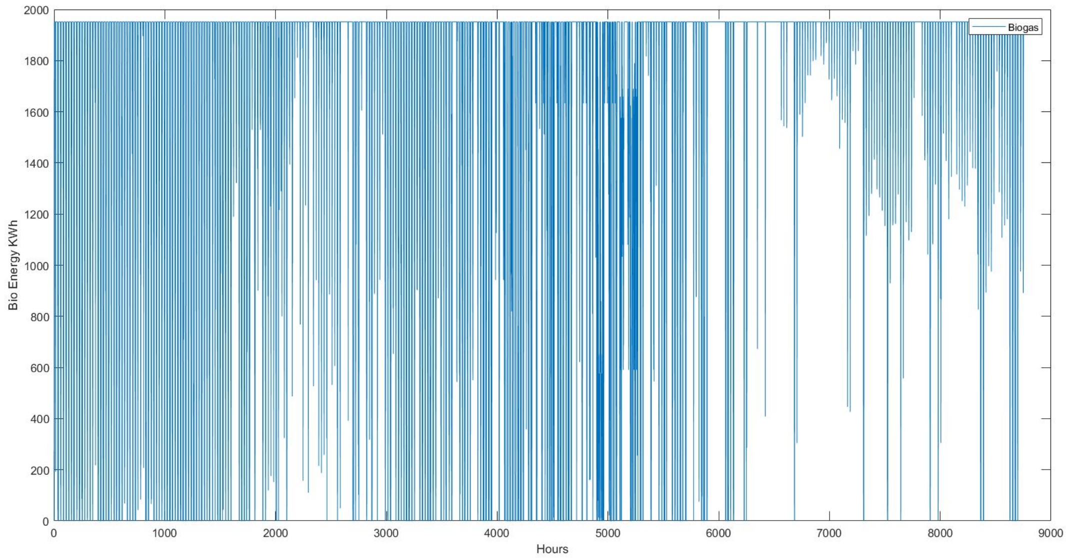

Figure 4.9: Biomass Gasifier Power Generation

4.8 Results Summary

Optimized Objective Function Value	
Levelized Cost of Energy (LCOE)	₹ 6.3802
Human Development Index (HDI)	0.7046

Optimal HRES Configuration	
Capacity of Solar PV (kW)	13930.69
Capacity of Wind Turbine (kW)	11678.76
Capacity of Biomass Gasifier (kW)	2179.38

Annualized Life Cycle Cost	
Solar Cost (INR)	52961000
Wind Cost (INR)	82783000
Biogasifier Cost (INR)	273100000
Inverter Cost (INR)	12676000
Grid Cost (INR)	299110000
Total Annual Cost (INR)	720630000

Annual Energy Interaction	
Total Solar Energy Generated (kWh)	31425000
Total Wind Energy Generated (kWh)	24999000
Total Biogasifier Energy Generated (kWh)	14798000
Grid Purchased (kWh)	43286000
Grid Sales (kWh)	1297800
Total Annual Load (kWh)	111649592

HRES Individual Contribution	
Solar Contribution %	28.1461
Wind Contribution %	22.3906
Biogasifier Contribution %	13.2540
Grid purchase %	38.7695
Grid sales %	1.1624

Plant Load Factor	
Solar PLF	0.2575
Wind PLF	0.2444
Biogasifier PLF	0.7751

Figure 4.10: HRES results summary

Chapter 5

Conclusions and Future Scope

5.1 Conclusions

- The present research project has made an effort to help in providing a brief idea of current trends and the latest research work in direction of multi-objective optimization using evolutionary algorithms for various objectives such as cost, optimal configuration of sizing, design, and various other parameters applied to the field of HRES.
- It was observed that although much research was carried out in optimizing the HRES, not much research had been done on the Biomass gasifier or Hydropower kind of HRES.
- In this study, HRES selected was Solar PV-Wind Turbine-Biomass Gasifier connected to the Grid for Billimora, Gujarat; further Genetic Algorithm search technique was implemented to carry Multi-Objective optimization of HRES to determine the optimal size configuration for individual RERs, Minimize the Levelized Cost of Energy (LCOE) and Maximize Human Development Index (HDI).
- The simulation is designed in such a way that it would firstly recruit the energy generated from Solar and Wind; the deficient energy for Load demand would be met by Bio. In case the load demand is not fulfilled by the renewable energies all combined, it would purchase the deficit from Grid. If the energy generated from HRES is in surplus, it would sell the excess

energy to the grid which can be utilized to run other auxiliaries and also would improve the HDI for the location.

- The optimal size configuration for HRES obtained from the GA optimization is as Solar PV - 13.9 mW, Wind Turbine - 11.7 mW, Biomass Gasifier - 2.1 mW
- The first objective was to Minimize the LCOE whose value returned as 6.3802 ₹/kWh after the Multi-objective GA optimization.
- Moreover, we noticed the individual contribution for fulfilling the load demand which was as Solar - 28.14%, Wind - 22.39% and Biogasifier - 13.25%. As HRES was Grid-connected, the remaining 38.76% of energy was purchase from the grid. Also, the surplus 1298 MWh energy generated was sold to the Grid after fulfilling 111650 MWh of Load Demand.
- The Plant Load factor for Solar, Wind and Bio was 0.2575, 0.2444, and 0.7751 respectively.
- The implementation of another objective was done considering the social aspect, i.e. maximizing the HDI; whose value after optimization returned by GA as 0.7046 which signifies High Human Development Index.
- I hope, this study would answer the research gap that was identified and would help other researchers as well for purpose of designing and optimization of HRES.

5.2 Future scope

We implemented the Genetic Algorithm search technique in order to carry Multi-Objective optimization of HRES; However, there are various other techniques, some automated tools/software which are still in practice. It gives an advanced approach to the same. These advance tools and software such as HOMERpro could be incorporated in future in order to validate the results obtained from Genetic Algorithm.

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