OPTIMIZATION OF INTEGRATED

RENEWABLE ENERGY SYSTEM – MICRO GRID

(IRES-MG)

By

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OPTIMIZATION OF INTEGRATED

RENEWABLE ENERGY SYSTEM – MICRO GRID

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NOMENCLATURE

BG: Biogas powered Generator

CHP: Combined Heat and Power

COE: Cost of Energy

CSP: Concentrating Solar Power System

DG: Distributed Generation

IEEE: Institute of Electrical and Electronics Engineer

HOMER: Hybrid Optimized Model for Electric Renewables

HRES: Hybrid Renewable Energy System

IRES: Integrated Renewable Energy System

IRES-MG: Integrated Renewable Energy System – Micro Grid

LGH: Low Grade Heat

MGH: Medium Grade Heat

NPC: Net Present Cost

O&M: Operation and Maintenance

PV: Photovoltaic

PV: Photovoltaic

WECS: Wind Electric Conversion System

WS: Water Supply

CHAPTER I

INTRODUCTION

I.1 Background

Human beings have always used energy to improve their living conditions. The discovery of fire and use of wind brought revolutionary changes in the ways to utilize energy. The most prevalent ones are biomass for firewood, wind for sailing, insolation for grain drying and falling water for milling purposes. The ability to harvest and convert energy to usable forms continues to be an important activity of human beings. The industrial revolution brought an era of fossil fuels, which are concentrated forms of solar energy that has been stored over millions of years. Industrial revolution, globalization and growth in population have rapidly increased energy consumption. Technological and industrial progress today is heavily dependent on readily available energy, basically fossil fuels. Over a century, human beings have consumed this easily available finite resource very inefficiently. This increasing energy consumption based on fossil reserves has resulted in major depletion of the reserves, climate change, financial instability and political turmoil in the world. Initially generation of electricity from large power plants was encouraged; as it was considered to be efficient than a large numbers of small dispersed power plants. Because of this trend in development along with depletion of fossil fuel reserves and the associated widespread environmental pollution, it has become increasingly urgent to find energy alternatives that are cost effective, sustainable and environment friendly.

Renewable energy sources such as wind, solar, hydro and biomass will play an important role in the future to supply increasing global energy demand and provide energy security. Research and development in renewable energy technologies confirm that renewable energy sources are indeed sustainable and that green technologies can shift global dependence away from fossil fuels. Making the transition to a renewable energy intensive economy would provide environmental and other benefits that cannot be solely measured in standard economic accounts, but in terms of reduced pollution, socioeconomic development, land restoration, abatement of global warming and fuel supply diversity [1]. From socioeconomic and environmental view points, utilization of renewable energy increases supply security, provides local solutions, lowers environmental impacts, offers sustainable energy development and provides job opportunities.

I.2 Current Energy Scenario and Energy Crisis

Energy is one of the basic needs for humans to survive. The sun is the primary source of energy on earth for life to sustain. The uneven heating of the planet by sun generates wind, rain, rivers, waves etc. for sustaining life. These along with organic matter that makes up plant and biomass can be used for heat, electricity and liquid fuels. Although humans have been tapping renewable energy for several thousands of years, only a tiny fraction of the available technical and economic potential of renewable energy sources has been captured and exploited so far.

Increases in population and urbanization in developing countries have led to poor quality of life along with high and wasteful consumption of energy. At present fossil fuel is the dominant source of energy generation. The reasons for this are they are readily available, cheap, and highly concentrated. Government subsidies, financial backups and existence of infrastructure help in continued dependence on these fuels. If all the social and environmental factors were to be considered, the cost of fossil fuels would be double of what it is at present [2]. The ability of fossil fuels to enable fast economic growth in any country has led to increasing dependence on fossil fuels. As seen in Figure I.1, the world still depends heavily on fossil fuels for energy and the trend will continue to be the same in the years to come. Data have suggested that with the ongoing trend, oil will essentially run out in 40 years, natural gas will be depleted in about 60 years and coal reserves will be exhausted in 200 years [3].

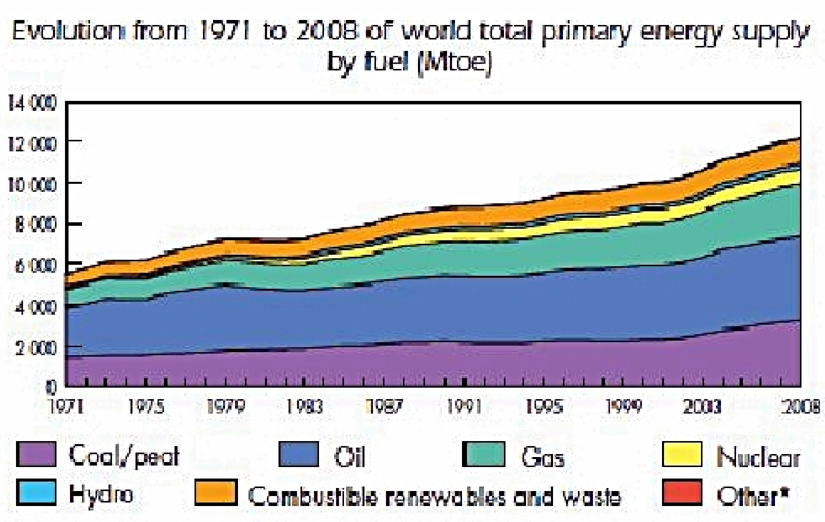


Figure I.1: World total primary energy supply by fuel [4]

Recent catastrophic events, such as BP oil leak have caused significant environmental damage which will take years to restore, along with losses of regional economies. With climate change and excessive use of fossil fuels, which have given rise to various catastrophes and downgraded environment, it is time to decide that the insatiable demand for fossil fuels is costing more than humans can afford [5]. Alternatives must be developed as these fossil fuels progressively become scarce and expensive over time. Therefore, there is an imminent need to pave a way to use renewable energy sources to live sustainably in the years to come. Every energy user can be empowered in a new energy economy based on renewable energy sources to become energy producer by conserving energy, reducing carbon footprints and installing distributed renewable energy systems.

Renewable energy is playing a significant role in mitigating climate change and carbon footprint in supplying energy needs. Recent developments and growth of solar, wind and biomass energy industries have shown that there has been a significant increase of renewable energy use in the energy sector. According to Global Wind Energy Council, there has been an increase of 24.1% in global wind installations in 2010, mostly in developing countries [6]. Just like the growth of wind energy, photovoltaic (PV) has an annual growth rate of 40% [7]. Similar are the cases for biomass, hydro and geothermal energy. Growth of these renewable technologies may be a result of decreased cost of energy generated and improvement in materials and technologies to harness these resources. Renewable energy can reduce the pressure on fossil fuels and can play an important role in realizing a sustainable world.

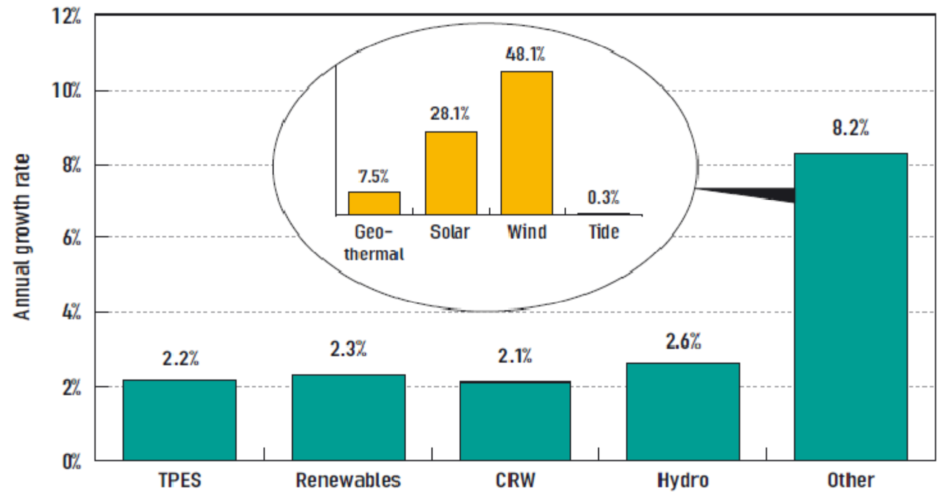


Figure I.2: Annual growth of renewable supply from 1971 to 2004 [6]

I.3 Renewable Energy in Rural Sector

The vast majority of global population lives in the developing world. And more than one third of developing nations comprise of rural areas with no access to commercial forms of energy. The main sources of income in developing countries are agriculture and tourism. Especially in rural areas people heavily depend on agriculture for all purposes and hence use traditional biomass such as firewood, charcoal, agricultural residues and animal dung for cooking and heating purposes. Poverty and illiteracy are the major problems in such areas. Poverty eradication, risk avoidance, environmental protection and sustainable economic growth are keys to transform the developing world energy scenario. Improvements in standard of living are linked to the availability of commercial energy, which facilitates economic development through job creation and transportation of products to the market, along with education and provision of health services.

At present, most of the rural sectors are in darkness and rely on traditional firewood and animal waste for their energy needs. This is primarily because these rural areas have very small loads and are isolated and far from the central grid, which makes it very expensive for the government to provide electricity. Providing electricity from the central grid would be inefficient and inconvenient as it would require adequate central generating capacity, high capital cost and would result in energy losses in long transmission and distribution lines. Hence, people in such areas continue to burn traditional fuels to fulfill their energy needs, which results in deforestation, air pollution and deterioration of their health.

Developing countries have slow moving economies that depend on agriculture. In order to speed up the economy of the country and improve the quality of life, they tend to follow similar pattern of lifestyles as of developed countries. Not only they follow the lifestyles, they follow similar pattern for energy consumption as well. This results in devastating impacts on the economy of country, as the country may not be producing enough generation to match the demand of people. Instead of blindly following, developing nations must learn from the experiences and mistakes made by industrialized nations which can offer a unique opportunity to select a sustainable energy route and develop the economy [8].

In an attempt to deal with energy problems, recent advances in renewable energy technology and techniques to harness renewable energy efficiently and economically have had a significant impact on developing nations. Unlike fossil fuels, renewable energy sources are fairly evenly distributed around the world. Even though renewable resources are site specific, have seasonal and diurnal variations and are highly stochastic in nature, they are eco-friendly, inexhaustible and pollution free. Harnessing locally available renewable energy resources to supply energy to rural areas is one of the potential solutions.

Many studies and papers have been published on the methods to supply electricity to rural sectors. Energy can be supplied by a single source or by a combination of sources such as hydroelectric power, intermittent renewable power sources (wind, solar-thermal electric and photovoltaic power), biomass power and geothermal power. Many have suggested hybrid renewable energy systems (HRES), with diesel generator as a backup power. In HRES, all the available energy sources are converted to one final form of energy, electricity that supplies the customer loads. Ramakumar [9-11] first proposed an integrated approach for harnessing available renewable energy sources to “energize” remote areas. Integrated Renewable Energy System (IRES) utilizes available renewable sources and supplies energy in various forms as per the need. This makes the system economical and efficient from the view point of end user.

At present, even in the most remote areas, renewable energy is playing an important role in providing access to basic energy services, including lighting and communication, cooking, heating and cooling, water pumping and generating economic growth. PV household systems, wind turbines, micro-hydro power, biomass based system, and other renewable energy technologies are being employed in homes, schools, hospitals, agriculture and small industries in these remote areas. This will have beneficial impact if the barriers to accessing information and financing products are addressed. It has been estimated that over 44 million households in the world use biogas made in household bio-digesters for lighting and cooking purposes, while 166 million households rely on improved biogas cooking stoves [12].

I.4 Electrification and Energization

Renewable energy sources are abundant and well distributed around the world. Insolation, wind, biomass and hydro have proved to be the most useful renewable energy sources and these resources are being harnessed in a number of ways world-wide. Solar energy can be used to generate electricity through PV panels or for heating purposes directly or by employing solar thermal system. Along with it, solar energy can be used for cooking, pumping water, refrigeration and desalination of water. The same is true for all the renewable energy sources. They can be harnessed to produce electric energy or any other forms of energy such as low-grade thermal, medium-grade thermal etc.

Currently all of the power plants, either based on fossil fuels or renewable sources, convert all the available energy forms to electricity to supply loads. The end product, electricity, can then be used to provide energy for any of the needs such as heating, cooling, pumping water etc. This is mostly suitable for urban and industrial sectors where electricity is the only form required to supply any kind of need. However, the case is quite different in rural areas, where electrical loads are few as compared to other loads. Electrification of a rural society is not the efficient and economical way to achieve a sustainable society.

As mentioned earlier, in remote areas electrical load is very small as compared to other energy needs such as cooking, heating etc. Hence, rural electrification is not the ideal solution in these areas. Providing energy needs in various forms to match the needs allows the end users to benefit from such system. For instance, medium grade heat required for cooking can be satisfied by biogas obtained from biomass. Water can be pumped and stored in an overhead tank through solar and wind powered water pumps. Low grade heat required for crop processing and industrial heat can be satisfied by biomass and solar collectors. These needs can be satisfied via electricity, but it would be inefficient and expensive because of the number of components required for energy conversions. Direct use of the resources lowers the overall energy cost, initial investment and makes the system effective and efficient. Energization involves harnessing all possible available renewable resources in a way such that several forms of energy of different quality and characteristics provide a variety of energy. The key to implementing such system is to match energy needs with resources to maximize end-use efficiency [11].

I.5 Objective of the Study

Ever growing demands of increasing world population has challenged the scientific and technical communities to supply quality energy in a sustainable manner. Dependence on fossil fuels has resulted in the depletion of the reserves and has a significant impact on global environment. The need to live a sustainable life has led to the use of renewable energy sources. This study is focused on the concept of IRES, which utilizes the locally available renewable energy sources to supply various forms of energy in an economical way. Using the IRES in conjunction with the micro grid concept, it is possible to create a self-sufficient sustainable rural community in cost effective and efficient way, without the need of central grid. Implementation of Integrated Renewable Energy System – Micro Grid (IRES-MG) in a rural area is proposed. The system is studied with cost optimization and then efficiency optimization to evaluate the suitability of the proposed system.

I.6 Organization of thesis

A brief outline of all the chapters that follow is presented next.

Chapter II: Review of Literature

A review of the literature work close to this research is presented. Also it discusses the various renewable energy sources and technologies with their current status and potential. Technologies to harness these renewable sources are outlined along with a brief description of micro grid and optimization procedure.

Chapter III: Integrated Renewable Energy System – Micro Grid (IRES-MG)

This chapter introduces the concept of integrated renewable energy system – micro grid (IRES-MG) in detail. It discusses the features and components of IRES-MG, resources and energy needs in rural sector scenario.

Chapter IV: Optimization of IRES-MG

Cost and efficiency optimization of IRES-MG in rural scenario are presented. Simulation results obtained using HOMER and MATLAB are presented and discussed.

Chapter V: Summary and Concluding Remarks

This chapter summarizes the work discussed in this thesis and outlines the scope and areas for further work.

CHAPTER II

REVIEW OF LITERATURE

II.1 Renewable Energy Sources

Renewable energy sources are energy sources that are renewed periodically by natural processes and are therefore inexhaustible. Hydro, insolation, wind, biomass and wave energies are some examples of renewable energy sources. Wind power has been long used for sailing, grinding grains and running machinery, insolation for grain drying, geothermal for bathing and other heating purposes etc. [13]. These renewable energy sources are clean and green sources of energy and have minimal environmental impacts. Unlike fossil fuels, renewable resources are fairly evenly distributed all over the world and are available at no cost. Table II.1 shows annual energy use in the US and the World. It can be deduced that, the world still depends largely on fossil fuel for energy. Only a small fraction, about 12% of the world's primary energy is provided by renewable energy sources [13]. Ever increasing energy needs and depleting fossil fuel reserves have led to increasing use of renewable energy sources to satisfy energy demands.

Sources	US (Quads)	World (Quads)
Petroleum	40.1	168.0
Natural Gas	23.0	103.0
Coal	22.3	115.0
Nuclear	8.2	28.0
Biomass	3.0	30.0
Hydro power	3.4	27.0
Geothermal and Wind power	0.4	0.8
Bio-fuels	0.5	0.9
Total	100.9	472.7

Table II.1: Energy use in U.S. and World in 2007 (1 quad = 10^{15}Btu) [14]

Globally, 1.4 billion people live without electricity and many people around the world face recurrent power outages. Growth of electricity demand, together with concerns related to climate change and suitability of other technologies has stirred interest in renewable energy technologies. Efficient use of diverse renewable energy sources can pave a path for sustainable development. Therefore, careful design and planning for utilizing renewable energy sources is required for sustainable development of a society. Renewable energy sources are capable of addressing global problems of energy security, climate change and sustainable development, so there is a pressing need to accelerate the development of renewable energy technologies. A brief description of various renewable energy sources along with their current status are presented next.

II.1.1 Solar Energy

Direct solar energy is considered to be practically unlimited. If all the energy received from the sun could be converted to usable form in the earth, it would be able to supply more than the world's current energy demand many times over. However, this is not possible because of cloud cover, rotation of the earth and amount of energy intercepted by the earth. It has been estimated that the desert area of southwestern United States could theoretically meet the electricity demand of the entire country with 10% conversion efficiency (Sandia National Laboratories 2001) [15].

Solar energy can be used directly to heat or light buildings and provide domestic hot water. It can also be used in concentrated form for cooking purposes, pumping water, desalinate water and refrigerate foods and medicines. Apart from the direct use of solar energy, it can be converted to usable forms through a variety of technologies; basically photovoltaic and thermal. Solar thermal technologies first convert solar energy to heat which can be used directly or stored in a medium, or converted to mechanical or electrical energy by an appropriate device. Photovoltaic devices directly absorb incident photons and convert the photon energy to either electricity or store it as chemical energy.

Concentrating solar power systems (CSP) utilize mirrors to concentrate the solar radiation, so that it can be captured in the form of heat. This heat is then converted to electricity by a conventional thermal power plant or drive chemical processes. It is an advanced and proven technology suitable for combined heat and power (CHP) generation. CSP technology encompasses three approaches; trough, power tower and dish. Photovoltaic (PV) technology is growing rapidly worldwide (as shown in Figure

II.1). This growth is because of existing supporting policies, significant cost reductions and material improvements. PV is commercially available and is a reliable technology with a potential for a long term growth in all regions of the world. And at the end of 2010, the total global installed PV capacity was 40GW.

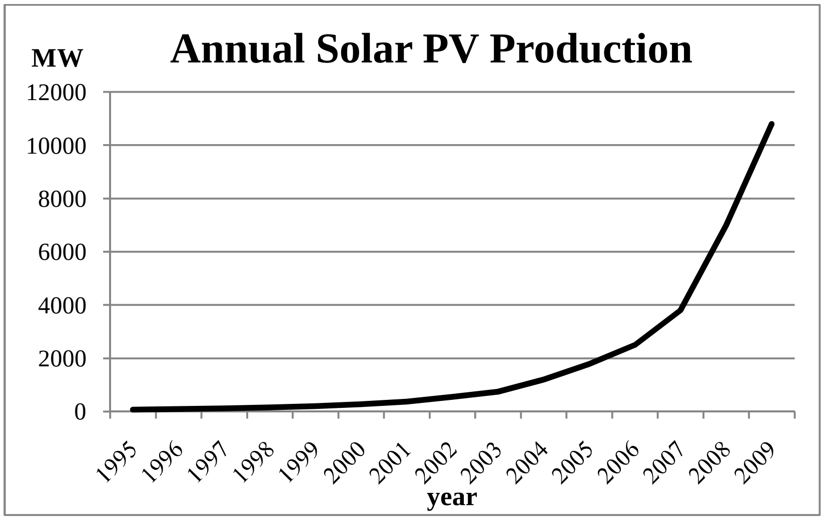


Figure II.1: World annual solar PV production [16]

II.1.2 Wind Energy

Extraction of energy from wind can be dated back to as early as 200 BC. Oil supply crisis of 1973 created a widespread interest in wind energy [13]. Due to lagging interest and drop in oil price, installation of wind turbines declined. Recent oil crisis, developments in wind technology and efforts to mitigate greenhouse gas emissions from fossil-fueled power plants have revived interest in wind power. Wind power is derived from solar energy due to uneven distribution of temperatures in different areas of the earth. The resulting movement of air mass is the source of mechanical energy that drives wind turbines for electricity generation, water pumping, milling, grinding grains and other uses.

Since energy in wind increases as the cube of wind speed, even a small wind speed difference plays a big role in determining the power generated from wind. The footprint of wind energy technology is minimal and the land around wind towers can be used for agriculture, providing locals an opportunity to increase their income. Advancements in wind turbine technologies have led to improvements in rotor blade efficiency, energy conversion techniques and reliability. At present, the cost of wind-generated electricity is competitive with coal-fired power plants and is continuing to decrease [17]. Current developments have made the goal of supplying 12% of world's electricity demand from wind by 2020 within reach [6]. Figure II.2 shows the growth of globally installed wind capacity. At present total global wind generation capacity is 198GW with annual growth rate of 27%. Wind technology is attractive to developed countries because of its excellent environmental credentials and to developing nations because of its suitability for indigenous production and operation and avoidance cost of long distance transmission costs.

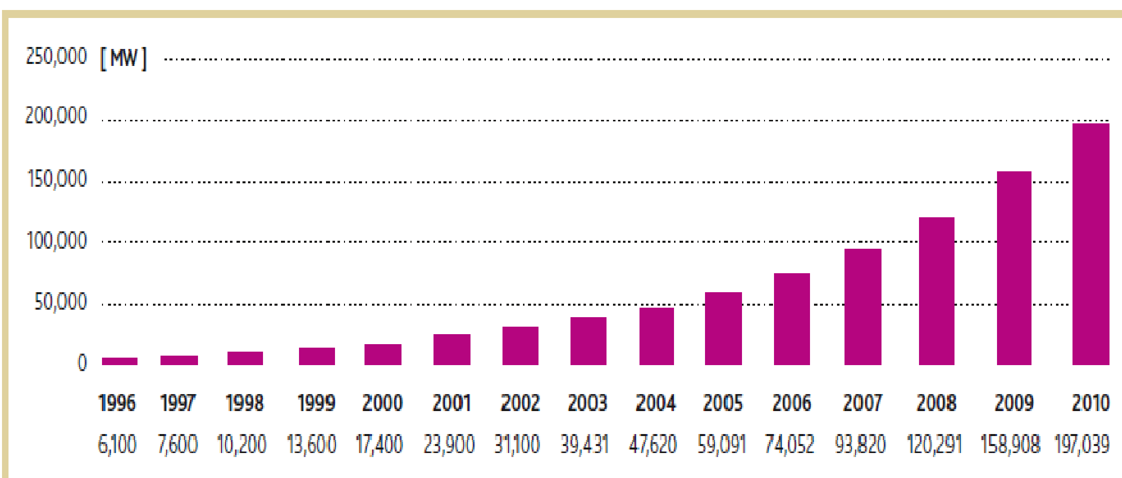


Figure II.2: Global cumulative installed wind capacity [6]

II.1.3 Hydro Power

Hydropower is a mature technology. It is a renewable energy resource resulting from stored potential energy in water that flows from higher to a lower elevation due to earth's gravitational field. In most installations, hydro energy is converted to electricity by water flowing through turbines that rotate shafts which, in turn, drive electric generators. Technology to perform this conversion is mature and efficient. For several centuries hydropower had been used to produce mechanical power, used for grain milling, textile processing and other industrial operations.

At present, hydropower plant technology on a small scale (mini and micro hydro) has gained popularity as it is associated with the fact that majority of rural areas have rivers and small water heads that can be used to power remote areas. Hydroelectric technology is proven, mature, and highly reliable and has low operation and maintenance (O&M) cost although it requires high initial investment. Its design life is more than a century, which is very high as compared to other electric power generation technologies. At the end of 2010, global installed hydropower capacity was 1010GW with an average growth rate of 3% per year [12]. It provides around 20% of world's total electricity and accounts for 88% of electricity from renewable energy [18]. Hydropower can perform frequent start-ups and shut downs and has the ability to quickly respond to changing load demands.

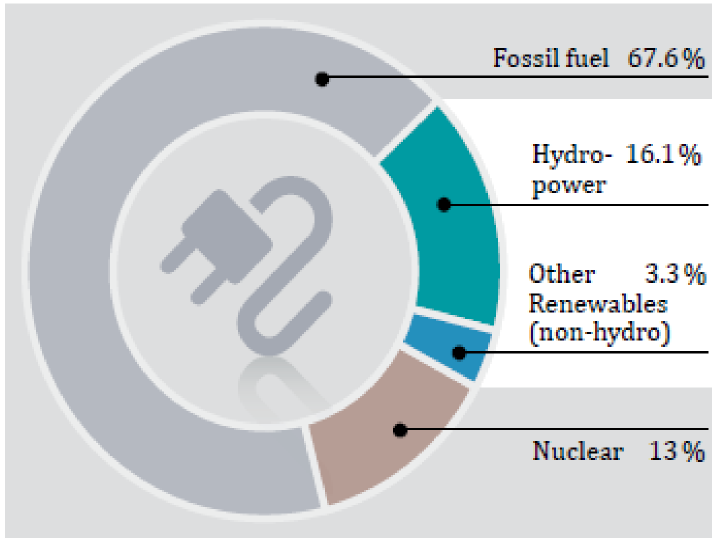


Figure II.3: Renewable energy share of global electricity production in 2010 [12]

Hydropower is playing a major role in power system management allowing planners to balance and regulate services by meeting peak load demands and helping in integrating variable renewable generation in energy mix. Several types of hydropower plants are in operation today. The three basic types are

- Run-of-river hydroelectric plants: They are built along a river or stream without lake formation for water intake. The river course is not altered and the minimum flow will be the same or higher than that of the turbine power output.
- Reservoir hydroelectric plants: They are developed with an accumulation reservoir. It has higher generation potential than run-of-river type plants and are very cost intensive.
- Pumped storage hydroelectric plants: This type of plants store energy for use in peak demand periods by pumping water from lower reservoir to upper reservoir during off-peak periods.

Many rural areas have the capability to build a mini or micro hydro plant with an overhead reservoir as needed and such plants are enough to supply the demand of the entire rural area. Hydroelectric plants also help countries to mitigate greenhouse gas emissions.

II.1.4 Biomass Energy

Biomass energy or bio-energy is the energy obtained from organic matter or organic wastes derived from plants, humans, animals and marine life. Trees, grasses, animal dung, sewage, agricultural wastes, garbage, wood chips and municipal wastes are all examples of biomass. In the past, biomass was the primary source of energy until the industrial revolution. Organic components from municipal and industrial waste, plants, agriculture and forest residues, home waste and landfills can be used very efficiently and they have the potential to reduce greenhouse gas emission worldwide. Energy crops such as fast-growing trees and grasses are called biomass feedstock. Use of biomass feedstock can help increase profits for the agricultural industry.

A major part of the developing world depends on freely collected traditional biomass in the form of firewood, forest residue, household waste and animal dung. But it is being used unsustainably with higher consumption than replacement. Most of the rural areas use biomass in large quantities for heating and cooking purposes. The attractiveness of biomass energy lies in its availability, simplicity, familiarity and low cost. The main processes for utilizing biomass sources include direct combustion, gasification, biological conversion (anaerobic fermentation) and chemical or biochemical conversion. About 5TW of human usage is associated with traditional burning of wood [17]. Most of the biomass is in the form of woody forest materials and plants. Table II.2 shows the biomass energy potential and current use in different regions of the world in the year 2004.

Biomass potential	N. America	Latin America	Asia	Africa	Europe	Middle East	Russia	World
Woody Biomass (EJ/yr)	12.8	5.9	7.7	5.4	4	0.4	5.4	41.6
Energy Crops (EJ/yr)	4.1	12.1	1.1	13.9	2.6	0	3.6	37.4
Straw (EJ/yr)	2.2	1.7	9.9	0.9	1.6	0.2	0.7	17.2
Other (EJ/yr)	0.8	1.8	2.9	1.2	0.7	0.1	0.3	7.6
Sum (EJ/yr)	19.9	21.6	21.4	21.4	8.9	0.7	10	103.8
Use (EJ/yr)	3.1	2.6	23.2	8.3	2	0	0.5	39.7

Table II.2: Biomass energy potential and current use in different regions 2004 [20]

At present, biomass resource potential is significantly higher than its use and this potential can be further utilized in the production of heat, electricity and fuels for electricity generation and transport. Biomass can be utilized to produce bioethanol, biodiesel for transportation or biogas for cooking and lighting. Several CHP generation plants with biogas and industrial waste have been implemented in various countries. Biomass energy has the potential to make a significant contribution to carbon-constrained energy future and to meet the future energy demand in a sustainable way.

When biomass undergoes anaerobic fermentation in bio-digesters, biogas is produced. Biogas contains about 50% by volume of methane and the rest carbon dioxide and has heating value of 5000 to 6000 kcal/m^3. The by-product of biogas production can be used as a natural fertilizer. As mentioned earlier, over 44 million households worldwide use biogas for cooking and lighting purposes [12].

II.1.5 Energy Storage

Electrical energy storage has been considered a critical technology in order to have a viable energy system. Energy storage systems play an important role of unifying, distributing and increasing the capabilities of alternative and renewable energy distributed generating systems. An average central generation system is large enough not to be affected by residential and commercial load changes. But distributed generation (DG) is exposed to fluctuations of individual loads. Energy storage permits decoupling of energy supply and demand profiles which is desirable for both economic and technical reasons. Energy storage systems capable of smoothing out load fluctuations, making up for diurnal and seasonal variation in renewable energy sources and reacting to fast transient power quality needs contribute to efficient energy management of power systems [5].

As renewable energy resources are stochastic in nature, it is imperative that appropriate storage and reconversion systems be employed. Energy storage technologies are classified according to the energy, time and transient response required for their operation. It may be designed for rapid damping of peak surges, to counter momentary power disturbances, to provide a few seconds of ride-through while the back-up generators start in response to a power failure or to store energy for future demand. Storage batteries are widely used as energy backup. Nickel metal hydride, lead acid, Lithium ion and Sodium Sulphur (NaS) batteries are economical and are gaining popularity. Pumped hydro, compressed air, fuel tanks, flywheels, water dams, ultra capacitors, biofuels, superconducting magnetic energy storage (SMES), thermal storage and other technologies are some of the options for energy storage. Figure II.4 illustrates mature and emerging energy storage technologies.

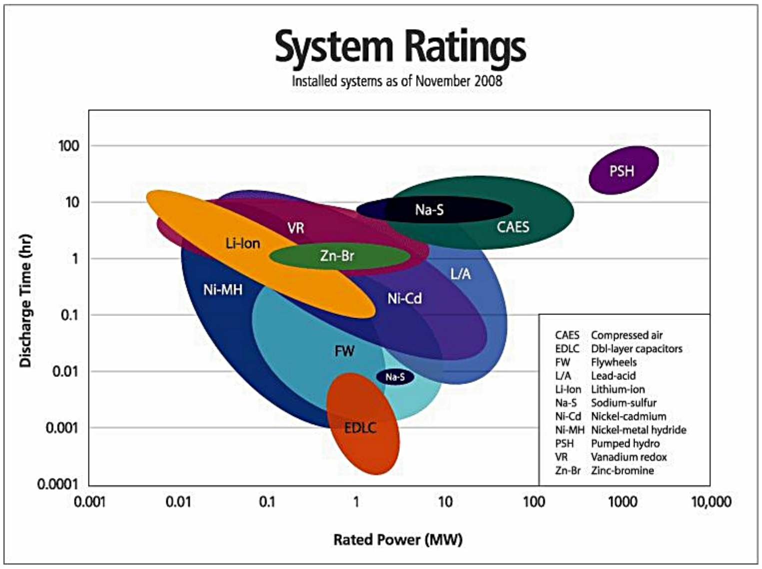


Figure II.4: Energy storage ratings and discharge time [21]

II.2 Approaches to Harness Renewable Energy Sources

Various technologies and techniques can be used to harness available renewable energy sources. Two approaches, hybrid and integrated, are discussed below.

II.2.1 Hybrid Renewable Energy System (HRES)

Hybrid renewable energy system (HRES) combines two or more energy resources and these resources are converted to one form of energy, typically electrical (DC or AC) for aggregation and distribution to customers [22]. A few examples of HRES are PV/wind electric system, wind/diesel generator system, wind/PV/fuel cell hybrid system, biomass/wind/fuel cell system etc. Most of the hybrid systems use diesel generator as a backup generator. A typical hybrid system consisting of wind turbines, hydro turbine, diesel generator with battery backup is shown in Figure II.5 [23]. Hybrid power systems can offer solutions and value to customers that individual technologies cannot match. Low end-use efficiency and high capital cost of HRES make it unsuitable for implementation in rural areas.

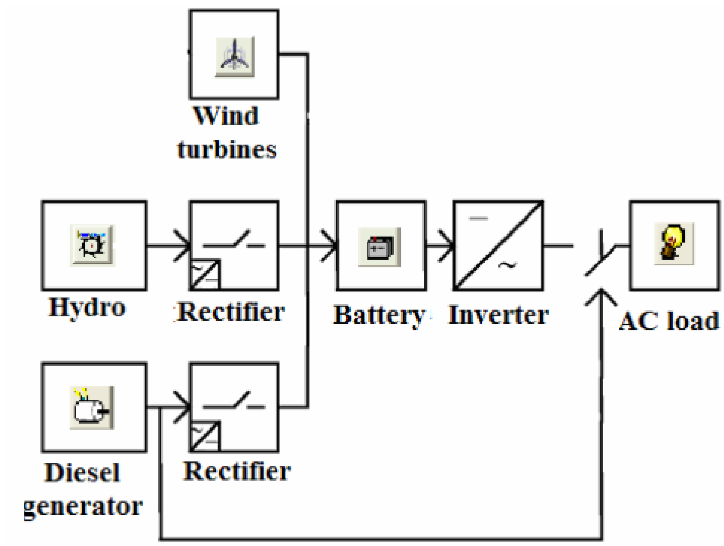


Figure II.5: Block diagram of Hybrid Renewable Energy System

II.2.2 Integrated Renewable Energy System (IRES)

Integrated renewable energy system (IRES) is based on the fact that different types of energy needs require different forms and quality of energy. It utilizes locally available renewable energy resources and end use technologies to satisfy a variety of needs. These needs include domestic and community lighting, communication and educational devices, cold storage, cooking, domestic and potable water supply, low grade thermal energy, irrigation water, and small-scale industries [24]. This approach requires a careful and strategic planning for matching needs and available resources to maximize benefits and end use efficiencies. IRES has the potential to aggregate benefits resulting from the combination of renewable energy, energy efficiency and energy conservation. Figure II.6

shows one possible schematic representation of IRES employing multiple resources and needs at a particular site.

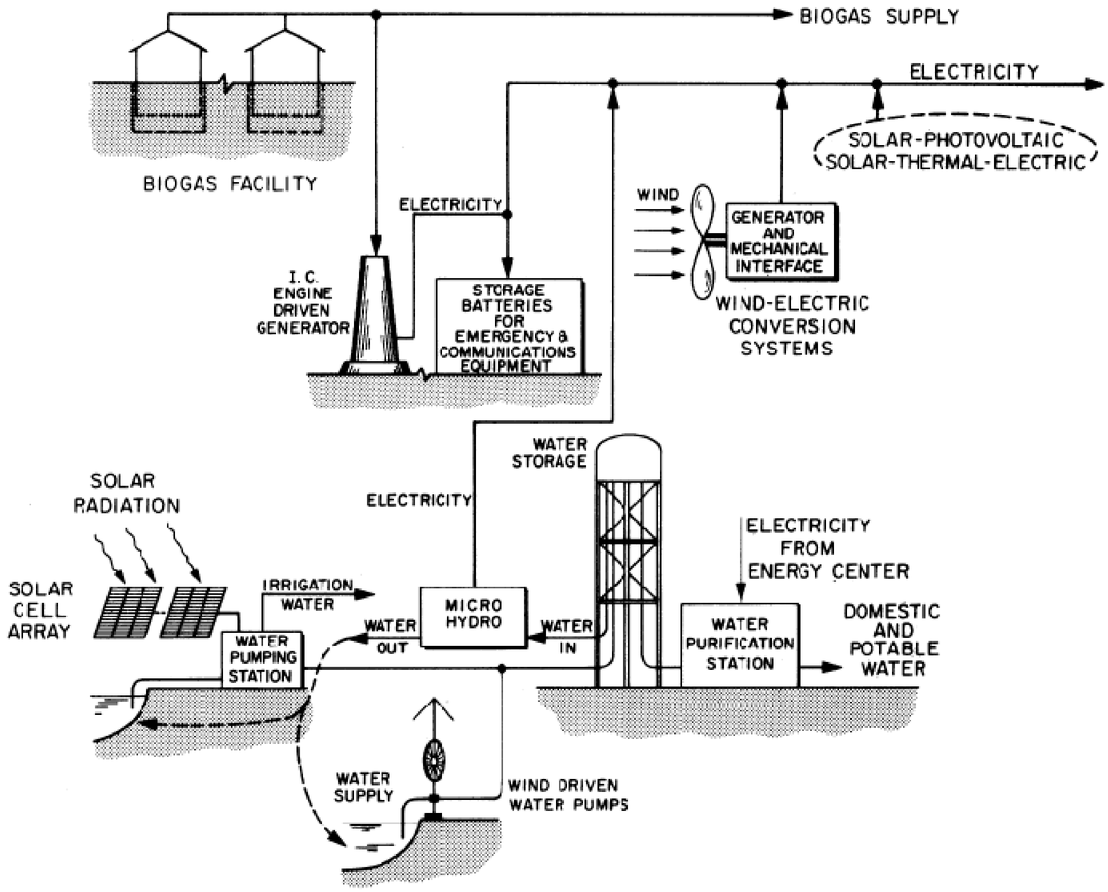


Figure II.6: Schematic of a possible IRES combination [25]

II.3 Micro Grid

Micro grid is a localized grouping of electricity generation, energy storage and load that may operate in standalone or grid-connected mode. Micro grid encompasses a wide range of technologies such as gas turbines, photovoltaics, fuel cell, wind power, micro turbines, energy storage and reconversion systems and internal combustion engines. These technologies have lower emissions and lower cost negating traditional economies of scale. From the point of view of grid operator, micro grid can be controlled as if it was a single entity and allows local control of the system. In the case of disturbances, micro grid can be separated from the central distribution system without affecting the transmission system. Smaller size of emerging generation technologies allow generators to be placed near the load, reducing line losses and allowing use of waste heat [26].

The micro grid structure assumes an aggregation of load and sources operating as a single entity providing both electricity and heat (Figure II.7). The sources must be integrated using power electronics to provide the required flexibility to insure controlled operation as a single entity. Micro grid increases local reliability and security. It can also be connected to the central grid but has to meet interface requirements as put forward by the IEEE P1547 standard.

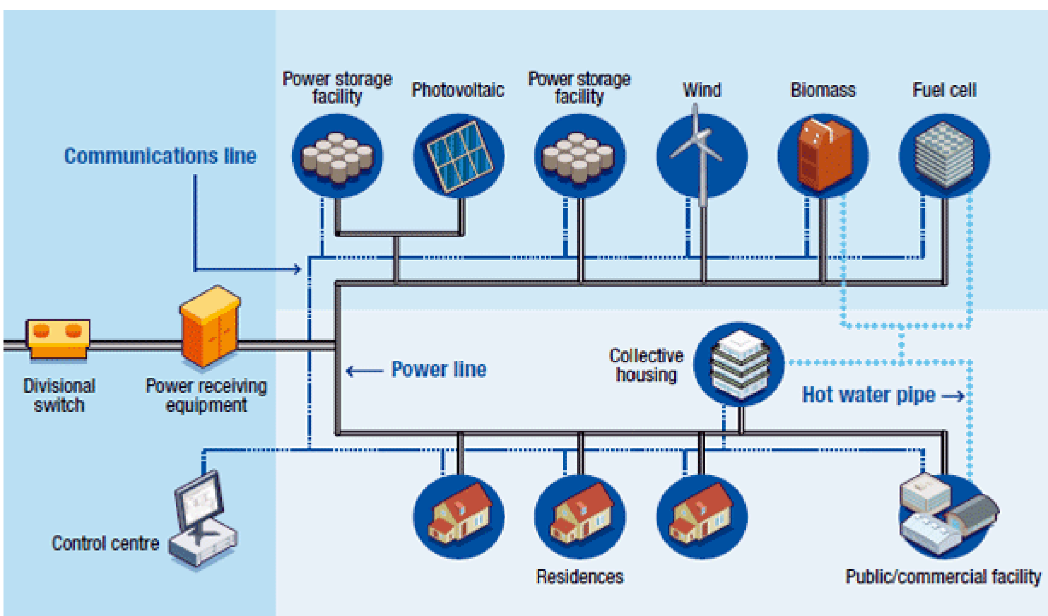


Figure II.7: A basic micro grid architecture [27]

II.4 Optimization of System

The basic function of a power system is to supply its customers with quality electrical energy reliably and economically. Power system must be sustainable, secure and environmentally safe. As such, optimization plays an important role. This enables to minimize the cost of operation, initial investment and environmental impacts and maximize reliability, quality and efficiency. Nowadays, optimization of power system enables to take into account different types of constraints and to consider all probabilistic, deterministic, uncertain and fuzzy information as well. Straightforward application of computational tools for analysis may not yield recommendations as to how the construction of any system should be modified in order to improve its performance. Therefore, solving specific optimization problem may be required for better results. The objective of optimization task is to minimize the maximum value of risk caused by the uncertainty of information [28].

II.4.1 Cost Optimization

Any system, standalone or grid-connected should be appropriately designed in terms of economic, reliability and environmental measures subject to physical and operational constraints. In the case of cost optimization, design of a system is usually done by searching the configuration and control that renders lowest total cost over the useful life of the system.

The cost objective function is the total net present cost (NPC) of a system, which includes the cost of initial investment and discounted present values of all future costs over the lifetime of the system. The cost of the system to be taken into account is the sum of the cost of all individual components such as cost of PV, wind turbine, battery, hydro, fuel cell and converter, etc. along with the installation cost. Cost of each of the individual components comprises of capital cost or initial cost, replacement cost, operations and maintenance cost and cost of fuel consumed. Some of the costs depend on control strategy selected amongst the possible strategies.

II.4.2 Efficiency Optimization

When a system design is proposed, it is usually done with the optimization problem where either, the cost and carbon dioxide emission are minimized or reliability, quality and efficiency is maximized. In the case of efficiency optimization, the overall efficiency of the system is maximized. Efficiency optimization of a system results in a maximum efficiency for a particular combination of the system components and individual component efficiency.

II.5 Current Status of Renewable Energy in Rural Sector

Currently, PV, solar collectors, solar home lighting systems, solar water heaters, wind energy conversion systems, micro hydro and biogas digesters are the various components that serve basic necessities such as lighting, communication, potable and domestic water, and education, etc. in rural areas. With enlightened government policies and developments in renewable energy technologies, millions of people in the rural sector have access to electricity and are benefitting from the installation of such systems.

As mentioned earlier, nearly one third of the world's population has no access to clean commercial energy. Utilizing locally available renewable energy resources in remote areas has made it possible to energize such areas. Currently, over 50 million households are served by small scale hydro power plants, around 10 million households are lighted by biogas and almost 1.1 million households use solar home systems or solar lanterns. Community scale wind power is serving more than 200,000 households [29]. Similarly, wind and PV powered water pumps have been serving millions of people for irrigation as well as providing water for domestic purposes. With the advancement in biogas technology, people have started using improved cooking stoves or efficient biogas stoves, for cooking and heating purposes which are more efficient and safe as compared to the use of traditional biomass for the same purpose.

The local as well as national governments of developing nations are playing a significant role in providing sustainable energy to remote areas, through various programs, projects and subsidies. United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) has undertaken a number of activities to assist green growth in Asia and Pacific regions. Grameen Shakti in Bangladesh has reported the installation of about 100,000 solar home systems, while Vietnamese government has successfully installed more than 2500 micro hydro plants to serve 200,000 households [28]. These types of projects are funded by the UN, World Bank or other international agencies to help the people in rural sector of under developed and developing nations. Such projects are a huge success and many countries such as Nepal, India, Bangladesh and some African countries, have also participated in such programs.

The current projects and programs are focused on one-resource or hybrid energy system with electricity as the end product. In order to fully achieve the potential of renewable energy sources, the concept of “energization”, “integration” and “resource-need matching” must be brought into the picture. IRES-MG has amalgamated all these concepts in the system architecture to energize a community, rural or urban, in an effective manner.

CHAPTER III

INTEGRATED RENEWABLE ENERGY SYSTEM – MICRO GRID (IRES-MG)

III.1 Introduction

The objective of IRES-MG is to supply the basic needs of people in rural sector in an economical and efficient way by utilizing two or more locally available renewable energy resources and end-use technologies. Available energy resources must be matched with the needs to provide energy in different forms efficiently.

IRES-MG is suitable in rural areas because of its low cost and its ability to provide different forms of energy as required by end users. This system is typically operated in stand-alone mode and if grid extension is possible, it can be operated with the utility grid. The key to supplying different forms of energy is ‘a-priori’ matching of available resources and needs. Matching resources, needs, energy conversion devices, energy storage and utilization technologies help to maximize end use efficiencies and benefits for end users.

IRES-MG can supply both DC and AC loads, making the system efficient and cost effective by avoiding the use of multiple converters. It can be operated as DC, AC or hybrid micro grid depending on types of loads. Figure III.1 shows a possible schematic of IRES-MG.

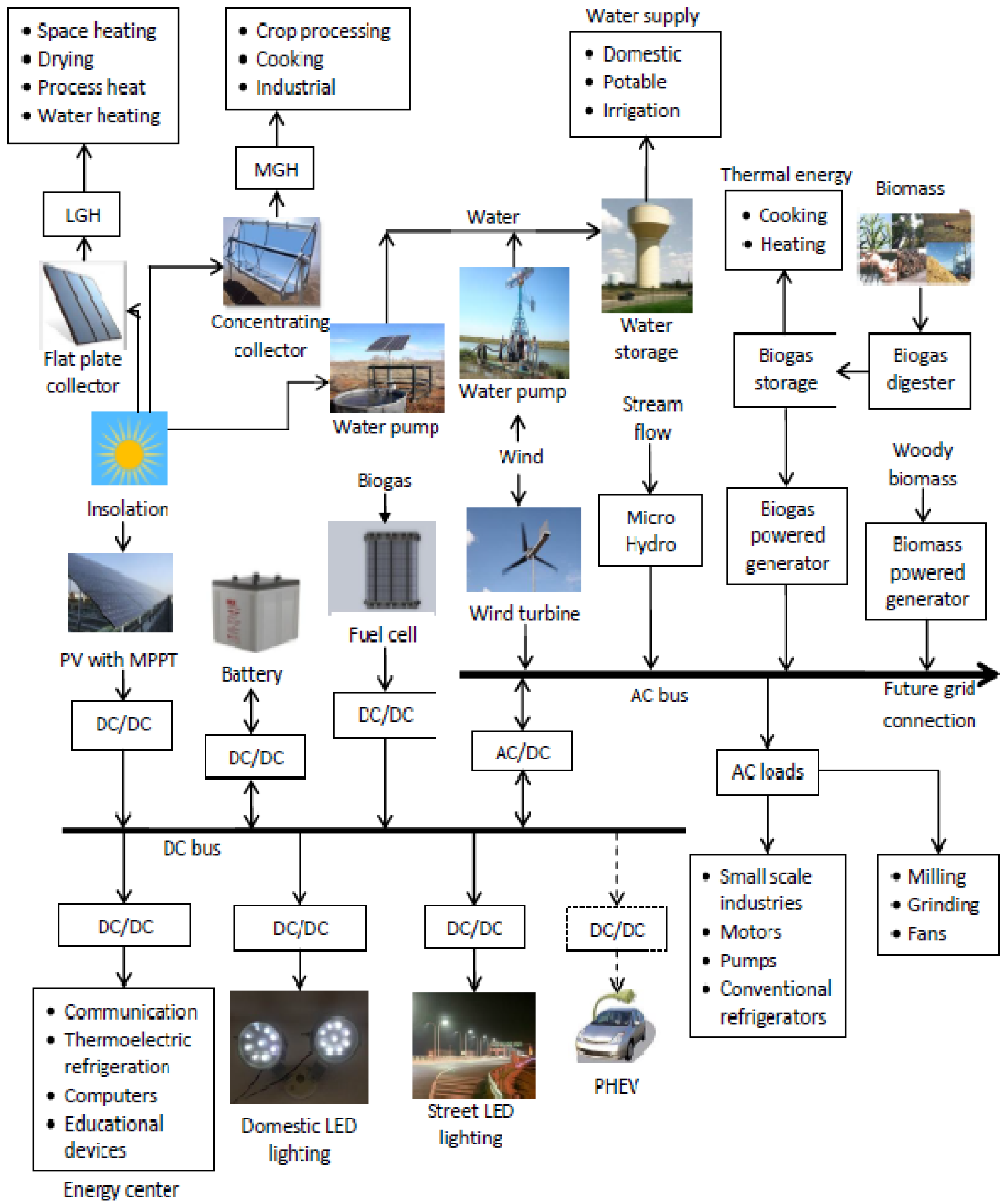


Figure III.1: Schematic diagram for IRES-MG

Renewable energy resources are stochastic in nature, site specific, fairly evenly distributed around the world and have no or minimal environmental impacts. Integrated use of these renewable energy sources will help overcome weakness of one resource by the strength of the other in some aspect. Integrated approach is suitable in rural areas where biomass is in abundance and solar, wind and hydro may be sparsely available depending on the terrain and other geographical factors. Along with energization, IRES-MG provides job opportunities and upgrades socio-economic conditions of rural communities.

III.2 Resources and Needs

Even today, people in rural areas use traditional biomass such as firewood, animal dung, straw, and charcoal to satisfy their daily energy needs. They use animal dung, charcoal, firewood, etc. for cooking, kerosene for lighting purposes and expensive dry cell batteries for communication purposes. These pose threat not only to the surrounding environment but also to their health. Therefore, renewable energy technologies must be promoted to play a vital role to improve their quality of life and provide a sustainable and safe environment to live.

IRES-MG provides energy by harnessing locally available renewable energy resources. Among all the available renewable energy sources, the following four are considered as inputs for IRES-MG.

a. Insolation
b. Wind
c. Hydro

d. Biomass

Solar energy can be utilized in two ways; thermal and photovoltaic to supply thermal and electrical loads. Insolation can be used for cooking with solar cookers, heat water using solar water heaters, dry crops with solar driers and solar PV system can be used for domestic and street lighting, to power communication devices and DC loads. Wind energy can also be used for pumping water for domestic use and small scale irrigation. Wind energy can be utilized by Wind Electric Conversion Systems (WECS) to generate electricity. Potential energy of water is utilized by micro hydro plant to generate electricity. The mechanical system used in micro hydro can be used for milling and grinding grains as well. Instead of using biomass in conventional ways, it can be converted to biogas, biofuels or biodiesel, which can be used in engines to produce power or transport fuels. Biogas can be used directly for cooking, and supplying thermal loads or generating power through CHP, conventional engine or micro turbine, while biofuels or biogas can be used as fuel in fuel cells with high conversion efficiencies. Biomass powered generator can also be included in IRES-MG if woody biomass is available.

Concept of IRES-MG is based on the fact that some technologies are more efficient than others for supplying some forms of energy needs at minimum cost. For instance, using biogas directly for cooking would be efficient and cheap as compared to using biogas in biogas powered engines for producing electricity and using this electricity for cooking purpose. Different types of energy needs are discussed next based on quality and type of energy required.

Medium grade thermal energy needs

Medium grade heat (MGH) refers to thermal loads with temperatures in the range of 100 to 300°C. Medium grade heat is required in households for cooking, in small scale industries for process heat and crop processing and drying. Biogas and concentrating solar collector can provide medium grade heat requirements.

Low grade thermal energy needs

Low grade heat (LGH) refers to thermal loads requiring temperatures less than 100°C. Low grade heat is used for water heating, space heating, crop drying and process heat. Solar flat plate collector provides low grade heat. The waste heat obtained from CHP can also be used to supply low grade heat.

Water supply needs

Water supply (WS) refers to water needs for domestic, irrigation and drinking purposes. Water needs can be satisfied through PV or wind powered water pumps or water stored from streams or rivers. If required and possible, solar system can be used for desalination.

Electrical loads

Electrical loads can be either AC or DC. DC loads comprise of domestic and street LED lightings, communication and educational devices and computers while AC loads comprise of small scale industry, motors, pumps, and milling and grinding machines. The main power consumers are health center, school, small shops and small scale industry.

Table III.1 shows the various possible combinations of available resources and needs that can be utilized in IRES-MG system [31].

Cooking	Improved cooking stoves Biogas from biogas digester Solar cooker
Water supply (domestic and community)	PV driven water pumps Wind powered water pumps Biogas fueled engine generator set
Water supply (irrigation)	PV driven water pumps Wind powered water pumps
Lighting (domestic and street)	Electricity from community level IRES-MG
Educational and Communication devices	Electricity from IRES-MG
Small scale industries, shops, school	Electricity from IRES-MG
Medium grade thermal energy (crop processing, industrial heat)	Solar concentrating collectors Biogas powered CHP
Low grade thermal energy (space heating, water heating, crop drying)	Flat plate solar collectors Improved heating stoves Solar crop dryers
Cold storage	Electricity from IRES-MG
Energy storage	Biomass and biogas energy storage Potential energy of water Battery storage

Table III.1: Resource – Need combination for IRES-MG

III.3 Components of IRES-MG

Out of many possible combinations, one possible IRES-MG configuration is shown in Figure III.1. IRES-MG comprises of WECS, solar PV system, anaerobic digesters, biogas driven generators, micro hydro plants, solar collectors, energy storage devices, water storage tanks and water pumps.

Insolation is tapped by solar photovoltaic arrays to produce DC power. Insolation can be utilized by flat plate and concentrating solar collectors to serve thermal loads. Wind is harnessed by wind turbines to generate AC power. Anaerobic fermentation of biomass produces biogas, which is used as a fuel to drive engine-generator sets or for fuel cells. Biogas is used directly for cooking and it can be stored for future use. Water from the stream runs micro hydro turbines which drives generator to generate electricity. Water pumped by PV and wind powered water pumps can be stored in overhead water tanks and the stored water can be used for irrigation. After serving the electrical loads, the remaining energy from IRES-MG charges batteries, which may be required during faults or emergency situations. Detailed information regarding available resources and energy needs are required before the implementation of IRES-MG.

CHAPTER IV

OPTIMIZATION OF IRES-MG

IV.1 Cost Optimization of IRES-MG

Cost optimization of IRES-MG determines the best possible configuration of IRES-MG that results in the lowest amount of total Net Present Cost (NPC) and Cost of Energy (COE). The Hybrid Optimization Model for Electric Renewable (HOMER) software, developed by the National Renewable Energy Laboratory (NREL), is used to perform the random selection of sizing and operational strategy of generating system in order to obtain the finest solution of IRES-MG with lowest possible net present cost and cost of energy.

HOMER facilitates the design of stand-alone or grid-connected electric power systems that utilizes renewable energy sources. It compares and evaluates small scale energy generation technologies to find the option that gives least life-cycle cost. In order to perform simulation of the proposed system, HOMER requires information on available resources, technologies required to harness the resources, component types and cost, load profile, economic constraints and control strategy. After simulation, HOMER displays a list of all possible configurations sorted according to the increasing NPC [32].

IV.1.1 System Description in HOMER

As mentioned earlier, HOMER requires information on the available resources and details of individual components before starting simulation. In this case study, it is assumed that the study area is a remote village dependent on agriculture, with no grid extension. The village consists of 700 people and 450 cattle including poultries, bovines, swine etc. [33]. The energy demands are summarized in Table IV.1 below. The latitude and longitude of the study area are 30° 32’ N and 78° 03’ E respectively [35]. The proposed IRES-MG consists of PV array, wind energy sub-system, micro hydro, biogas fueled generator, fuel cell with biogas as fuel and battery storage sub-system [36-38].

Energy Need	Energy Demand
Low Grade Heat	400 kWh/day (P_{max} = 65kW, P_{min} = 0kW)
Medium Grade Heat	700 kWh/day (P_{max} = 100kW, P_{min} = 0kW)
DC load	178 kWh/day (P_{max} = 22kW, P_{min} = 3kW)
AC load	272 kWh/day (P_{max} = 30kW, P_{min} = 5kW)
Water Need	120 m^3/day

Table IV.1: Summary of energy demand in the study area [33] [34]

IV.1.1.1 Solar Radiation and PV Array

Solar resource indicates the amount of global solar radiation that strikes earth’s surface. Solar radiation for this study area was obtained from the NASA Surface Meteorology and Solar Energy website. An average solar radiation of 5.224kWh/m^2/day and a clearness index of 0.6 were identified for the study area. Clearness index is the ratio of the solar radiation striking earth's surface to the solar radiation striking the top of atmosphere. Figure IV.1 shows the average monthly solar radiation and clearness index for the study area. The mathematical model of PV array using solar radiation available on the surface is given as in equation 4.1 [39-41],

$$E_{PV}(kWh) = G(t) \times A \times \eta_{PV} \tag{4.1}$$

Where, G(t) is hourly solar irradiance in kWh/m^2, A is the surface area of PV array in m^2 and η_{PV} is the efficiency of PV array.

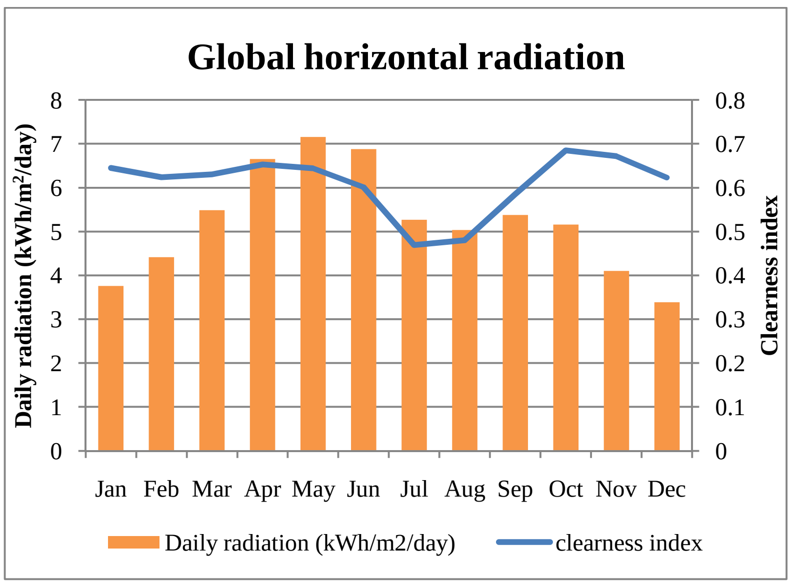


Figure IV.1: Global horizontal radiation of study area

The PV array modeled in HOMER gives DC output in direct proportion to incident solar radiation. The installation cost of PV array is taken \$3500/kW [42] and replacement cost is \$3000/kW. Operation and maintenance (O&M) cost is practically zero and its lifetime is 25 years. A derating factor of 80% is applied to each panel to account for the degrading factors caused by temperature, soiling, tilt, shading etc.

IV.1.1.2 Wind Speed and Wind Turbine

Wind speed data are measured at a height of 10m and average wind speed is determined to be 5.184m/s. Weibull parameter is estimated as k = 2 and 8 hours of daily peak wind speed is assumed. Technical information of wind turbine is presented below in Table IV.2 [43] and Figure IV.2 shows monthly average wind speed. Expression 4.2 defines the hourly energy generated by wind generator.

$$E_{WECS}(kWh) = \frac{1}{2}\,\rho_{wind}\,A \times v^3 \times C_p \times \eta_{WECS} \times t \qquad (4.2)$$

Where, ρ_{wind} is the density of air, A is the rotor swept area in m^2, v is the velocity of wind in m/s, C_p is the maximum power coefficient or Betz limit, which is 0.59 theoretically, η_{WECS} is the efficiency of WECS and t is the hours of operation of WECS per day.

Manufacturer	Bergey Wind Power
Turbine Type	BWC Excel S
Output	10kW AC
Rotor Diameter	7m
Capital Cost	$31,770
Replacement Cost	$28,000
Operation and Maintenance Cost	$65 per year
Lifetime	30 years

Table IV.2: Technical information of wind turbine

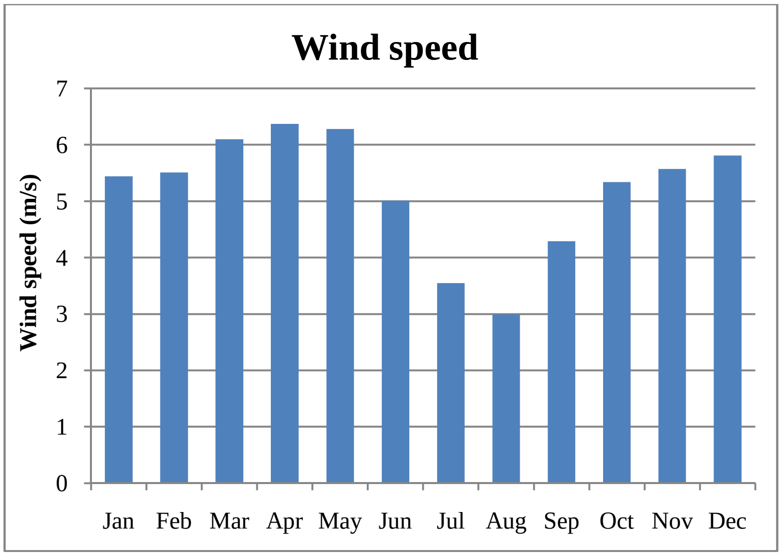


Figure IV.2: Monthly average wind speed

IV.1.1.3 Hydro Resource and Micro Hydro

In the study area, the stream has a monthly average flow of 47L/s. With design flow of 45L/s (0.045m^3/s), 30m head and 70% efficiency, it is determined that a run-of-river type micro hydro plant of 9.27kW rated capacity can be installed. The capital cost for the installation of micro hydro is taken as \$23,200 with replacement cost of \$19,470 and operation and maintenance (O&M) cost of \$475 per year [23]. The electrical power generated by micro hydropower generator in kW is given by,

$$P_{MHP}(kW) = \eta_{hydro} \frac{9.81 \times Q \times \rho_{water} \times h}{1000} \qquad (4.3)$$

Where, η_{hydro} is the efficiency of hydro power plant, Q is the discharge in m^3/s, ρ_{water} is the density of water in kg/m^3 and h is the available head in m.

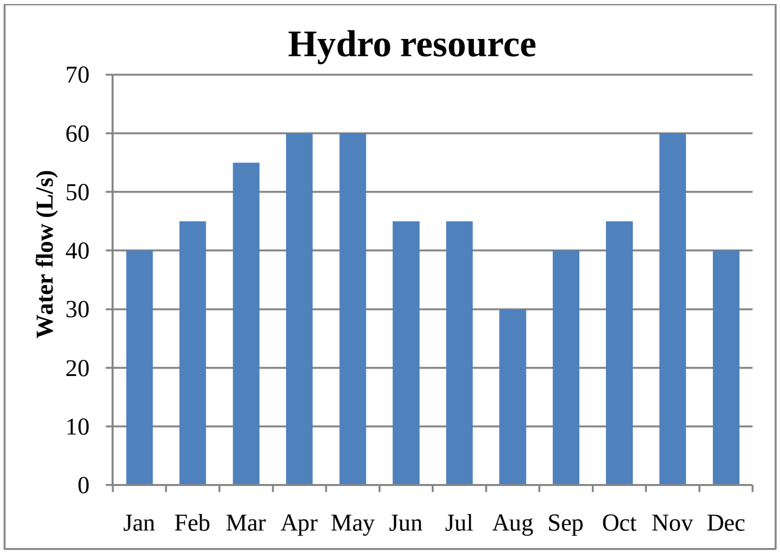


Figure IV.3: Monthly average stream flow

IV.1.1.4 Biomass Resource and Biogas Generator

As mentioned earlier, biomass comprises of wood chips and wastes from wood industry, agricultural and forest residues, animal wastes, kitchen wastes and energy crops if available. Biomass undergoes anaerobic fermentation to produce biogas in community scale or household scale biogas digesters. Biogas is used as fuel to generate power from engine-generator set. The average biomass available in study area is 3.9tonnes per day and monthly available average biomass resource is shown in Figure IV. 4. The capital cost of biogas powered generator is $1,000/kW with replacement cost of $850/kW and O&M cost of $0.01/hour [44]. The hourly energy generated by biogas generator is given by,

$$E_{BG}\,(kWh) = P_{BG} \times \eta_{BG} \times t \qquad (4.4)$$

Where, P_{BG} is the rated power of biogas powered generator in kW, η_{BG} is the efficiency of biogas generator and t is the hours of operation of biogas generator in a day.

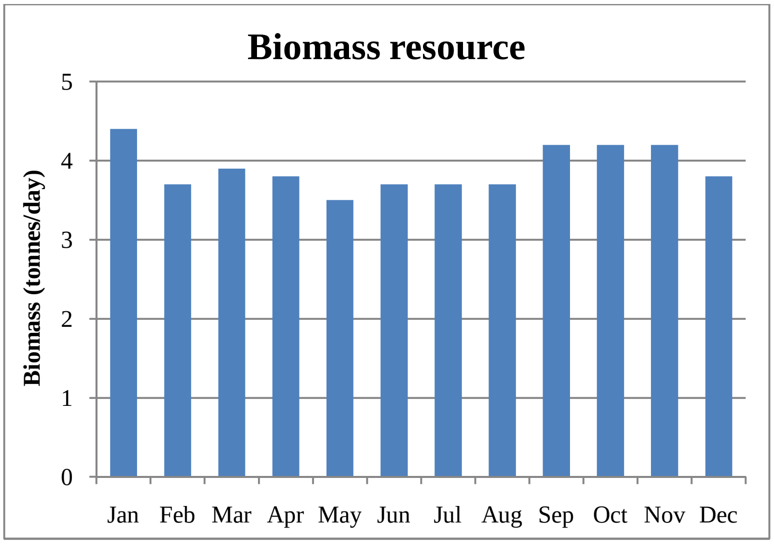


Figure IV.4: Monthly average available biomass resource

IV.1.1.5 Fuel Cell and Hydrogen Tank

Reformer uses hydrocarbon fuel to generate pure hydrogen and the produced hydrogen is stored in hydrogen tank which is used by fuel cell to generate DC electricity. The cost details of reformer, hydrogen tank and fuel cell is given in Table IV.3. Biogas is used as the hydrocarbon fuel, as it is cheap, readily available and renewable resource. The heating value of biogas is 20MJ/kg or 5.56kWh/m^3 and the cost of biogas is assumed to be \$0.3/m^3 [38].

	Reformer	**Hydrogen Tank**	**Fuel Cell**
Capital Cost	\$2,000/(kg/hr)	\$1,500/kg of H_2	\$2,000/kW
Replacement Cost	\$2,000/(kg/hr)	\$1,400/kg of H_2	\$1,500/kW
O&M Cost	\$15/yr	\$10/yr	\$0.02/hr

Table IV.3: Cost details of reformer, hydrogen tank and fuel cell

IV.1.1.6 Energy Storage Devices

Battery bank is the collection of one or more individual batteries. HOMER models a single battery as a device capable of storing a certain amount of DC electricity at a fixed round trip efficiency. It is assumed that battery properties remain constant throughout its lifetime and are not affected by external factors. The detail of battery used for IRES-MG in HOMER is listed in Table IV.4. Surrette 6CS25P is a deep cycle, high capacity, lead-acid battery and is most suitable for renewable energy application [44].

Battery Type	Surrette 6CS25P
Nominal Voltage	6V
Nominal Capacity	1,156Ah (6.94kWh)
Lifetime Throughput	9,654kWh
Capital Cost	$1,250
Replacement Cost	$1,100
O&M Cost	$15/yr

Table IV.4: Technical details of battery bank

IV.1.1.7 Converter

A converter is a device that converts DC power to sinusoidal AC power in inversion process and from AC to DC power in rectification process. The bidirectional converter costs $800/kW, has replacement cost of $750/kW and O&M cost of $15/yr for a lifetime of 30 years. The inverter and rectifier efficiencies are assumed to be 85% and 90% respectively [45].

IV.1.1.7 Daily Electrical Load Profile

Generally, load refers to the electrical or thermal energy demand. Serving load is the primary purpose of any power system. Daily electrical load profile is acquired based on basic demands of utilities such as lighting, cooling, communication and other household appliances etc. for each household. A school, health care center and a small scale industry are the major power consumers. The total electrical load consumption is 450kWh/day with average DC load demand of 178kWh/day and average AC load demand of 272kWh/day. Figure IV.5 shows the daily load profile [35].

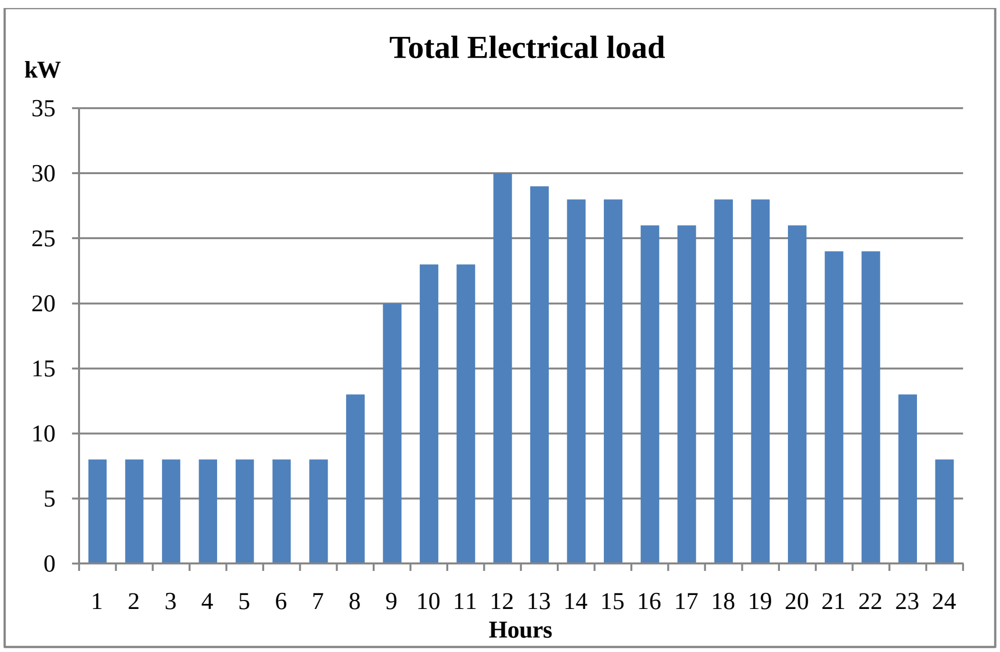


Figure IV.5: Daily electrical load profile of study area

IV.1.1.8 Economics Constraints and Control Strategy

A control strategy determines the operation of any system. It may require hourly decisions about the operation of generators, charging and/or discharging of batteries, grid-connection or stand-alone mode. Dispatch strategy must be applied for any system with battery bank. It can be either load-following or cycle-charging. Under load-following strategy, generator produces enough power to serve load and does not charge battery bank. While under cycle-charging strategy, generator runs at maximum rated capacity to serve load as well as charge battery bank.

Economics play an important role in determining NPC and feasibility of a system. Annual interest rate of the project is assumed to be 8% and the project lifetime is set to 25 years. Cycle-charging dispatch strategy is considered for the proposed IRES-MG.

IV.1.2 HOMER Simulation Model

The proposed model of IRES-MG for cost optimization in HOMER is shown in Figure IV.6. PV array, fuel cell and battery bank are connected to DC bus while wind turbine, biogas generator and hydro turbine are connected to AC bus. These AC and DC buses are connected through bidirectional converter.

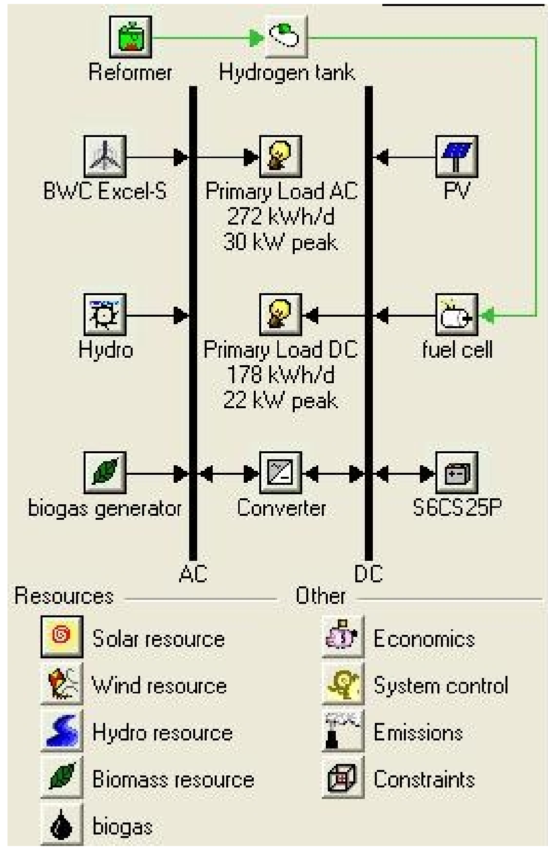
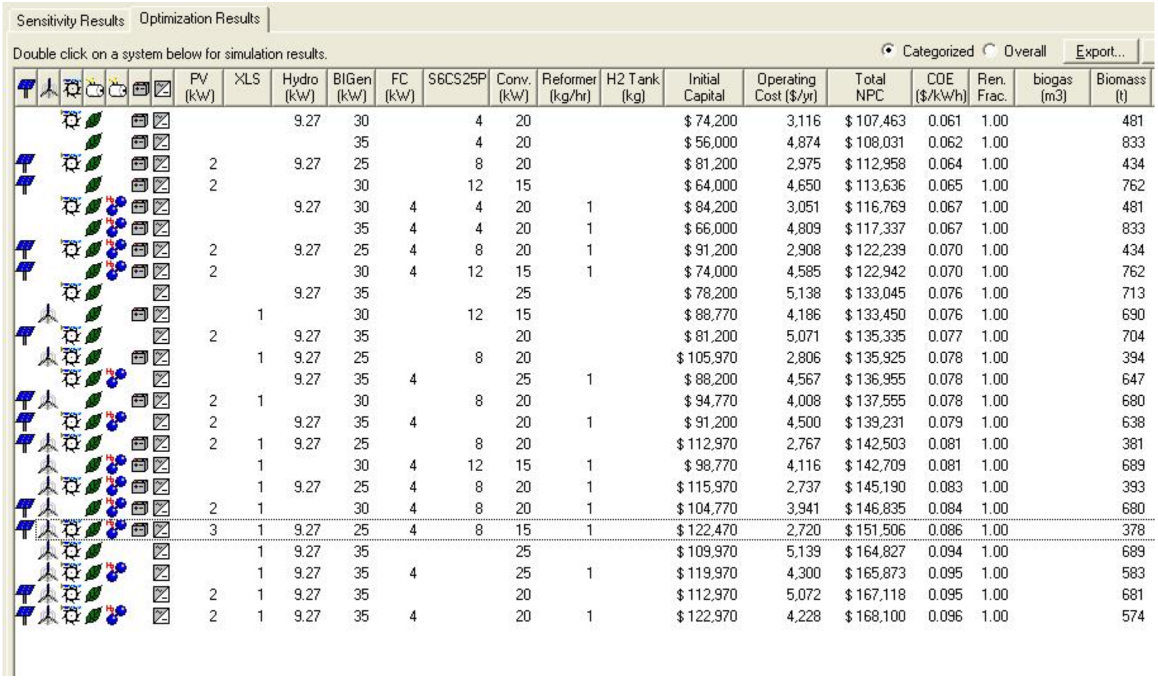


Figure IV.6: IRES-MG model in HOMER for cost optimization

IV.1.3 Simulation Result

Simulation of IRES-MG in HOMER for cost optimization provides results in terms of optimal system configurations based on total net present cost and cost of energy. Several simulations were performed for different sizes of PV array, biogas generator, and converter, number of wind turbines and battery banks. The search space for each component is widened by introducing various sizes for each simulation to find the optimal system configurations. Combination of the equipment depends on the optimization parameters and sensitivity variable, if present. HOMER identifies and lists out all possible configurations for IRES-MG. Figure IV.7 shows optimization results of IRES-MG.


Sensitivity Results | Optimization Results

Double click on a system below for simulation results. ⦿ Categorized ○ Overall Export...

PV (kW)	XLS	Hydro (kW)	BIGen (kW)	FC (kW)	S6CS25P	Conv. (kW)	Reformer (kg/hr)	H2 Tank (kg)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	biogas (m3)	Biomass (t)
		9.27	30		4	20			$ 74,200	3,116	$ 107,463	0.061	1.00		481
			35		4	20			$ 56,000	4,874	$ 108,031	0.062	1.00		833
2		9.27	25		8	20			$ 81,200	2,975	$ 112,958	0.064	1.00		434
2			30		12	15			$ 64,000	4,650	$ 113,636	0.065	1.00		762
		9.27	30	4	4	20	1		$ 84,200	3,051	$ 116,769	0.067	1.00		481
			35	4	4	20	1		$ 66,000	4,809	$ 117,337	0.067	1.00		833
2		9.27	25	4	8	20	1		$ 91,200	2,908	$ 122,239	0.070	1.00		434
2			30	4	12	15	1		$ 74,000	4,585	$ 122,942	0.070	1.00		762
		9.27	35			25			$ 78,200	5,138	$ 133,045	0.076	1.00		713
	1		30		12	15			$ 88,770	4,186	$ 133,450	0.076	1.00		690
2		9.27	35			20			$ 81,200	5,071	$ 135,335	0.077	1.00		704
	1	9.27	25		8	20			$ 105,970	2,806	$ 135,925	0.078	1.00		394
		9.27	35	4		25	1		$ 88,200	4,567	$ 136,955	0.078	1.00		647
2	1		30		8	20			$ 94,770	4,008	$ 137,555	0.078	1.00		680
2		9.27	35	4		20	1		$ 91,200	4,500	$ 139,231	0.079	1.00		638
2	1	9.27	25		8	20			$ 112,970	2,767	$ 142,503	0.081	1.00		381
	1		30	4	12	15	1		$ 98,770	4,116	$ 142,709	0.081	1.00		689
	1	9.27	25	4	8	20	1		$ 115,970	2,737	$ 145,190	0.083	1.00		393
2	1		30	4	8	20	1		$ 104,770	3,941	$ 146,835	0.084	1.00		680
3	1	9.27	25	4	8	15	1		$ 122,470	2,720	$ 151,506	0.086	1.00		378
	1	9.27	35			25			$ 109,970	5,139	$ 164,827	0.094	1.00		689
	1	9.27	35	4		25	1		$ 119,970	4,300	$ 165,873	0.095	1.00		583
2	1	9.27	35			20			$ 112,970	5,072	$ 167,118	0.095	1.00		681
2	1	9.27	35	4		20	1		$ 122,970	4,228	$ 168,100	0.096	1.00		574

Figure IV.7: Cost optimization results for IRES-MG in HOMER

HOMER uses following equation to calculate the net present cost [46].

$$\text{Net Present Cost} = \frac{C_{ann,total}}{CRF(i,N)} \tag{4.5}$$

Where, $C_{ann,total}$ is the total annual cost, 'i' is the annual real interest rate, N is the project lifetime, and CRF (i, N) is the capital recovery factor given by

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N-1} \tag{4.6}$$

Levelized cost of energy is calculated as,

$$COE = \frac{C_{ann,tot}}{E_{prim}+E_{def}+E_{grid,sales}} \tag{4.7}$$

Where, E_{prim} and E_{def} are total amount of primary and deferrable loads respectively, served per year and $E_{grid,sales}$ is amount of energy sold to grid per year. In the proposed system, deferrable loads are not considered and the system is not grid-connected so, E_{def} and $E_{grid,sales}$ are both zero.

The optimal configuration of IRES-MG obtained from HOMER consists of 3kW of PV array, 1 number of BWC Excel S 10kW AC wind turbine, 9.27kW rated micro hydropower plant, 25kW biogas powered generator system, 4kW fuel cell, 8 numbers of Surrette 6CS25P battery banks of 1156Ah nominal capacity and 15kW bidirectional converter. Simulation result also provided the costs of optimal IRES-MG for given configuration. The total net present cost for IRES-MG over the project lifetime is $151,506. The capital cost, operating cost and levelized cost of energy for IRES-MG is around $122,470, $2,270 per year and $0.086 per kWh respectively. Table IV.5 shows a summary of the system components.

Components	**Rated Capacity**	**Capacity Factor (%)**	**Production (kWh/yr)**	**Annual Hours of Operation**
PV Array	3kW	19.7	5168	4380
Wind Turbine	10kW	24.7	21640	8226
Micro Hydro	9kW	89.0	72246	8760
Biogas Generator	25kW	37.5	82079	5434
Fuel Cell	4kW	0	0	259
Battery (1156Ah)	8 nos.	N/A	4128	N/A
Inverter	15kW	0	N/A	43
Rectifier	15kW	46.2	N/A	8317

Table IV.5: Summary of cost optimization of IRES-MG in HOMER

Table IV.6 shows annual AC and DC primary load consumption as determined by optimization result from HOMER.

Load	AC Primary Load	DC Primary Load	Total
Consumption (kWh/year)	99,280	64,905	164,186
Fraction	60%	40%	100%

Table IV.6: Annual AC and DC load consumption

The levelized cost of energy of IRES-MG (8.6¢/kWh) is less than the present day cost of electricity in the US, which is around 11.6¢/kWh for residential customers [47]. Also, it is cheaper than cost of electricity from PV, CSP, natural gas and competitive with that from wind and coal. This shows that cost of energy from IRES-MG is competitive and therefore, suitable in rural areas.

Emission from IRES-MG is also less compared to coal fired plant or diesel engine. The yearly emission from IRES-MG is shown in Table IV.7. Planting trees after consumption of forest residues for biogas production will minimize this emission.

Pollutant	**Emission (kg/yr)**
Carbon dioxide	65.40
Carbon monoxide	2.46
Unburned hydrocarbons	0.27
Particulate matter	0.18
Nitrogen oxides	21.90
Sulphur dioxide	0.0

Table IV.7 Emissions from IRES-MG

Simulation in HOMER was done a number of times to evaluate the relationship of aggregate cost of energy with the biogas generator capacity. The graph below (Figure IV.8) shows the variation of cost of energy in \$/kWh with change in biogas generator capacity in kW.

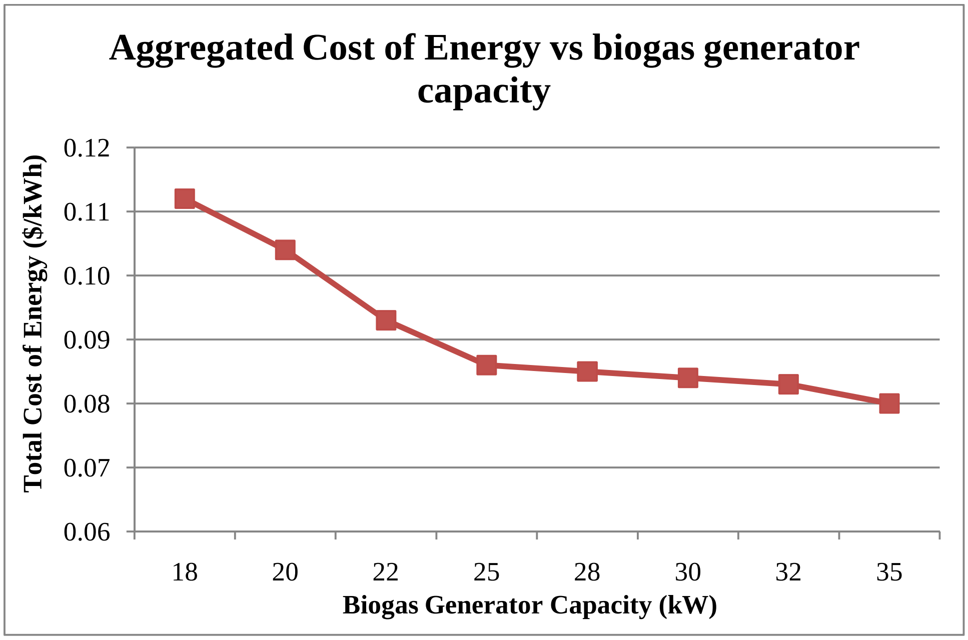


Figure IV.8: Variation of total unit cost of energy with biogas generator rating

The graph implies that as the capacity of biogas generator increases, the total cost of energy from IRES-MG decreases. This is because biogas is a cheap source of energy and biomass required to produce biogas is available at minimum or no cost. Also, the operation and maintenance cost of biogas generator does not increase with the increase in the capacity of generator. When the capacity of biogas generator is increased to see the variation in COE, capacity of some other generation sources is decreased, so that the same amount of energy is generated in each case. In this particular case, the capacity of PV and fuel cell was decreased. Since, the cost of electricity from PV is very high, decreasing the capacity, decreased the overall cost of energy from IRES-MG.

The cost optimized IRES-MG resulted in optimal configuration with a 3kW PV array, 1 number of 10kW WECS, 9.27kW of micro hydro, 25kW biogas powered generator, 8 numbers of battery bank with nominal capacity of 1156Ah, 4kW of fuel cell and 15kW bi-directional converter. These rated capacities of IRES-MG components are now used for efficiency optimization.

IV.2 Efficiency Optimization of IRES-MG

One of the features of IRES-MG is the power generation from more than one renewable energy sources. Integrating these sources help to overcome the weakness of one resource by the strength of other, thus helping to achieve high efficiency and/or improved performance. Also, combined heat and power operations of micro turbine or fuel cell will improve the overall efficiency than either system can achieve. Theoretical efficiency of any system cannot be achieved due to losses and material limitations.

The objective in efficiency optimization is to maximize the overall efficiency of IRES-MG. Efficiency can be defined as

$$\eta_{total} = \frac{P_{output}}{P_{input}} \tag{4.8}$$

Where, P_{output} is the output power of a system (kW) and P_{input} is the input power (kW). Efficiency also depends on the size and type of generators and engines.

The problem formulation in IRES-MG differs depending on the configuration and system components. Inputs to IRES-MG are insolation, wind, water flow and biogas and the outputs are DC, AC and thermal loads. Since we have already determined the rated system capacity from HOMER for cost optimization, the same rated system capacity is used for efficiency optimization. The efficiency optimization problem can be defined as

$$\text{Maximize } \eta_{total} = \frac{P_{demand}}{P_{input}} \tag{4.10}$$

$$\text{Where, } P_{demand} = P_{DC} + P_{AC} + P_{MGH} + P_{LGH} \tag{4.11}$$

$$P_{input} = P_{ins} + P_{wind} + P_{stream} + P_{biogas,BG} + P_{biogas,FC} + P_{biogas,thermal} \tag{4.12}$$

P_{ins} is the power input to the PV array (kW), P_{wind} is the input power to wind turbine (kW), P_{stream} is the input power to hydro power plant (kW), $P_{biogas,BG}$ is power input to biogas generator(kW), $P_{biogas,FC}$ is the input power of fuel cell (kW) and finally $P_{biogas,thermal}$ is the biogas as an input for thermal load (kW). It is difficult to determine the input power of these components. But, efficiency and output of all the components are known. Equation (4.12) can be rewritten as follows [46],

$$P_{input} = \frac{P_{PV}}{\eta_{PV}} + \frac{P_{WECS}}{\eta_{WECS}} + \frac{P_{MH}}{\eta_{MH}} + \frac{P_{BG}}{\eta_{BG}} + \frac{P_{FC}}{\eta_{FC}} + \frac{P_{biogas}}{\eta_{biogas}} \tag{4.13}$$

From equations 4.11, 4.12, and 4.13, we can write,

$$\text{Maximize } \eta_{total} = \frac{P_{DC}+P_{AC}+P_{MGH}+P_{LGH}}{\frac{P_{PV}}{\eta_{PV}}+\frac{P_{WECS}}{\eta_{WECS}}+\frac{P_{MH}}{\eta_{MH}}+\frac{P_{BG}}{\eta_{BG}}+\frac{P_{FC}}{\eta_{FC}}+\frac{P_{biogas}}{\eta_{biogas}}} \tag{4.14}$$

Subject to constraints:

$0 \leq P_{PV} \leq 3kW$, 3kW is the rated capacity of PV array

$0 \leq P_{WECS} \leq 10kW$, 10kW is the rated power output of WECS

$0 \leq P_{MH} \leq 9kW$, 9kW is the rated power output of micro hydro

$0 \leq P_{BG} \leq 25kW$, 25kW is the rated output of biogas powered generator

$0 \leq P_{FC} \leq 4kW$, 4kW is the rated capacity of fuel cell

$0 \leq P_{biogas} \leq 100kW$, 100kW is the maximum power of biogas for thermal load

$0 \leq P_{DC} \leq 22kW$, 22kW is the peak DC load

$0 \leq P_{AC} \leq 30kW$, 30kW is the peak AC load

$0 \leq P_{MGH} \leq 100kW$, 100kW is the maximum MGH demand

$0 \leq P_{LGH} \leq 65kW$, 65kW is the maximum LGH demand

IV.2.1 System Description

For efficiency optimization of IRES-MG, the highest possible efficiency of each system component is considered. Efficiencies of various system components used in IRES-MG is shown below in Table IV.7.

System Component	Efficiency	System Component	Efficiency
PV array	12%	AC to DC converter	90%
WECS	35%	AC Power Supply	90%
Micro Hydro	70%	DC to AC Converter	85%
Biogas Generator (CHP)	80%	DC to DC Converter	97%
Fuel Cell	68%	MPPT	99%
Battery	77%	Biogas for Cooking	60%
Concentrating Solar Collector (CSC)	73%	Flat Plate Solar Collector (FPC)	72%

Table IV.8: Efficiency of various system components

The concept of ‘resource-need’ matching is implemented in IRES-MG, so that the end use efficiencies are maximized. Energy generated by PV, WECS, micro hydro plant, biogas generator and fuel cell is used to meet the electrical demands, i.e. DC and AC loads. DC load is first served by IRES-MG and then the remaining energy generated serves AC loads. Medium grade thermal energy (MGH) requirements are met by biogas and concentrating solar collectors. Flat plate solar collectors serve low grade thermal energy (LGH) requirements. If solar collectors cannot satisfy thermal loads, electricity from IRES-MG is utilized to serve thermal loads. Finally, water supply needs for domestic and irrigation purposes are satisfied by wind powered and solar powered water pumps. If water supply demand is high than that can be served by water pumps, water is pumped from the stream from electricity generated by IRES-MG.

IV2.2 Simulation Result

For the simulation, following assumptions are made. 1kW solar powered water pump could pump 1000 gallons of water per hour i.e. 3.785m^3 of water per hour [49]. Wind powered water pump of rotor diameter 4.5m and pumping head of 10-40m could pump 30-70m^3 of water per day [50].

Biomass comprises of animal wastes, forest and agricultural residues and household wastes. The minimum available biomass in rural area is about 2000kg/day and maximum available biomass is 3900 kg/ day. 1 kg of biomass produces 0.0625m^3 of biogas and the energy value of biogas is 5.6kWh/m^3.

Flat plate collector and concentrating solar collector are used to serve thermal loads. The area of flat plate collector and concentrating solar collector is 100m^2.

Simulation was performed in MATLAB. The energy needs and resource availability were varied randomly on an hourly basis. Simulations for 10 time steps were generated and time step of one hour was considered. The time step of one hour is sufficient as these renewable resources do not vary significantly over an hour. Apart from the water needs, all the energy needs and resources are in kWh and the water supply needs and resources are in m^3/hr.

Figures IV.9 to IV.14 show the variations of available resources, i.e. energy generated from photovoltaic, WECS, biogas powered generator, micro hydro, fuel cell, flat plate and concentrating solar collectors and biogas for thermal load in hourly basis.

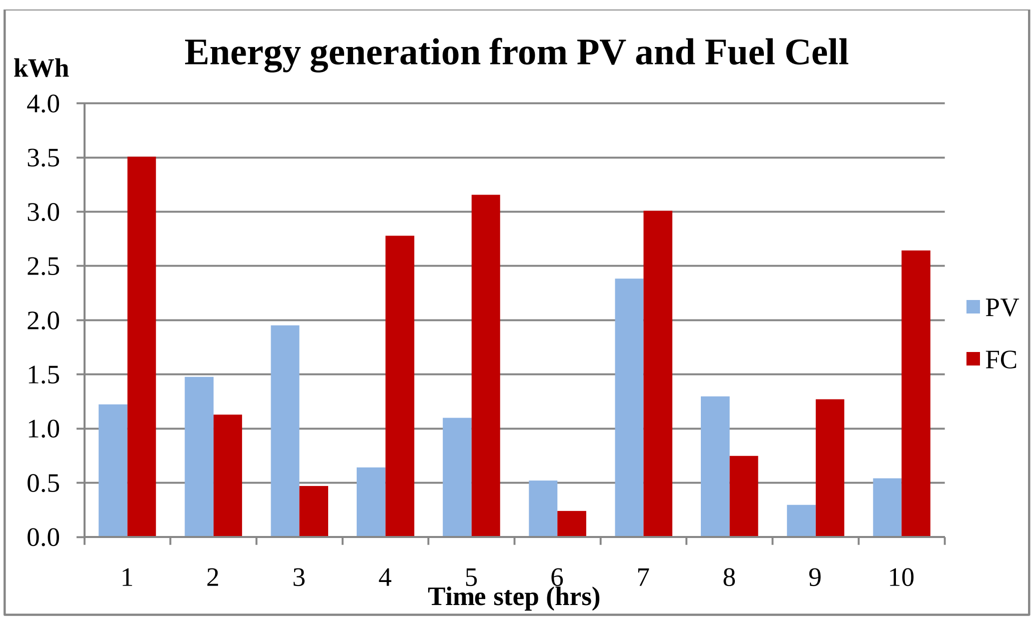


Figure IV.9: Energy generation from photovoltaic and fuel cell

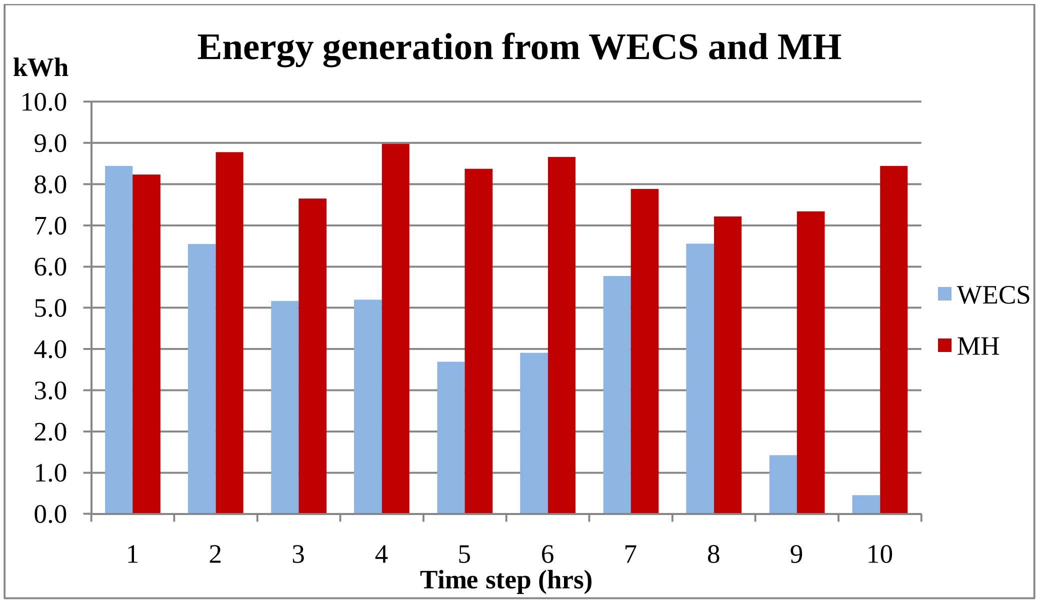


Figure IV.10: Energy generation from WECS and micro hydro

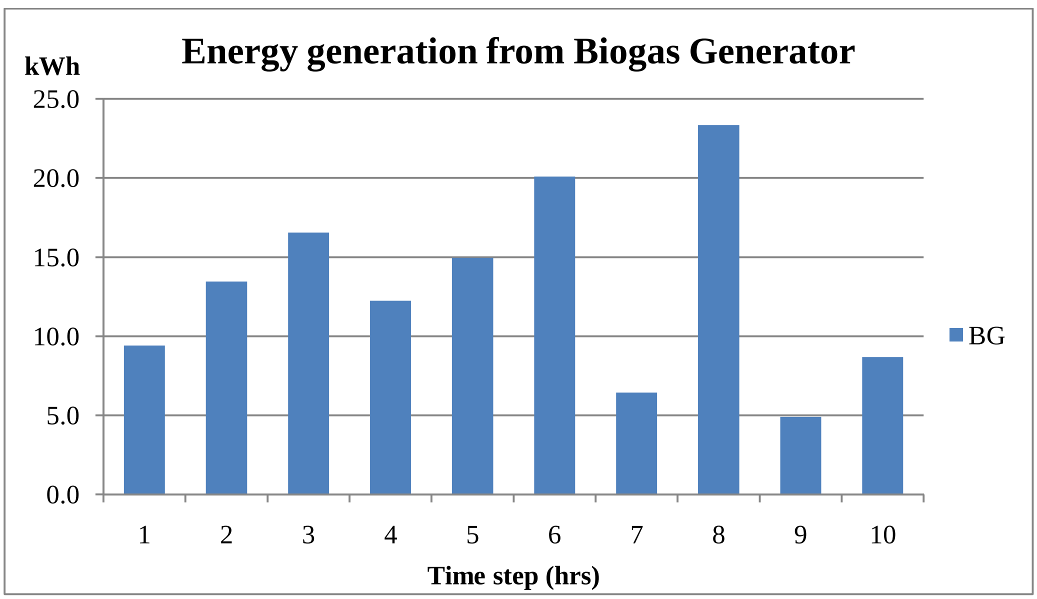


Figure IV.11: Energy generation from biogas powered generator

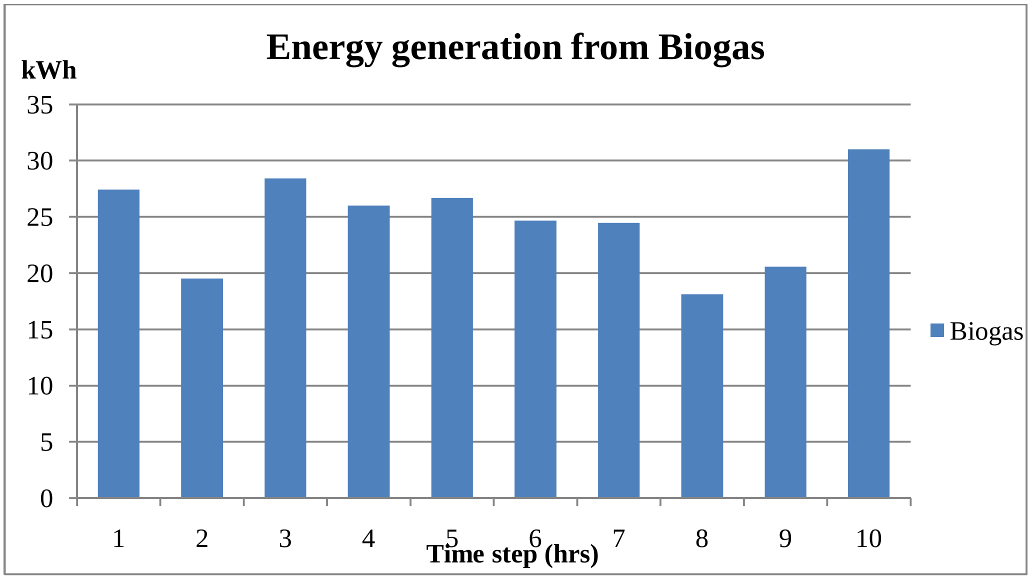


Figure IV.12: Energy generation from biogas to serve thermal load

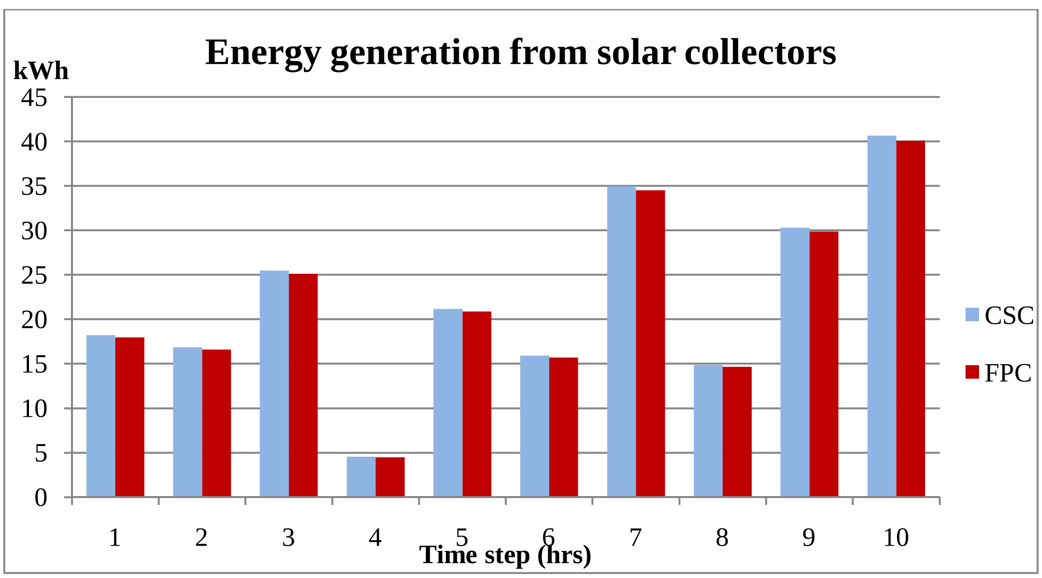


Figure IV.13: Energy generation from concentrating and flat plate solar collector to serve thermal load

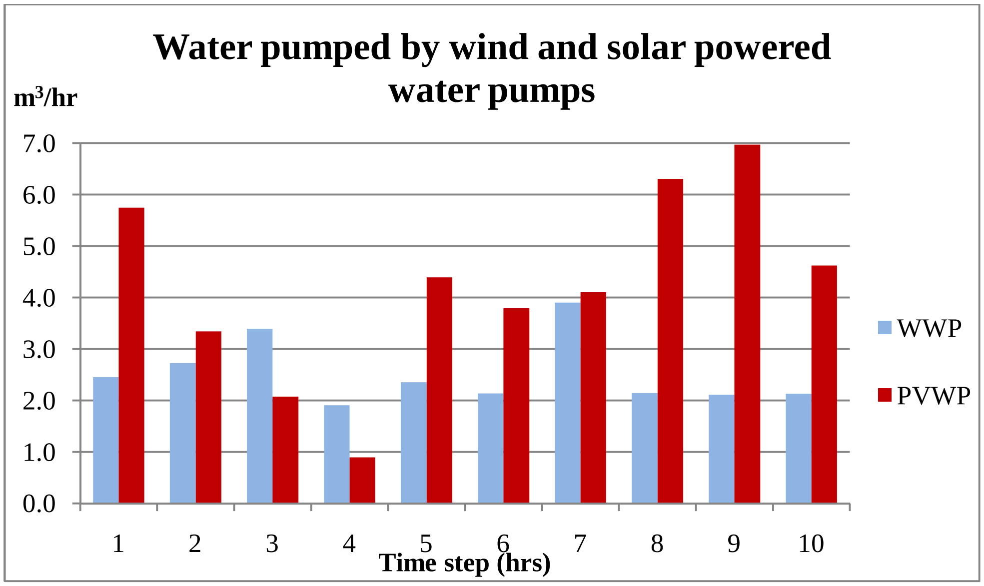


Figure IV.14: Water pumped by solar and wind powered water pump

Figures IV.9 to IV.11 show hourly energy generation from PV array, WECS, micro hydro, biogas and fuel cell. Figure IV.12-13 show hourly energy generation from biogas and solar collectors. And Figure IV.14 shows the amount of water pumped in an hour by solar and wind powered water pumps.

Next, Figures IV.15 to IV.19 show DC, AC, MGH and LGH energy demands and water supply demands served by the energy generated from IRES-MG.

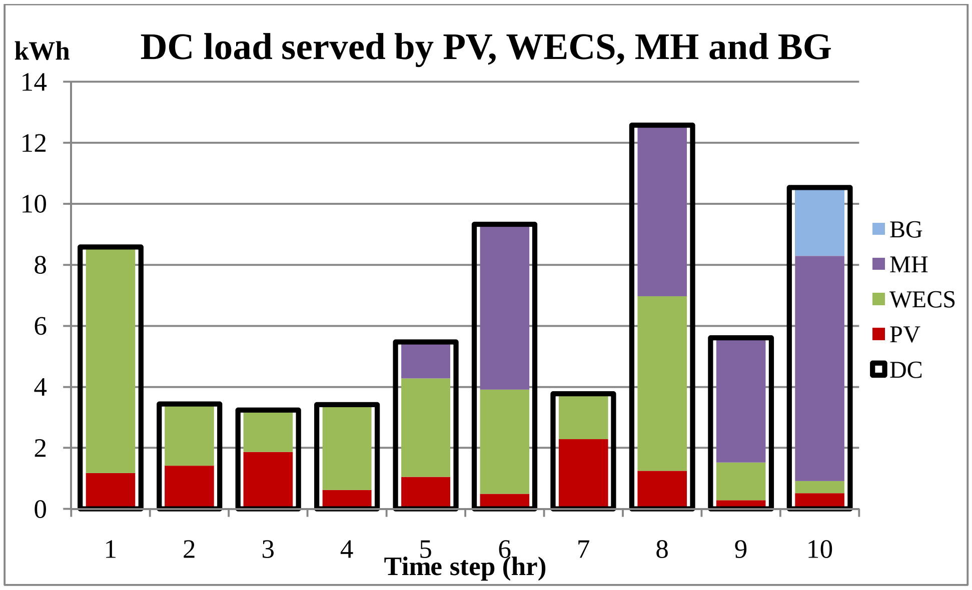


Figure IV.15: DC load served by PV, WECS, micro hydro and biogas generator

IRES-MG first serves DC load as shown in Figure IV.15. Energy generated by PV is utilized first to meet the DC load. Since PV array is rated only 3kW, in most of the cases it is not enough to satisfy DC load. Therefore, WECS, micro hydro (MH) and biogas generator (BG) is utilized to serve DC loads. The remaining energy generated from these sources is then utilized to meet AC loads. If all the energy generated from any of these sources is consumed by DC load, it would not be able to supply AC loads. Here, PV cannot be utilized in serving AC load, as all the energy generated from PV is consumed by DC load.

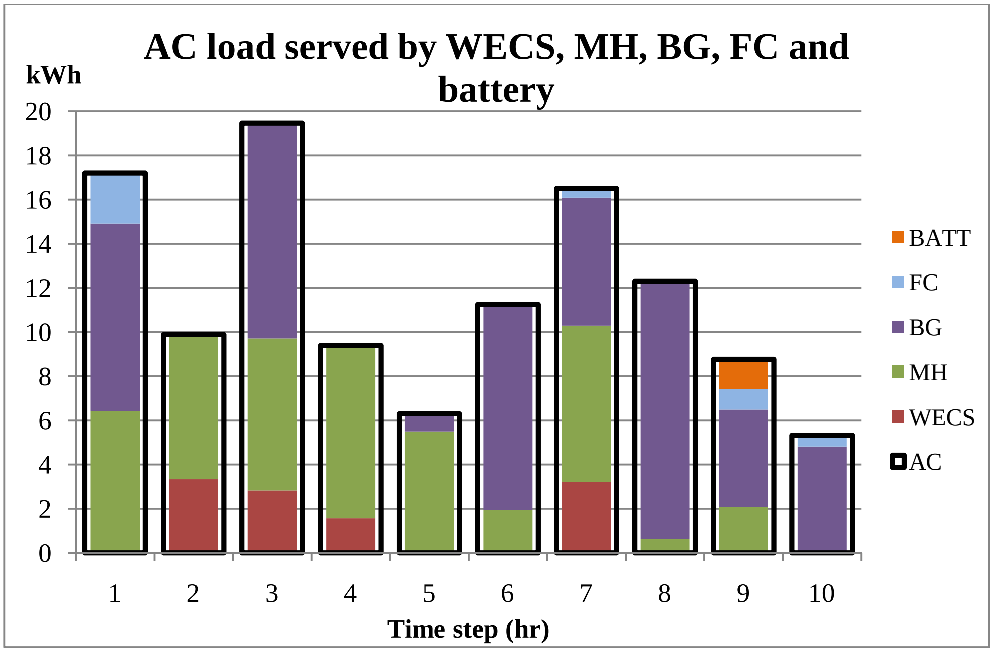


Figure IV.16: AC load served by WECS, micro hydro, biogas generator, fuel cell and battery

Figure above shows energy generated by WECS, MH, BG, fuel cell (FC) and battery is utilized in serving AC load. PV is not available as the energy generated by PV array is consumed by DC load. 9th time step shows that MH, BG and FC were not enough to satisfy AC load, so battery and fuel cell was used to serve the remaining AC load. The remaining energy, if available, after serving DC and AC loads, is then used to serve thermal loads, in case biogas and solar collectors are not enough.

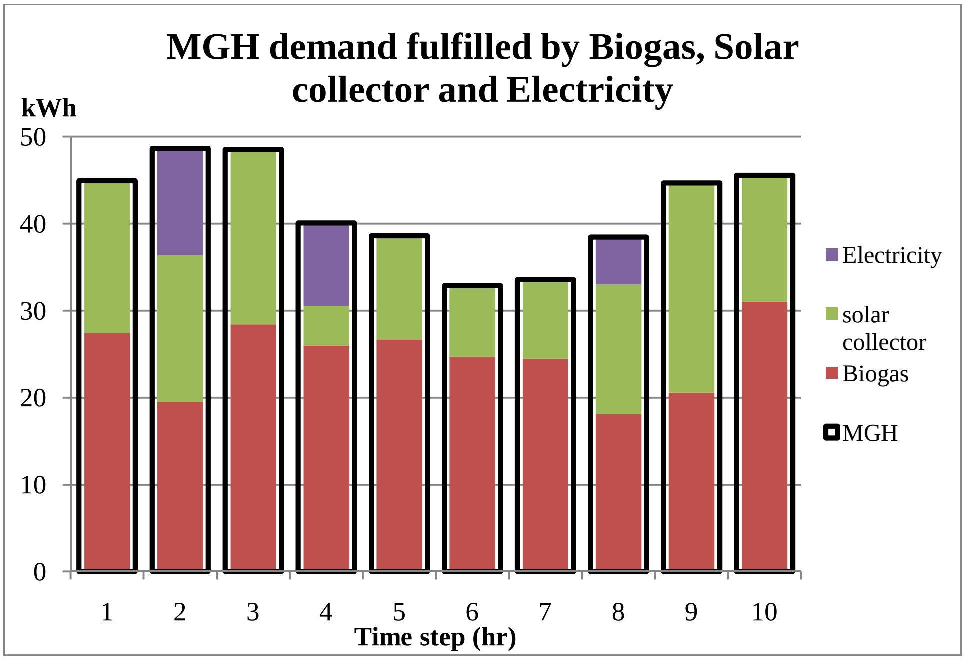


Figure IV.17: Biogas, concentrating solar collector and electricity serves MGH demand

Figure IV.17 shows MGH demand served by thermal resources. Biogas is first used to meet MGH load and if biogas is not able to fulfill all MGH load, concentrating solar collector is used. If these two are not capable to serve entire MGH load, electricity is used. As shown in Figure, in 2nd, 4th and 8th time step MGH load is served by biogas and concentrating solar collector along with electricity, as biogas and solar collector were not enough to serve MGH load.

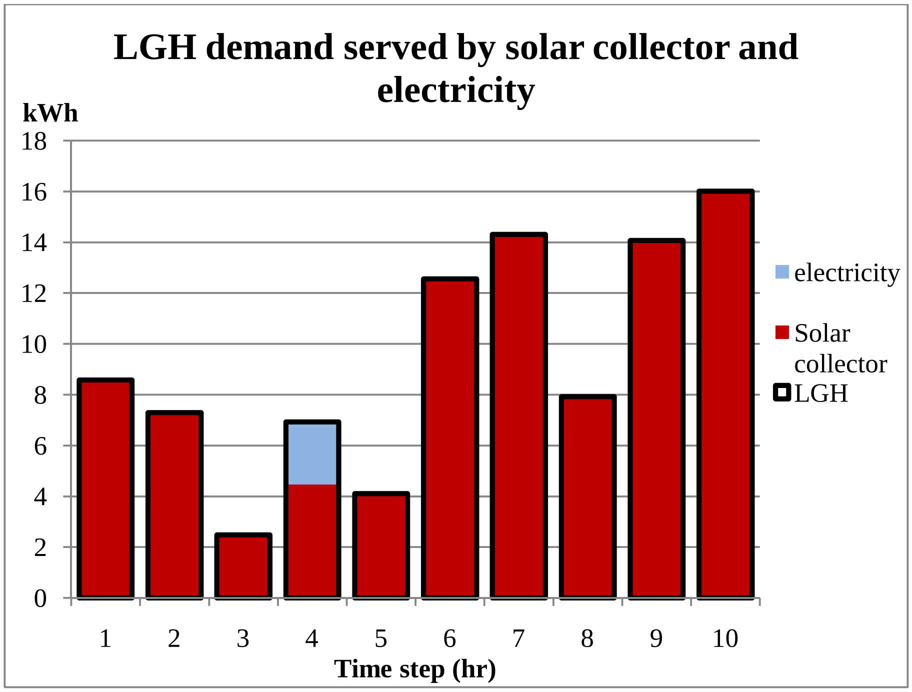


Figure IV.18: LGH demand is satisfied by flat plate solar collector and electricity

LGH load is served by flat plate solar collector most of the time. Normally, solar collector is enough to serve LGH load, but in cases where insolation is not enough, electricity from IRES-MG is used to serve LGH load. 4^{th} time step in Figure IV.18 shows LGH demand is satisfied by flat plate solar collector and electricity.

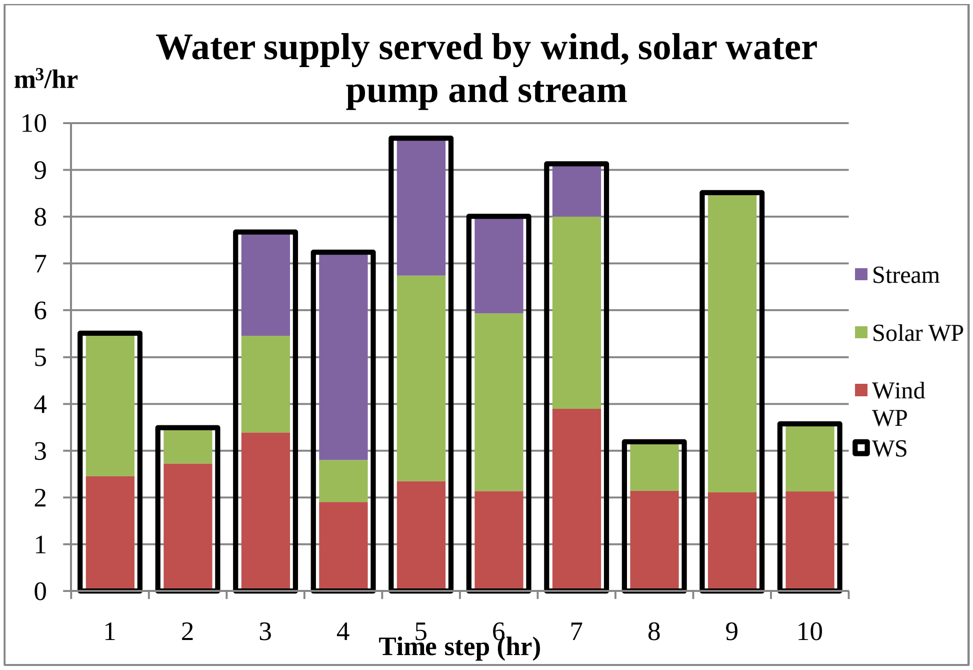


Figure IV.19: Water supply needs satisfied by solar and wind powered water pump

Water supply in this study area is needed for irrigation and domestic purposes. Wind powered and solar powered water pumps are used to pump water to fulfill water supply demand. Both water pumps, stores the water pumped in the overhead tank. If these two are not enough to supply water needs, water is pumped by electricity from IRES-MG from the stream to fulfill the water supply needs, as shown in Figure IV.19.

The efficiency of IRES-MG was calculated using,

$$E_{demand}(kWh) = E_{DC} + E_{AC} + E_{MGH} + E_{LGH} \quad (4.15)$$

$$E_{input}(kWh) = E_{PV} + E_{WECS} + E_{MH} + E_{BG} + E_{FC} + E_{BATT} + E_{biogas} + E_{SC} \quad (4.16)$$

$$\eta_{IRES-MG} = \frac{E_{demand}}{E_{input}} \quad (4.17)$$

Where, E_{DC}, E_{AC}, E_{MGH} and E_{LGH} are the hourly energy demands in kWh for DC, AC, MGH and LGH loads respectively. E_{PV}, E_{WECS}, E_{MH}, E_{BG}, E_{FC}, E_{BATT}, E_{biogas} and E_{SC} are the hourly energy generated in kWh by PV array, WECS, micro hydro, biogas generator, fuel cell, battery, biogas and solar collectors respectively. The graph of overall efficiency of IRES-MG for the 10 random simuation is shown in Figure IV.20.

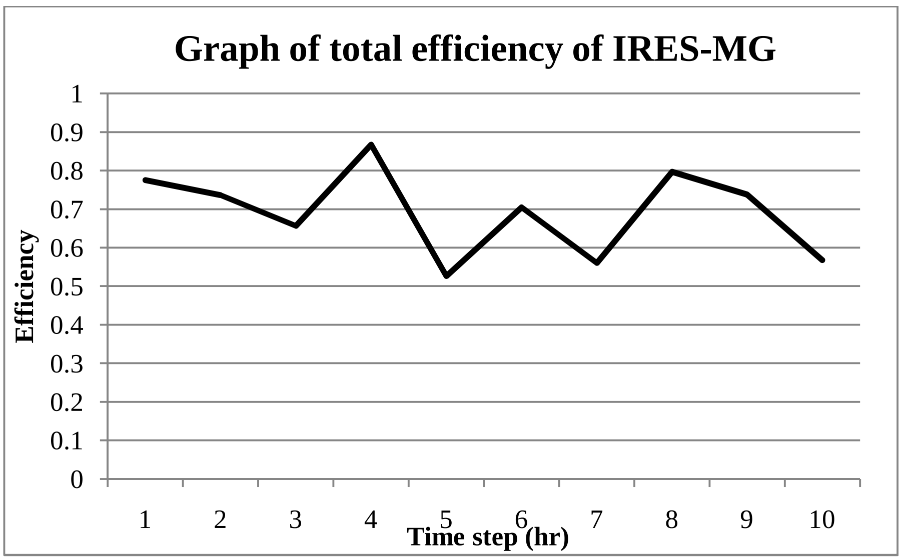


Figure IV.20: Graph showing total efficiency of IRES-MG after efficiency optimization

Figure IV.21-22 shows the variation of efficiency with input energy and energy demand of IRES-MG for randomly generated values.

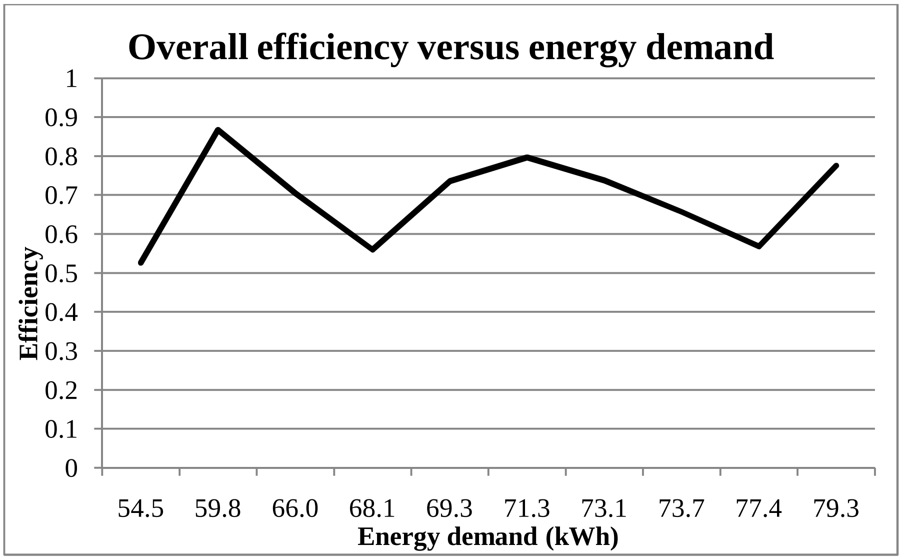


Figure IV.21: Variation of overall efficiency of IRES-MG with energy demand

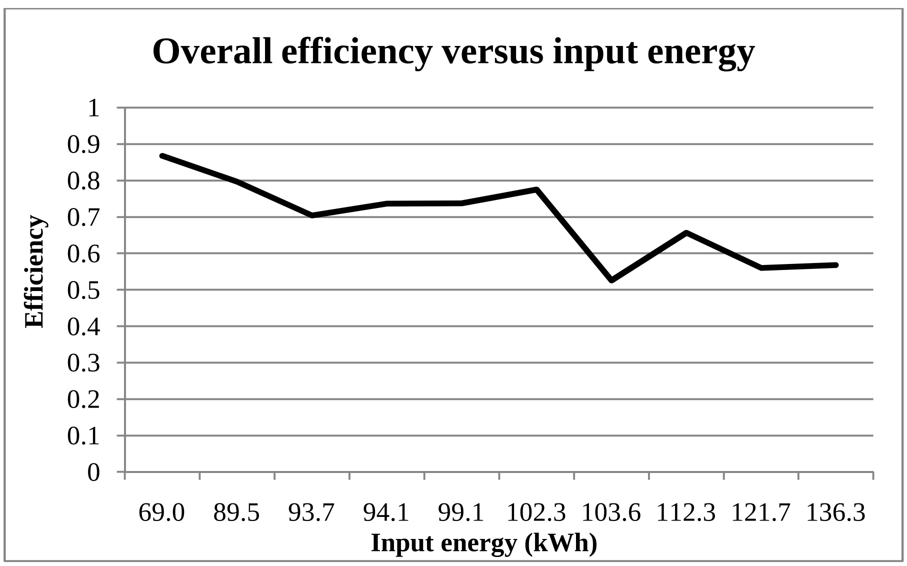


Figure IV.22: Variation of overall efficiency of IRES-MG with energy input

Figures IV.20-22 shows that, efficiency of IRES-MG is as high as almost 90% to as low as 58%. This shows that efficiency of IRES-MG is high than the individual efficiency of the components. Also the overall efficiency depends on demand and input of IRES-MG.

IV.2.3 Efficiency Comparison with HRES

Figure IV.23 shows the block diagram of HRES and Figure III.1 shows the block diagram of IRES-MG for efficiency comparison between these two systems.

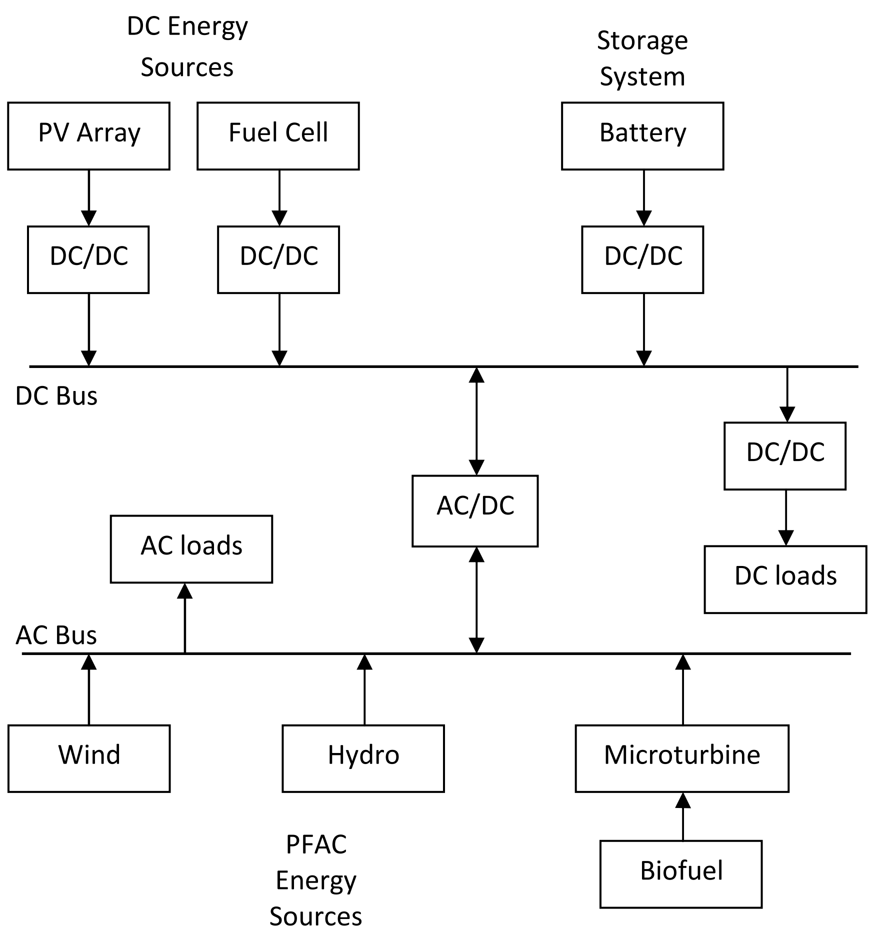


Figure IV.23: Schematic of hybrid-coupled Hybrid Renewable Energy System

Table IV.9 shows the efficiency comparison of IRES-MG with HRES for different resources like PV, WECS, micro hydro, biogas generator and fuel cell for DC, AC and thermal energy demands.

PV system					
IRES-MG					
	MPPT	DC-DC	DC-AC	AC PS	overall η
DC loads	0.99	0.97			0.960
AC loads	0.99		0.85	0.90	0.757
	Solar collector				overall η
thermal load	0.72				0.720
HRES					
	MPPT	DC-DC	DC-AC	AC PS	overall η
DC loads	0.99	0.97			0.960
AC loads	0.99	0.97	0.85	0.90	0.735
	MPPT	DC-AC	AC PS	AC-heat pump	overall η
thermal load	0.99	0.85	0.90	0.50	0.379

Wind System				
IRES-MG				
	AC-DC	DC-DC	AC PS	Overall η
DC loads	0.90	0.97		0.873
AC loads			0.90	0.900
HRES				
	AC-DC	DC-DC	AC PS	overall η
DC loads	0.90	0.97		0.873
AC loads			0.90	0.900

Micro Hydro				
IRES-MG				
	AC-DC	DC-DC	AC PS	overall η
DC loads	0.90	0.97		0.873
AC loads			0.90	0.900
HRES				
	AC-DC	DC-DC	AC PS	overall η
DC loads	0.90	0.97		0.873
AC loads			0.90	0.900

Fuel Cell				
IRES-MG				
	DC-DC	DC-AC	AC PS	overall η
DC loads	0.97			0.970
AC loads	0.97	0.85	0.90	0.742
HRES				
	DC-DC	DC-AC	AC PS	overall η
DC loads	0.97			0.970
AC loads	0.97	0.85	0.90	0.742

Battery Storage				
IRES-MG				
	DC-DC	DC-AC	AC PS	overall η
DC loads	0.97			0.970
AC loads		0.85	0.90	0.765
HRES				
	DC-DC	DC-AC	AC PS	overall η
DC loads	0.97			0.970
AC loads	0.97	0.85	0.90	0.742

Biogas Generator System/Microturbine				
IRES-MG				
	AC-DC	DC-DC	AC PS	overall η
DC loads	0.90	0.97		0.873
AC loads			0.90	0.900
	Cooking			overall η
Thermal load	0.6			0.600
HRES				
	AC-DC	DC-DC	AC PS	overall η
DC loads	0.90	0.97		0.873
AC loads			0.90	0.900
	AC PS	AC-stove		overall η
Thermal load (cooking)	0.90	0.50		0.450

Table IV.8: Efficiency comparisons of IRES-MG with HRES

The efficiency comparison table includes only the efficiency of the system components excluding PV array, WECS, micro hydro, biogas generator, fuel cell and battery storage system. For this particular HRES, the efficiency with which the sources can supply DC and AC loads is the same as that of IRES-MG. In case of thermal loads, the efficiency with which HRES can supply thermal loads is less than that of IRES-MG. This is because HRES has only one final form of energy, electricity, unlike IRES-MG which can directly supply thermal load. For example, IRES-MG can serve thermal load in appropriate energy form unlike HRES, which converts all the energy sources to electricity and then to suitable form to serve thermal load. Lot of energy conversion and losses makes HRES inefficient and expensive. Therefore, overall efficiency of IRES-MG is higher than that of HRES.

CHAPTER V

CONCLUDING REMARKS

V.1 Summary

IRES-MG is an effective and efficient system that can be employed to energize rural areas by harnessing locally available renewable energy sources. The resource-need matching employed by IRES-MG enables effective and economic means to provide energy in such areas. Optimization study of IRES-MG in for a rural community shows that the system can be implemented in cost effective manner as compared to other systems such as HRES and other present day system.

The study area is a remote rural village located at 30° 32’ N latitude and 78° 03’ E longitude. The village has a population of 700 with 60 scattered households and 450 cattle including bovine, poultries, swine etc. The study area has adequate sunshine, low to moderate wind speeds, falling water and abundant biomass year round.

IRES-MG is first cost optimized in HOMER software that resulted in an optimal configuration with a 3kW photovoltaic system, 10kW wind generator system, 9kW hydro turbine-generator, 25kW biogas powered generator system, 4kW fuel cell backed up by eight batteries with nominal capacity of 1156Ah. The optimized IRES-MG had a capital cost of $122,470, total net present cost (NPC) of $151,506, operating cost of $2,720 per year and aggregated unit cost of energy 8.6¢/kWh.

After the system is cost optimized, efficiency of IRES-MG was studied in some detail. Efficiency of IRES-MG as obtained from simulation is as high as 90% and the efficiency comparison has shown that it is more efficient than hybrid system and individual systems. Simulation results have shown that efficiency of IRES-MG is greater, especially in the case of thermal loads, as IRES-MG can supply thermal load directly, unlike HRES or grid connection.

IRES-MG is flexible enough to be adapted and upgraded, so that it can be implemented not only in a remote rural area, but also in urban communities or in a building setting. The system is self-sufficient and it can open up job opportunities as well. The implementation of IRES-MG will also bring about socio-economic benefits such as improved quality of life, lighting for studies, street lights, educational activities, communication, and provisions of water near farms and homes. As can be seen from the simulation result, biogas usage is high because of the year round availability of biomass. Using biogas for cooking and heating instead of traditional biomass results in a significant improvement in women's health. IRES-MG can be modified according to the changes in resources, needs and requirements of the community as well as the availability of new and cheaper technologies.

V.2 Scope for Future Work

Since IRES-MG utilizes the locally available renewable energy sources, it is site specific. In order to implement IRES-MG, consultation with rural communities and a detailed study of area must be done before-hand. This helps in learning about the needs and resources of the site for the resource-need matching of IRES-MG. A detailed optimization using MATLAB optimization toolbox and genetic algorithm can be done in future. A comprehensive study can be undertaken to evaluate the system performance under various conditions. Issues as voltage regulation, stability, power quality, etc. can be studied so that the system under consideration can be designed to deliver energy effectively and reliably. IRES-MG can be automated with digital devices by employing sensors and intelligent control.

IRES-MG's capability to "energize" a community with locally available renewable energy resources is based on its inherent efficient and flexible design. Hence, it can be concluded that IRES-MG will prove to be a very economical and efficient energy system, not only in the rural sector but in urban communities as well.

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APPPENDIX A

Hourly energy generation from renewable energy resources

	PV	WECS	MH	BG	FC	BATT	biogas	CSC	FPC
	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh	kWh
1	1.22	8.44	8.23	9.42	3.51	7.85	27.42	18.21	17.96
2	1.48	6.55	8.78	13.46	1.13	9.76	19.51	16.84	16.61
3	1.95	5.16	7.65	16.54	0.47	1.48	28.42	25.46	25.12
4	0.64	5.20	8.98	12.25	2.78	4.11	26.00	4.54	4.48
5	1.10	3.69	8.37	14.95	3.16	3.68	26.67	21.15	20.86
6	0.52	3.91	8.66	20.08	0.24	3.99	24.68	15.91	15.69
7	2.38	5.77	7.88	6.44	3.01	2.29	24.47	34.98	34.50
8	1.30	6.55	7.22	23.34	0.75	2.66	18.12	14.87	14.67
9	0.30	1.42	7.34	4.91	1.27	3.16	20.57	30.28	29.86
10	0.54	0.45	8.45	8.69	2.64	3.84	31.02	40.63	40.08

Appendix B

Randomly generated energy demand, energy efficiency and the efficiency of IRES-MG.

S.N.	Energy demand(kWh)	Energy input (kWh)	Efficiency
1	79.30	102.27	0.78
2	69.28	94.12	0.74
3	73.70	112.26	0.66
4	59.81	68.98	0.87
5	54.48	103.63	0.53
6	65.98	93.68	0.70
7	68.14	121.72	0.56
8	71.26	89.48	0.80
9	73.09	99.10	0.74
10	77.39	136.33	0.57

VITA

Preety Mathema

Candidate for the Degree of

Master of Science

Thesis: OPTIMIZATION OF INTEGRATED RENEWABLE ENERGY SYSTEM – MICRO GRID (IRES-MG)

Major Field: Electrical Engineering

Biographical:

Education:

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Name: Preety Mathema Date of Degree: December, 2011

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: OPTIMIZATION OF INTEGRATED RENEWABLE ENERGY SYSTEM – MICRO GRID (IRES-MG)

Pages in Study: 80 Candidate for the Degree of Master of Science

Major Field: Electrical Engineering

Scope and Method of Study: The purpose of this study was to consider cost and efficiency optimization of integrated renewable energy system – micro grid (IRES-MG) in a rural scenario. Proposed IRES-MG comprises of harnessing solar energy using photovoltaics and solar collectors, wind energy, hydro energy and biomass energy in the form of biogas. This work suggests an approach to optimize cost of energy from IRES-MG and determine optimal system configuration to meet the energy needs of a small rural area using locally available renewable energy sources. Resources and needs are matched based on a prioritized set of needs. Analysis of IRES-MG operation in order to satisfy different types of energy needs is discussed and efficiency is calculated.

Findings and Conclusions: Simulations are performed using HOMER and MATLAB software. Optimal system of 3kW PV, 10kW WECS, 25kW biogas generator, 9kW micro hydro, 4kW fuel backed up by 8 numbers of 1156Ah batteries with cost of energy of 8.6¢/kWh from IRES-MG is obtained from simulation in HOMER with given available energy resources in the study area. Results from MATLAB show that renewable energy generated from IRES-MG satisfies all the electrical and thermal demands along with water supply demands. Efficiency of IRES-MG was calculated and found to be as high as 90%. Efficiency of IRES-MG was compared with hybrid renewable energy system. Resource-need matching improves the efficiency of IRES-MG for the given optimal system configuration. IRES-MG is self-sufficient, and capable of energizing a community. The flexible design of IRES-MG will prove to be the most economical and efficient energy system not only in the rural sector but in urban communities as well.

ADVISER'S APPROVAL: Dr. Ramakumar