PRIORITY BASED APPROACH FOR OPERATION OF RURAL ENERGY CENTERS

By

HARINARAYAN SUBRAMANIAN IYER

Bachelor of Engineering

University of Mumbai

Mumbai, India

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PRIORITY BASED APPROACH FOR OPERATION OF RURAL

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Thesis Approved:

R. Ramakumar.

Thesis Adviser

Daniel R. Grischkowsky

Alfred Carlozzi

Dean of the Graduate College

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CHAPTER 1

Introduction

1.1 Background

Renewable Energy has been defined as "energy obtained from the continuous and repetitive currents of energy occurring in the environment" [1]. An ever growing human population and the consequent growth in global energy demand has put considerable strain on existing depletable energy resources to satisfy the current and future needs. Environmental issues such as green house gas emissions and acid rain, depleting fossil fuel resources, Chernobyl nuclear reactor disaster, Arab oil embargo of 1973, global warming and harmful emissions such as mercury into the atmosphere have resulted in an increased interest in the field of renewable energy. Although nuclear fuels, once considered the ultimate source of energy for the future, can be used to supply the growing energy demand, dangers of radioactive emissions, problems of spent fuel management and potential environmental damage have resulted in its downfall. With rapidly decreasing fossil fuel reserves along with rising costs, it is imperative that search for alternative sources of energy be accelerated.

1.2 Energy Dilemma faced by Developing Countries

Most of the developing countries (DCs) of the world are in Asia, Latin America and Africa. They lie in the tropical belt along the equator. With rapid growths in population and urbanization, most developing countries are facing serious problems in providing basic amenities to ensure good quality of life, especially in remote rural areas. Developing countries, on the whole, currently have a population of about 4 Billion and census reports forecast this figure to reach nearly 6 Billion in about a decade from now. As the standard of living in these developing countries increases, the per capita energy demand would increase exponentially as in developed countries. According to World Bank reports, approximately 5 million MW of additional electricity generating capacity will be needed in the next 30-40 years in developing countries alone. Supplying this additional amount of energy would require an extra investment of one Trillion Dollars [2]. Such a huge investment by the developing countries would further weaken their already fragile economies. This would result in further deterioration in the standard of living of people in these countries. As a result, one of the critical questions facing the engineering and scientific community today is how to supply this much amount of energy without putting additional strain on the economy and the environment.

The main issues faced by these resource-scarce and population-rich developing countries involve population growth, energy supplies and economic development, and mass migration from rural to urban areas. These complex problems have given rise to a new form of economy known as "Dual Economy" [3]. In this form of economy, there is a vast difference in the quality of lives of people in urban areas as compared to those in rural areas. While those in urban areas have a comparatively better standard of living, lack of energy supplies appear to be a major factor in the deterioration of the quality of life in rural areas, resulting in mass migration to urban areas. Therefore it is highly essential that development policies in such countries be aimed at providing appropriate energy supplies to rural areas in order to improve their standard of living.

Environmentally sound development is seen as a process which is primarily directed towards the following aspects:

- Satisfying basic human needs in order to reduce inequalities between and within countries.
- Indigenous self reliance through self participation and control.
- Harmony with the environment.

Such a development process needs to start with an adequate source of energy supply and efforts should be made to increase it as the demands grow. Increasing energy supply is the key to increased capacity to produce the necessities and amenities of life such as food, clothing, shelter, communication and health care, thus resulting in an overall economic development of the region and the country as whole. Increased energy supply to rural areas can be provided by either increasing the amount of energy resources bought in from outside or by efficient use of locally available resources.

It is important to recognize the fact that rural development policies should be aimed at improving the economic, social and the living environment of rural people. While deciding on such policies, various issues need to be kept in mind such as

- Threat of mass migration from rural areas to urban areas, thereby increasing the strain on energy infrastructure to supply the growing population in urban areas.
- Improve the quality of life in rural areas by proper harnessing of the labor and local resources available.

1.3 Possible Solutions to the Problem

It has often been suggested that rural electrification is the solution to the energy problem faced by developing countries. However, it is not feasible for most developing countries to provide rural electrification without causing serious difficulties to their economies. Providing electricity through electric grids to remote places with minimal loads could prove to be very expensive. As a result, most rural areas in developing countries are not connected to the grid at the present time. Also, load demands in these areas are very low and this makes the supply of electricity to these areas highly uneconomical. The main sources of energy supply in these areas are human and animal labor, and poor use of biomass (plant and animal wastes) which causes further deterioration of the environment and the standard of living of people in these areas. One of the possible solutions to this issue is the development and introduction of an Integrated Renewable Energy System (IRES) [4]. Renewable energy resources such as wind, insolation, hydro and biomass are readily available and can be harnessed in a very effective manner to supply the energy and other needs of rural areas. Over the past two decades, considerable research has been conducted in the field of renewable energy and several technologies have become commercially viable. Most attempts to provide energy to rural areas have utilized one or two forms of renewable resources to supply some of the energy requirements. This thesis focuses on a system which uses insolation, wind and biomass in conjunction to supply energy and other needs of the rural area, without depending on electricity supply through the electric grid.

1.3.1 Hybrid versus Integrated Energy Systems

While developing renewable energy systems for rural areas, two approaches have been used:

- Convert all forms of energy into one form, mostly electricity, to supply customers (hybrid systems).

- Use different renewable forms of energy to supply energy and other needs in an appropriate manner (integrated systems).

The first approach is the most conventional one since electric system technology has been well established over the years in developed countries. However, such conversions would prove to be very inefficient and the costs would further burden the economies of developing countries. For example, a biogas driven I.C engine generator set has a conversion efficiency of only 20%, whereas using biogas stoves to directly supply cooking needs has about 60% efficiency of utilization.

The second approach of not converting all renewable resources into electricity, though economical, has poor efficiency in satisfying some of the load demands. IRES uses a combination of both approaches. For example, solar heat could be used for drying and heating purposes, biomass converted to biogas could be used to supply cooking needs, wind driven water pumps could be used to pump water for potable and irrigation purposes, while at the same time, electricity could be generated using all these forms of renewable resources to satisfy certain loads such as communications, cold storage, lighting and some industrial needs.

The primary objective of an integrated renewable energy system is to provide rural energy centers (REC) with suitable forms of energy required to meet its varied requirements at the present time and to provide a base for future agricultural and industrial growth. The system should be able to provide reliable and adequate energy supply to satisfy basic household and agricultural activities as well as other social services. The technologies used in such systems should be of appropriate nature in order to meet the energy demands using locally available energy resources in an economic and effective manner.

1.4 Objective of the Study

The main objectives of this research are to study the feasibility of developing a rural energy center in an off-grid location (primarily in developing countries), utilizing locally available renewable energy resources, and to propose an approach for priority-based operation of such systems and centers.

This research envisages the concept of integrating components and systems capable of harnessing, converting and storing these distributed forms of energy as well as integrating these with the needs and operational activities of the rural area.

1.5 Work Outline

This work presents an approach for developing fully automated rural energy centers that form the core of IRES proposed to be introduced in rural areas of developing countries. Earlier work in this field comprised of using one or two forms of renewable resources in conjunction with an existing electric grid. The approach contemplates the utilization of four forms of renewable resources in an off-grid location. These resources are solar radiation, solar heat, wind and biomass. Although hydro is a possibility, it is very highly site-specific and therefore it is not included in the energy mix considered in this study. Chapter 2 discusses the basic forms of renewable resources and their availabilities around the world. It also introduces the concept of Integrated Renewable Energy Systems ($IRES$) and summarizes some of the research conducted in this field. Chapter 3 discusses some of the issues that need to be considered while designing rural energy centers. Issues such as choice of system components and rationale for choice of technology used in REC are also discussed in Chapter 3. Chapter 4 introduces the Priority Based Strategy developed to be employed in automating the rural energy center along with the associated energy flow diagram. Simulation results based on this strategy for REC are documented in Chapter 5 along with description of various scenarios considered. The thesis concludes with a discussion of the major findings, issues to be considered in dealing with such systems and scope for future work in Chapter 6.

CHAPTER 2

Literature Review

Considerable research has been conducted in the field of applications of renewable energy resources in developing countries [5] -[10]. Most of them focus on the socio-economic situation in developing countries and problems faced due to lack of suitable infrastructure. It is a well established fact now that too much reliance on fossil and nuclear fuels is not very sustainable in the long run. Issues such as high cost of electricity and achieving nuclear-non proliferation have still not been resolved satisfactorily by developed countries. Therefore, developing countries ought to be aware of these challenges before embarking on such projects. Besides, fossil and nuclear power plants require a well developed transmission and distribution network infrastructure, which most developing countries lack. Most rural areas in developing countries are located far away from the grid and development of such an infrastructure would further strain their economies. Planning agencies in developing countries need to deal with world-wide rapid depletion of available fossil fuel resources also. Too much reliance on them would force them to increase the need to import fuel resources which are expensive and subject to unpredictable geopolitical shocks. It is therefore necessary for developing countries to look for locally available renewable resources and develop methods to harness them in an efficient, effective and economical manner.

Harnessing and utilization of renewable energy resources is one of the possible and attractive solutions to improve the basic quality of life of the people in developing countries. Estimates of hydrocarbon and coal resources in developing countries and the rest of the world [11] are given in Table 2.1. Figures given are as of 1993. Reserve years were estimated on basis of constant rate of consumption.

Locations	*Oil*	*Reserve Years*	*Natural Gas*	*Reserve Years*	*Coal*	*Reserve Years*
Latin America	16.9	80	6.1	75	7.6	330
MiddleEast	23.5	121	22.7	240	0.1	40
Saharan Africa	3.0	80	3.5	700	41.3	600
DCs of Pacific	4.6	22	3.1	100	98.7	165
South Asia	0.9	15	2.3	96	42.5	335
Total for all DCs	48.9	68	37.7	160	190.2	225
Rest of the world	135.4	43	111.6	59	693.3	240
DCs % of World	36%		34%		27%	

Table 2.1: Hydrocarbon and coal reserves in Billion Tons of Oil Equivalent (BTOE) in developing countries and the rest of the world

The basic advantages and disadvantages of harnessing renewable resources in developing countries are discussed next

2.1 Advantages of Renewable Energy Resources

- Ideally suited for off-grid locations in rural areas.
- No recurring fuel costs.
- Appropriate designs can minimize maintenance needs.
- Minimal environmental hazards.
- Can aid in the economic growth of rural areas in developing countries significantly by creating local job opportunities through manufacturing, repair, maintenance and small-scale industries.

- Reduces reliance on fossil and nuclear fuels.
- Reduces green house gas emissions and the associated impacts.
- Reduces dependence on imported energy products, thereby boosting the economies of developing countries.
- Different renewable resources complement each other well over the year, contributing to the energy security and regional development of developing countries.

2.2 Disadvantages of Renewable Energy Resources

- Systems are highly capital intensive.
- Most renewable resources are highly stochastic in nature. Therefore achieving acceptable reliability will require additional components for energy storage and reconversion, further adding to the overall cost.
- Will take effort to convince policy makers and local populace of the advantages and need to utilize renewable energy resources.

2.3 Types of Renewable Energy Resources

All the renewable energy resources (except geothermal) trace back to the sun. Depending on the form, they are classified as discussed in this section:

2.3.1 Hydro Energy

Most of the developing countries (DCs) around the world have very good hydro resources [11] except in the Middle East and Saharan Africa as shown in Table 2.2 for

1990. Even though DCs have good hydro resources, they have been sparsely expolited

Locations	*Generation TWh*	*Annual Capability TWh*	*Generation/Capability %*
Latin America	344	3290	10.5
MiddleEast	42	250	16.0
Saharan Africa	39	1280	3.0
DCs of Pacific	190	2900	6.6
South Asia	100	450	22.2
Total of DCs	715	8170	8.8
Entire world	2100	13,900	15.1
DCs % of World	34%	59%	

Table 2.2: Hydroelectric resources in developing countries (TWh).

to the extent of 8.8% of their capacity as compared to the 15% figure for the entire world. In most developing countries the primary reason for this lack of exploitation has been the absence of capital resources needed for setting up the necessary infrastructure. If suitable infrastructure were available in developing countries to fully exploit their hydro resources, they could generate almost 2,800 TWh annually, which is nearly equivalent to total annual energy production world-wide in early 1990s.

This immense potential could be effectively harnessed by constructing dams across these hydro resources. However, lack of capital resources, proper infrastructure and costs incurred in transmission of power to electric grids make these projects highly uneconomical in DCs. In the case of very remote areas, especially in off-grid locations with good small hydro resources, a better alternative would be to use microturbine units to generate electricity to satisfy some of the electrical loads of the area.

2.3.2 Wind Energy

Amongst all the forms of renewable energy resources, wind energy is gaining considerable popularity, primarily for its utility in distributed generation [12]. Utilities are now showing interest in harnessing the available wind energy for generating electricity along with the other conventional forms.

Wind power systems convert the kinetic energy of wind into other forms of energy. Although wind conversion is relatively simple, designing wind turbines is a complex process. Typical size for wind turbines range from 10-1500 kW. Larger units upto 5 MW capacity are in the design stages. Rapid developments in wind technology has greatly reduced its costs, and they are now comparable with those of conventional power. Capital costs have reduced from about $2.2/W in the early 1980s to less than $1/W today [13].

Wind resources are abundant throughout the world. Wind resource distribution in various continents is given in Figure 2.1.

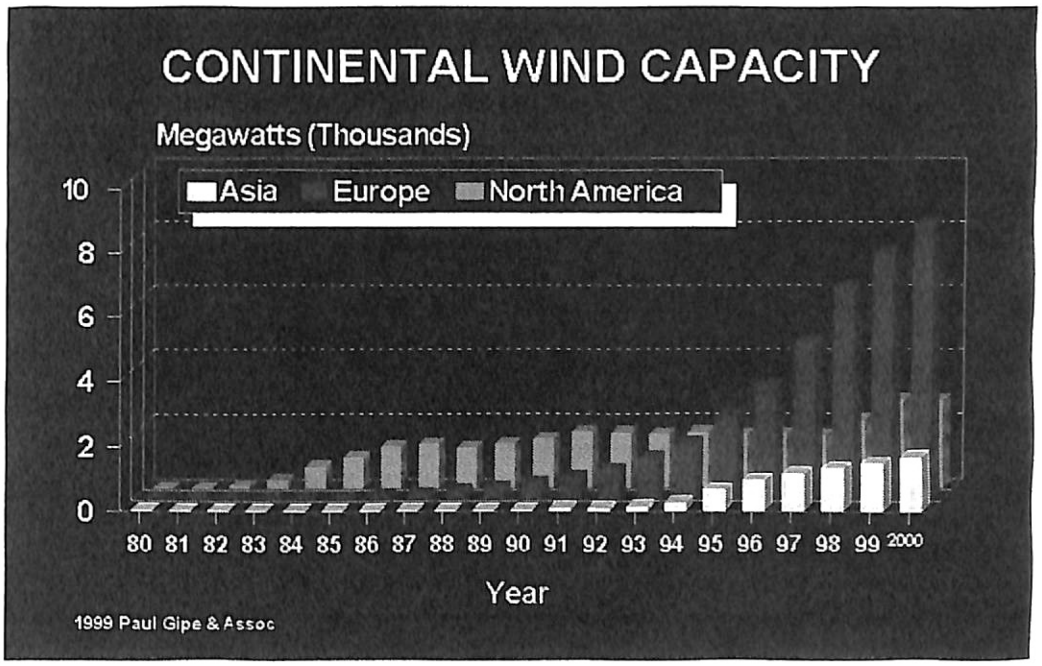

Figure 2.1: Wind resource distribution in various continents.

World wide installed wind generating capacity is given in Figure 2.2. It is estimated that about 1670 Trillion (1.67e15) kWh are available annually in the winds sweeping the land area of the earth [14].

Installed capacity in Europe, especially in Denmark and Germany has surpassed installations in US as can be seen from Figure 2.2. China has more than 100,000 wind

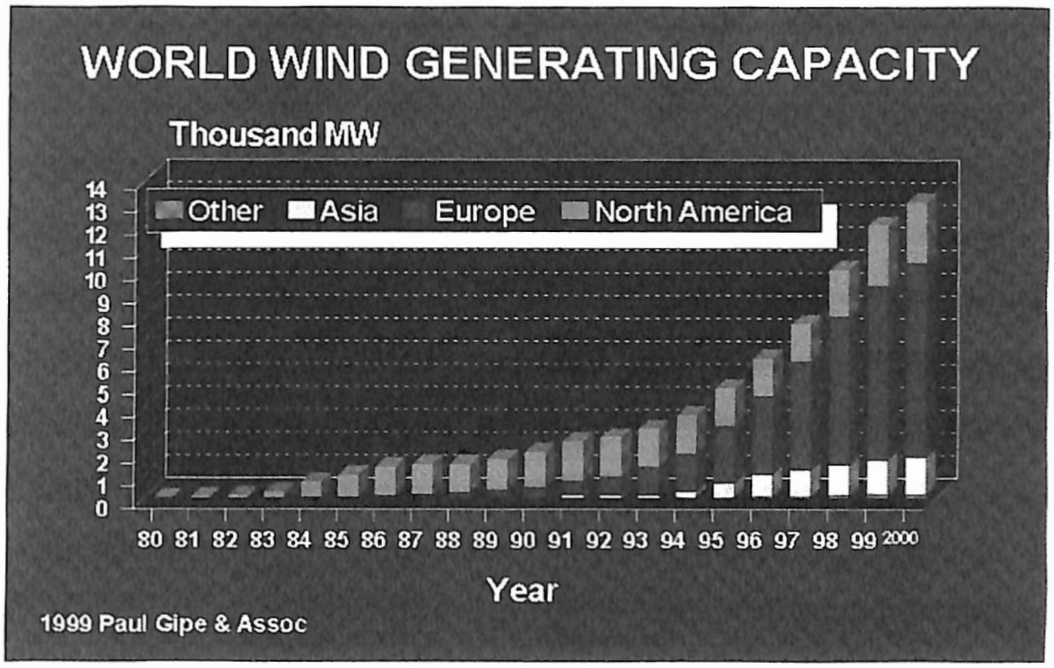

Figure 2.2: World wide installed wind generating capacity.

turbines generating electricity and pumping water in remote rural areas. According to the American Wind Energy Association, as much as 13,500 additional MW of wind capacity may be installed worldwide in the next decade or so.

2.3.3 Insolation

Insolation refers to the incident solar radiation. Even if a small fraction of the solar radiation reaching the surface of the earth is converted to electricity, it could satisfy all of the world's energy needs by itself. However, the energy reaching earth is very dilute (about 1kW per square meter on a bright sunny day near the equator) in nature and conversion to useable forms becomes very costly.

Photovoltaic devices use semiconductor materials such as silicon to convert sunlight into electricity. Efforts to develop more efficient semiconductor materials and device designs have bought down the capital costs. Capital costs for photovoltaic devices have decreased from more than $50/Wp in the early 1980s to about less than

$5/Wp today, which is still quite expensive compared to wind energy systems. However, with more research in this field, costs of photovoltaic devices are expected to go down in the next decade or so. Recent developments in the field of photovoltaics include the development of thermophotovoltaics, which uses the energy of heat to generate electricity. Thermophotovoltaics will enable generation of electricity during night time or under heavy cloud cover, eliminating the need for storage devices [15].

Photovoltaic markets have been growing steadily over the past few years. World-wide shipments of photovoltaic systems in 2000 were 288 MW; of this US had 26%, Europe 41% and Japan had 21% share [13].

Most developing countries lie along the equatorial belt. Therefore with proper infrastructure and as the cost of PV comes down, it would be possible to harness energy from available insolation on a wide scale in these countries.

2.3.4 Biomass

World-wide consumption of wood is approximately 2.8 to 3 Billion tons annually in the form of firewood and industrial applications. Energy sector uses approximately 15% of this. Combined with firewood usage, more than 50% of the wood consumption world-wide is accounted for energy purposes. This problem is more wide spread in developing countries where firewood is still the primary source of fuel, especially for cooking. Usage of firewood as the primary source of fuel has poor efficiency of utilization; and with increasing population and poverty, demand for firewood is increasing exponentially. As a result forests are depleting at an alarming rate throughout the world. In addition, large areas of rainforests are simply burnt to clear for agricultural purposes. This is resulting in depletion of the resource base for firewood and shrinking of the carbon dioxide sink.

As a result, efforts need to be made in DCs to make efficient use of available biomass resources. Instead of direct combustion of firewood for cooking, provisions should be made to use biogas stoves for cooking which have better efficiency than firewood (biogas stoves have almost 60% efficiency compared to 20% for direct firewood combustion). Animal wastes along with crop residues constitue a very good biomass resource for anaerobic digestion to produce biogas. In many developing countries special crops are being raised for use as very good biomass resource.

Recent technological developments in the field of biomass include the production of biofuels which can be used as an alternative fuel for diesel generators, direct efficient biomass combustion, gasification, and others. Direct-combustion systems burn biomass in a boiler to produce steam that can be used to drive a turbine/generator to produce power. Gasification is a process of converting available biomass resources to a fuel gas, to be substituted for natural gas in combustion turbines.

Today the US biopower industry comprises of 1000 plants, each of 20MW capacity involving direct combustion of biomass resources. Biopower capacity of the rest of world is estimated to be around 20,000-25,000 MW.

2.3.5 Geothermal Energy

Geothermal resources includes hot water, dry steam, heat from ground, hot rocks and magma. Dry steam and hot water resources are used for electricity generation while ground heat is used in heat exchange pumps. Hot water from geothermal resources can also be used commercially, for space heating and crops drying. However, this resource is extremely site specific and cannot be relied on in many parts of the world.

2.3.6 Wave and Tidal Energies

There is significant potential across various sites in the world to harness these forms of renewable energy. However the technologies required to harness them are not quiet mature, and as a result are quiet expensive. There are a few projects across the globe where experimental on-shore small-scale devices are used to provide power to electric grids.

Table 2.3. gives an indication of current and future estimated costs of generating power from different renewable resources [13].

Resource	*Current Cost cents/kWh*	*Next generation cost cents/kWh*
Photovoltaics	20-30	15 or less
Biopower	7-15	4-6
Wind Energy	4-6	2-4
Geothermal Energy	5-8	3-5

Table 2.3: Cost of energy from different renewable energy resources

2.4 Models for Integrated Energy Systems

There have been a number of pilot projects involving the use of integrated energy systems [16]-[18] across the globe. The model presented in [18] includes an economic analysis and a discussion of environmental impacts posed by integrating a photovoltaic array, wind generator system and a diesel engine generator set with the electric grid in a remote village in Alaska. Results indicate savings in the cost of fuel and less environment hazards as a result of implementing such a system.

Integrated Renewable Energy Systems (IRES) use a combination of two or more renewable energy resources in a stand alone mode to supply a variety of energy and other needs. Various methods have been presented for the design of such systems. These include chronological simulation[19], linear programming[20], probabilistic approach involving loss of power supply probability as measure of power quality (LPSP) [21] and a knowledge based approach design (IRES-KB) [4]. In the knowledge based approach, the IRES comprises of solar-thermal collectors, water turbines and pumps, wind-mechanical conversion systems (WMCS), wind-electric conversion systems (WECS), photovoltaic arrays, biogas systems, water storage and a battery energy storage system. The main objective of this approach is to obtain the best combination of PV ratings, WECS ratings and size of energy storage required for supplying the load requirements, while maintaining the required level of LPSP. Design steps include dividing the year into a number of time sections wherein it is assumed that within a particular time section load requirements and availability of energy resources remain nearly constant. Next, the ratings of PV arrays and WMCS are determined in order to satisfy low grade heat and mechanical load requirements respectively using IRES-KB software. IRES-KB uses a database system and a search strategy to find the best combination of PV and/or WECS ratings and the size of energy storage required to minimize capital costs, while maintaining the required level of LPSP. It is assumed that medium grade heat requirements (primarily for cooking) are to be satisfied using biogas, if available. Any unmet load requirements are treated as electrical loads and are to be satisfied using water-turbine driven generator. In order to obtain the ratings of all units required for satisfying the load at a predetermined reliability limit and at minimal capital cost, a database is created wherein all possible combinations of unit ratings are considered before arriving at the optimum result.

This research is an extension of the work done in above mentioned papers. In this work, a priority based strategy is proposed and developed to operate rural energy centers using locally available renewable energy resources (wind, insolation and biomass) based on a logical set of priorities.

CHAPTER 3

Design of Rural Energy Centers

While developing the priority based strategy for the operation of rural energy centers, certain preliminary steps need to be followed. These steps include:

- A study of the energy consumption pattern of the rural area under consideration.
- Translating these patterns in to energy needs according to a set of priorities.
- Estimating the available energy resources.
- Matching the available energy resources to the energy needs in order to obtain the "best fit" or "best option".
- Integration of the selected option in to the system.

3.1 Energy Consumption Pattern of the Rural Area under consideration

The rural area chosen for this research work is a typical rural village in India. The main activities in this area include agriculture, grazing of livestock, gathering firewood for fuel, fetching water for potable and domestic purposes and small scale industrial activities. This area has a human population of 400 along with a cattle population

Activities	*Energy/capita/day kWh/capita/day*	*Total needs kWh/day*
Cooking	0.9	360
Communication, cold storage and REC	0.11	44
Street Lighting and Household Electricity	0.18	72
Water pumping	0.15	60
Small-scale industries	0.2	80

Table 3.1: Typical energy requirements of the rural area under consideration

of 200 and other livestock population (sheep, pigs, chicken etc) of about 100. The energy requirements of the rural area under consideration [3] [5] is given in Table 3.1. Total energy demand per day per capita is about 1.54 kWh, whereas the total energy demand of the entire area per day (excluding cooking) is about 256 kWh/day.

Typical observations of relevance are:

- Most of the energy for consumption come from traditional renewable resources i.e. agricultural activities depend on human and animal labor and cooking is entirely dependent on firewood.

- A great deal of time and human energy is wasted in fetching water for potable and domestic consumption (average of 1.5 hr per day).

- Grazing livestock which forms an essential component of the rural economy consumes approximately 46% of human energy.

- A very small percentage of such areas are electrified, whereas major parts of the rural village depends on kerosene for domestic lighting.

These observations form the basis for designing the operation of the rural energy center. The first step in designing the REC is identifying the various energy needs of the rural area and sorting them according to a set of priorities. The basic energy needs are energy for cooking, household electricity, street lighting, small-scale industrial activities, pumping water for potable, domestic and irrigation purposes and for communication/educational devices and cold storage. Cooking is satisfied entirely using biogas and an additional woody biomass reserve is maintained for use in case of emergencies, whereas the battery storage system provides energy to REC, communication and educational devices, and cold storage. The balance of the energy needs are ordered according to the following set of priorities:

- Energy required for pumping water for potable, domestic and irrigation purposes.
- Energy required for street lighting and household electricity.
- Energy required for small-scale industrial activities.

3.2 Design of System Components

3.2.1 Wind Energy Systems

A 10 kW wind turbine (BWC Excel) is used to generate electricity whereas a separate dedicated 1.5 kW unit is used for water pumping purposes. The BWC Excel is designed for low maintenance, high reliability and automatic operation in adverse weather conditions. It is often installed on a guyed lattice tower which is available for heights ranging from 18m to 37 m. The three blades constructed of aluminum are automatically feathered in case of high winds. The output is 3 phase ac at variable frequency. The output is rectified and stored in a battery bank. The unit provides 7 kW at 25 mph and at a voltage of 110 volts dc.

A typical power output versus wind speed curve is given in Figure 3.1. (Reference : www.bergey.com)

Performance parameters for BWC Excel wind turbine are enumerated below:

- Start-up wind speed : 7.5 mph.

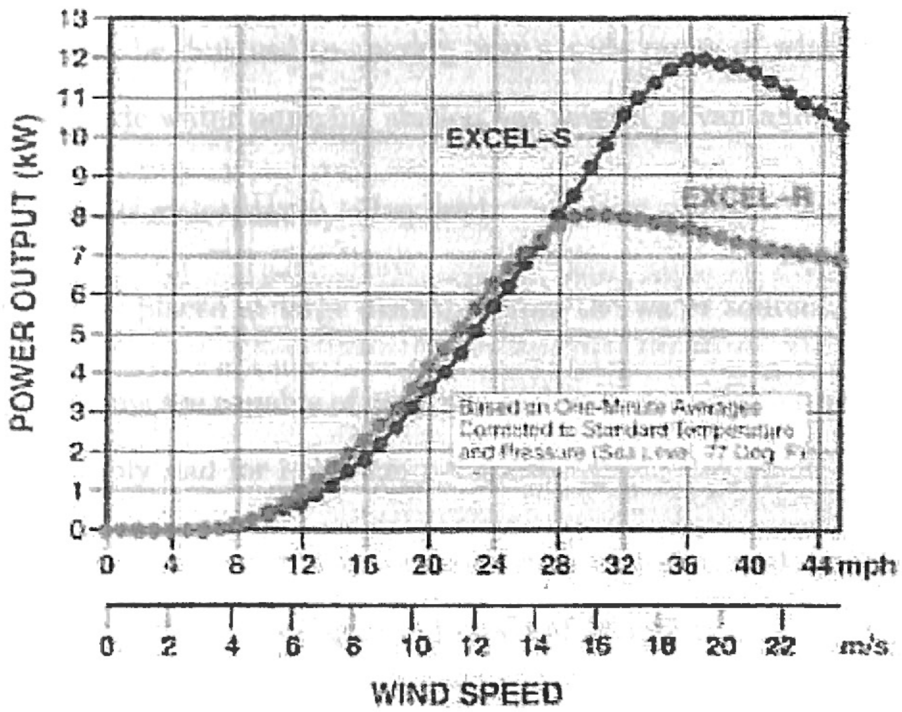

Figure 3.1: Power output versus wind speed curve for BWC Excel 10 kW class wind turbine

- Cut-in wind speed : 8 mph.
- Rated wind speed : 31 mph.
- Rated rotor speed : 310 rpm.
- Furling wind speed : 36 mph.
- Max.Design wind speed : 125 mph.

A 1.5 kW Bergey wind turbine is used in the water pumping station. Technology developed by BWC allows wind-electric pumping station to run a three phase induction motors over a frequency of 30 to 90 Hz. The system works like a conventional variable speed drive except, instead of an inverter, the variable voltage and frequency are provided directly by the turbine's permanent magnet alternator. Since the power requirements of a centrifugal pump match well with the output of a wind turbine, these systems can be designed to operate over a wide range of wind speeds. Using a wind driven electric water pumping station has several advantages

- No scheduled maintenance is required.
- They can be placed at large distances from the water sources.
- These systems are capable of pumping higher water volumes necessary for community supply and for irrigation purposes.

A typical performance of such a system consists of pumping 4800 gallons/day over a head of 100 ft and with an average wind speed of 11 mph.

3.2.2 PV Array

A 2 kW array of photovoltaic modules is used to convert available insolation into dc electricity to be used by REC for supplying various energy needs. For this design, the PV array consists of BP350U solar panels and are of silicon nitride multicrystalline type. Each panel has a maximum output power of 50W.

Specifications for BP350U solar panels are:

- Rated power (P_{max}) : 50W.
- Nominal Voltage : 12V
- Voltage at P_{max} : 17.34V.
- Current at P_{max} : 2.89A.
- Short circuit current (I_{sc}) : 3.17A.
- Open circuit voltage (V_{oc}): 21.8V.

3.2.3 Biogas Digesters

A large biogas digester with a capacity to produce approximately 240 m^3 of biogas daily is used in this design. In order to produce this amount of gas, approximately 2000 to 2500 kg of fresh dung is required on a daily basis. Most of the biomass input requirements are met by a sufficient cattle population as well as other livestock (sheep, pigs, chicken etc) population along with crop residues. The biogas produced by the digester is used for cooking purposes and to run a 20 kW IC engine/generator set as needed. The electricity generated by the IC engine/generator set is used by the REC for battery charging, water pumping as well as for satisfying other energy needs. The digested slurry is dried and sold or used as fertilizer.

3.2.4 Battery Storage System

The batteries used in the REC are regulated lead acid batteries and are capable of deep discharge and recharge cycles. In this design a 100 kWh battery energy storage systems is used. The battery system is charged through an IC engine/generator set fueled by biogas using an ac/dc battery charging system as well as through PV array and wind energy system. The battery system is used to supply power for communication and educational devices, cold storage and for the operation of REC.

3.2.5 Sensors

Sensors are installed at various locations to collect information for prioritized operation of REC. They include a pyranometer to measure available insolation, an anemometer to measure wind speed, pressure sensor to measure pressure of stored biogas in the biogas digester, sensor to monitor the state of charge in the battery bank and a sensor to monitor the water level in the overhead storage tank. These data are stored on a separate server for future analysis and use. Based on the available information, decisions are made and command signals sent to appropriate locations, to satisfy as much of the energy needs of the rural area as possible according to the pre-set list of priorities.

3.3 Choice of Technology Mix

Due to several reasons, utilization of renewable resources to improve the quality of life in rural areas of developing countries has not found wide spread acceptance. One of the reasons is the lack of maturity of technologies for large-scale global applications involving renewable resources. Most of these systems were developed for single family applications. As a result, only families which could afford these expensive hardware could use it. Also, most renewable resources are stochastic in nature. Therefore, it is very difficult and/or expensive to maintain a reliable power supply. Lack of awareness coupled with lack of funding also resulted in lack of interest in renewable energy systems. Another primary reason for this is the tendency of national policy makers to imitate the history of developed countries and opt for highly visible projects such as nuclear power plants and hydroelectric projects which wind up helping mostly urban areas.

This research involves the combined use of different renewable energy resources to satisfy most of the energy needs of rural areas. Suitable matching of the resources, hardware and needs is needed for the success of such an approach. Some of the issues involved are discussed next.

3.3.1 Wind Energy System

While choosing a wind energy system for generating electricity, the main criteria are cost, reliability of hardware and matching of system characteristics with the wind regime at the location. Typical system lifetime at present range from 20 to 25 years. Some of the other considerations are listed below:

- Lesser the mechanical components involved, greater the reliability with less maintenance needs.
- Diversity in end uses. For example, it can be used to generate electricity as well as can be used for water pumping.
- Flexible in terms of location, i.e. it can be located where the wind regime is strong, far from the rural energy centers.

3.3.2 Photovoltaic Arrays

Most developing countries lie along the equatorial belt. Therefore they have a good source of solar radiation and heat year round. As a result, energy from insolation forms a crucial renewable resource in satisfying the energy needs of rural areas in these countries. This system consists of photovoltaic panels for generating electricity. Photovoltaic panels have a useful lifespan of around 10 years. Usage of photovoltaic panels has the following advantages:

- Modularity, resulting in flexible operation.
- Minimal maintenance required.
- No moving parts, thus resulting in simpler operation.
- Can produce an effective output even with moderate cloud cover.

3.3.3 Biogas Digesters

Some of the advantages of using a biogas digester to produce biogas for cooking and driving IC engine/generator set are listed below:

- They can be fabricated using locally available materials, thus keeping the cost of construction low.
- In addition to producing biogas, they also produce slurry which is very rich in nitrogen and can be used as a fertilizer. This fertilizer can be used by the rural people or could be sold thereby improving the economy of the rural area.
- These digesters process animal wastes and crop residues and help in maintaining an improved sanitation in the rural area.
- It can be used as a effective biogas storage.

Biogas digesters have a guaranteed economic life span of over 25 years, making them an important component of an integrated renewable energy system. Energy storage in this system is in batteries, overhead storage tank (potential energy), and, in addition biogas digesters inherently store biogas. The main purpose of the battery energy storage system is to supply power required for the functioning of REC as well as to power communication and educational devices along with cold storage.

3.4 Final guidelines for designing rural energy centers

The following guidelines need to be kept in mind while designing rural energy centers [22]:

- The main goal of the REC should be to strive to satisfy the basic needs of the rural area as a whole.
- Meticulous planning and quality time spent in studying the energy patterns of the rural area goes a long way in the success of the project.

- Determining a priority list for energy needs should be based on critical aspects of rural development and on improving the standard of living of people in those areas.
- It is very essential to identify a proper mix of technologies to be used in order to optimize the available resources and match it with the needs.
- Importance of reliable power supply should not be underestimated as it goes a long way in maintaining interest amongst the local people.
- Partnering with local institutions and people living in rural areas is quite essential.
- Though the REC is designed for minimal maintenance, it is essential to train local people with the workings of the REC and its components in case some maintenance/repair is required.
- Use of locally available materials in building the REC along with its components is encouraged. This helps to keep costs down as well as improve the economy of the rural area.
- Rural tariffs need to be designed such that efficient use of electricity is ensured. Also, more subsidies should be given to poor people than the wealthier ones.
- Outright free benefits will ultimately defeat the purpose of establishing rural energy centers.

CHAPTER 4

Priority Based Strategy for the Operation of Rural Energy Centers

This chapter documents the proposed priority based strategy for the operation of rural energy centers as well the generic energy flow diagram.

The generic energy flow diagram for a rural energy center is given in figure 4.1.

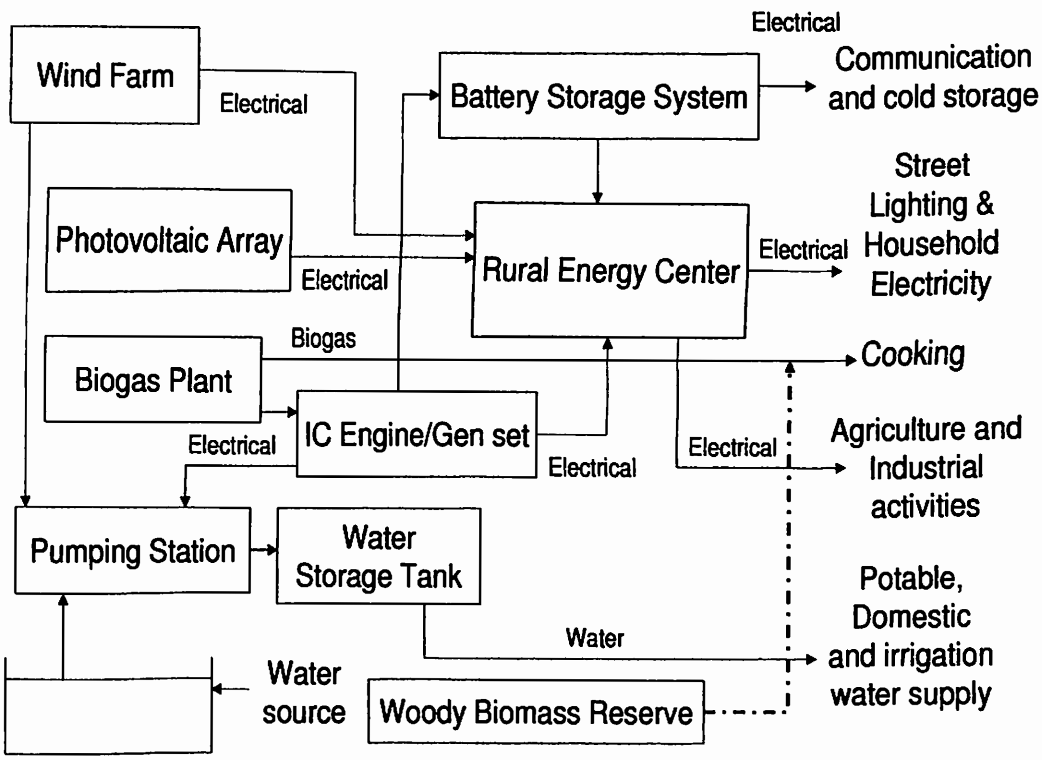

Figure 4.1: Energy flow diagram for a rural energy center

4.1 Priority Based Operation of Rural Energy Centers

4.1.1 Objective

The main objective of this work is to develop and propose an strategy to operate rural energy centers utilizing locally available renewable energy resources based on a logical set of priorities.

4.1.2 Priority Based Strategy

The various steps involved in the strategy development are outlines as follows:

- Parameters such as cut-in wind speed S_{cutin}, initial amount of stored biogas present(E_{biogas}) and maximum and minimum permissible charge levels in the battery energy storage system (E_{batmax} and E_{batmin}) are set initially.
- The rural energy center (REC) is the core of the integrated renewable energy system. Therefore it is necessary to ensure that energy supply to the REC is uninterrupted. Energy required for educational and communication devices, cold storage and the operation of REC infrastructure are aggregated and designated as E_{rec}.
- In order to ensure uninterrupted power supply to the REC, a suitable battery energy storage system is installed. It is monitored constantly to ensure that the battery charge (E_{bat}) is maintained between a minimum prescribed limit and a maximum prescribed limit.
- The energy stored in the battery (E_{bat}) is estimated and if it is insufficient to meet E_{rec}, the battery is charged using an internal combustion engine/generator

set fueled by stored biogas. If sufficient biogas is not available to charge the battery, energy from PV array or wind energy system can be used to charge the battery system. Once the energy stored in the battery reaches its maximum permissible charge (E_{batmax}), charging of the battery is stopped.

- After supplying E_{rec}, amount of biogas spent in charging the battery system through the IC engine/generator set is computed as $E_{icbattery}$.

- The remaining amount of biogas ($E_{biogasremaining}$ = E_{biogas} - $E_{icbattery}$) is stored to be used later for various purposes.

- Cooking requirements of the entire rural area under consideration for a period of 24 hours is computed as $E_{cooking}$.

- Cooking is to be satisfied entirely using biogas. If sufficient biogas ($E_{biogasremaining}$) is not available, a woody biomass reserve is maintained to satisfy the unmet cooking requirements. Any excess biogas available ($E_{biogasstored}$ = $E_{biogasremaining}$ - $E_{cooking}$) after satisfying the cooking requirements is stored to be used at a later time to run an internal combustion engine/generator system as required.

- Energy (E_{water}) required for pumping water for irrigation, potable and domestic water supply; energy (E_{light}) required for street lighting and household electricity; and energy (E_{indus}) required for small-scale industrial activities for a period of 24 hours are estimated.

- Total daily energy demand (excluding cooking) is calculated as E_{demand}= E_{water} + E_{light} + E_{indus}.

- Available wind energy (E_{wind}) for a period of 24 hours is calculated using mean hourly wind speeds and summing the estimated hourly outputs.

- Available energy from the photovoltaic system (E_{PV}) during daytime is computed.
- Total available input energy for a period of 24 hours is computed as $E_{input} = E_{wind} + E_{PV} + E_{biogasstored}$.
- If E_{input} is greater than E_{demand}, the balance available input energy can be used for other purposes such as water and space heating, crop drying and targeted small-scale industrial activities.
- If E_{demand} exceeds E_{input}, a prioritization module is started, wherein the energy needs are ranked according to their importance as follows:
  - E_{water}.
  - E_{light}.
  - E_{indus}.

  As much of the needs as possible will be met starting with the first and going down the list.

CHAPTER 5

Simulation and Discussion of Results

A remote rural village with no electric grid connection and a human population of 400 is chosen as an example to discuss the various design scenarios used for simulation purposes. The area has a cattle population of 200 and other livestock (sheep, pigs, chicken etc) population of 100. It is assumed that animal wastes are not seasonal whereas crop residues are. Proper conversion devices (digesters) are used for converting animal wastes and crop residues into biogas. The amount of biogas available per kg of dry animal wastes and its energy content are given in appendix A [23]. The various scenarios considered for simulation purposes are enumerated below:

- Scenario 1: Rural area has all the resources (wind, insolation and biomass) available for use during the entire day. (Insolation available only during daylight hours).

- Scenario 2 : Wind speed is assumed to be very low for the day. Other resources are available as in Scenario 1.

- Scenario 3 : Heavy cloud cover is present during the day, greatly reducing the output of the *PV* system; all other resources are available as in Scenario 1.

- Scenario 4 : Combination of low wind speed and heavy cloud cover is assumed. leaving biogas as the only available resource.

- Scenario 5 : Only very small amount of biogas resources is available for use during the day. The other two resources (wind and insolation) are available as in Scenario 1.

The energy needs of the area for all the scenarios is given in Table 5.1.

Energy needs kWh/day	*1*	*2*	*3*	*4*	*5*
Cooking	360	360	360	360	360
REC infrastructure	4	4	4	4	4
Communication	20	20	20	20	20
Cold Storage	20	20	20	20	20
Lighting	72	72	72	72	72
Water pumping	60	60	60	60	60
Industries	80	80	80	80	80

Table 5.1: Energy requirements for the scenarios considered

Energy resources available for all the five scenarios considered are tabulated in Table 5.2.

5.1 Simulation

Simulations were performed using the priority based strategy for rural energy centers for all the above mentioned scenarios using VisualBasic.net. The code for the program is given in the appendix B. Typical screens from the program runs are shown in

Energy resources	*1*	*2*	*3*	*4*	*5*
Animal Wastes kg/day	600	600	600	600	250
Volume of biogas *produced* m^3/day	234	234	234	234	95
Wind Energy *kWh/day*	37.5	0	42	4	70
Energy from *PV* system *kWh/day*	1.76	1.76	0.26	0.22	1.86

Table 5.2: Resources available for the scenarios considered

Figures 5.1., 5.2. and 5.3.

Figure 5.1. shows the main menu screen. Menu comprises of modules for battery charging, cooking requirements, energy requirements, available input energy and for printing the final results. Figure 5.2 shows the module used for charging the battery

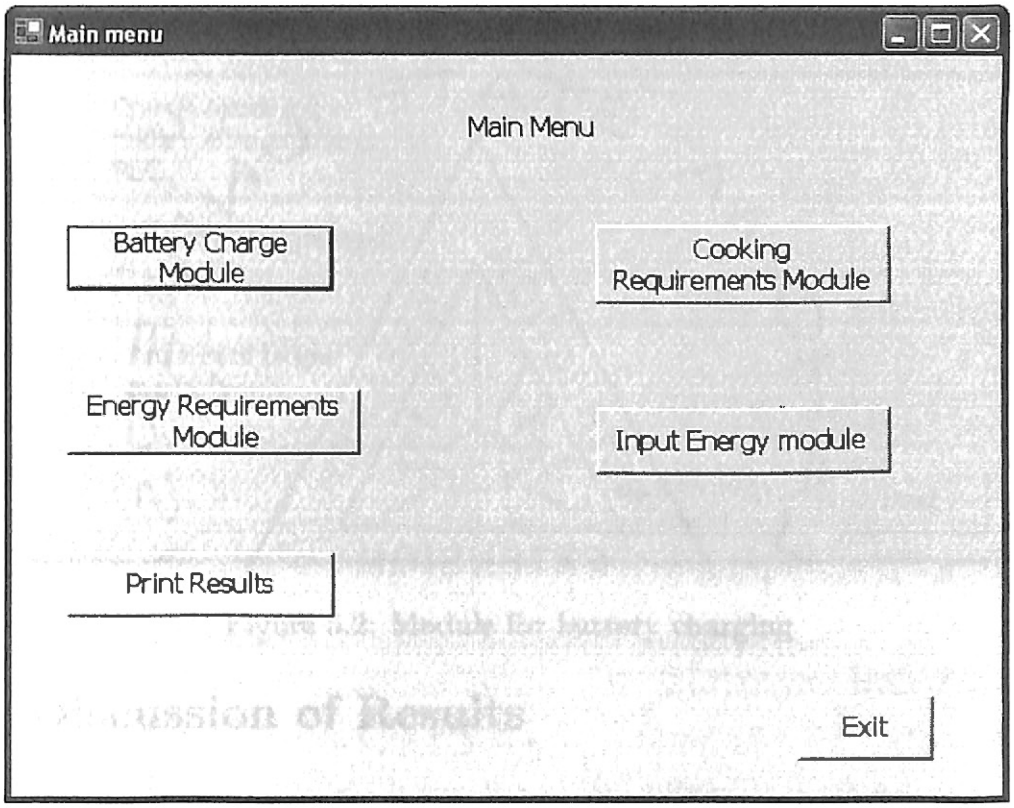

Figure 5.1: Main menu

energy storage system. If the charge battery falls below the minimum prescribed limit, REC sends a signal to charge the battery using the IC engine/generator set. Values for amount of biogas used in charging and amount of biogas remaining after charging are also displayed.

Figure 5.3 shows the energy needs (excluding cooking and REC) for Scenario 1. The figures indicate a need of 72 kWh/day for lighting purposes, 60 kWh/day for water pumping purposes and 80 kWH/day for small-scale industrial activities.

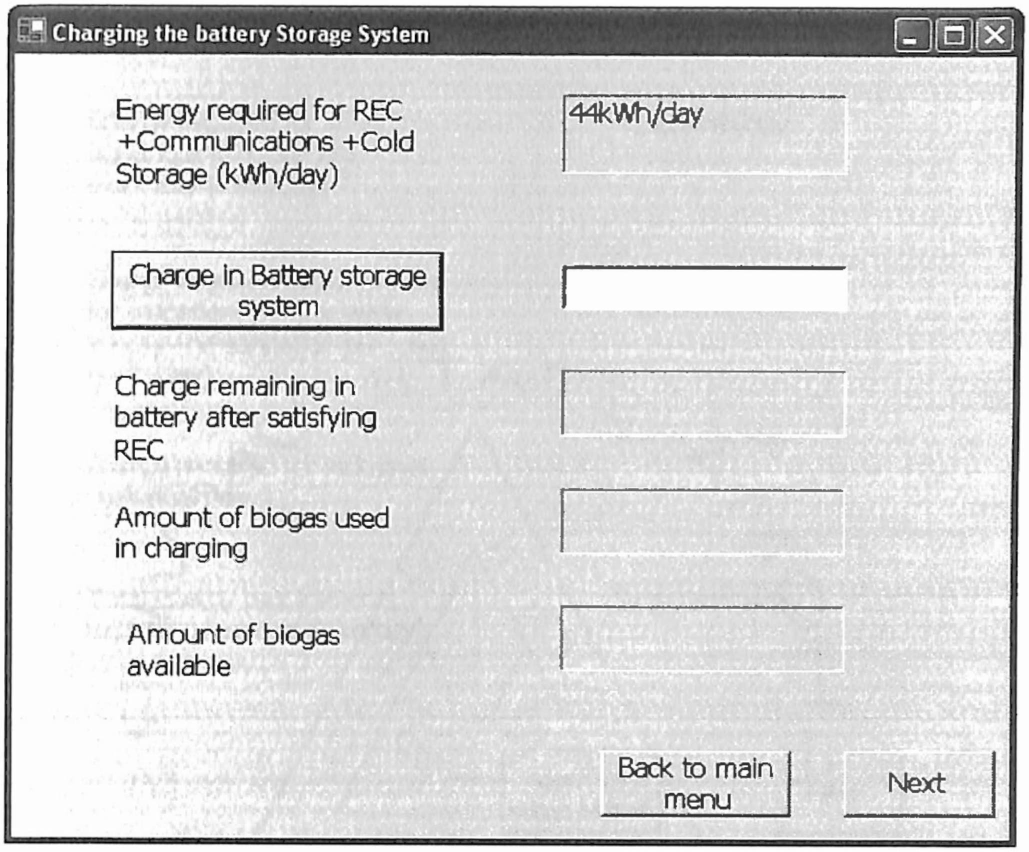

Figure 5.2: Module for battery charging

5.2 Discussion of Results

5.2.1 Scenario 1

In this scenario, cooking requirements are satisfied completely by biogas. Communication, cold storage and REC requirements are satisfied by the battery energy storage system. Available wind energy is used fully to satisfy the requirements for pumping water. Energy requirements for lighting and small-scale industrial activities are satisfied by electricity generated by IC engine/generator set fueled by stored biogas and energy from the *PV* system. Excess amount of input energy available can be used for water and space heating, crop drying and for targeted small-scale industrial activities. The results for all the scenarios are tabulated in Table 5.3.

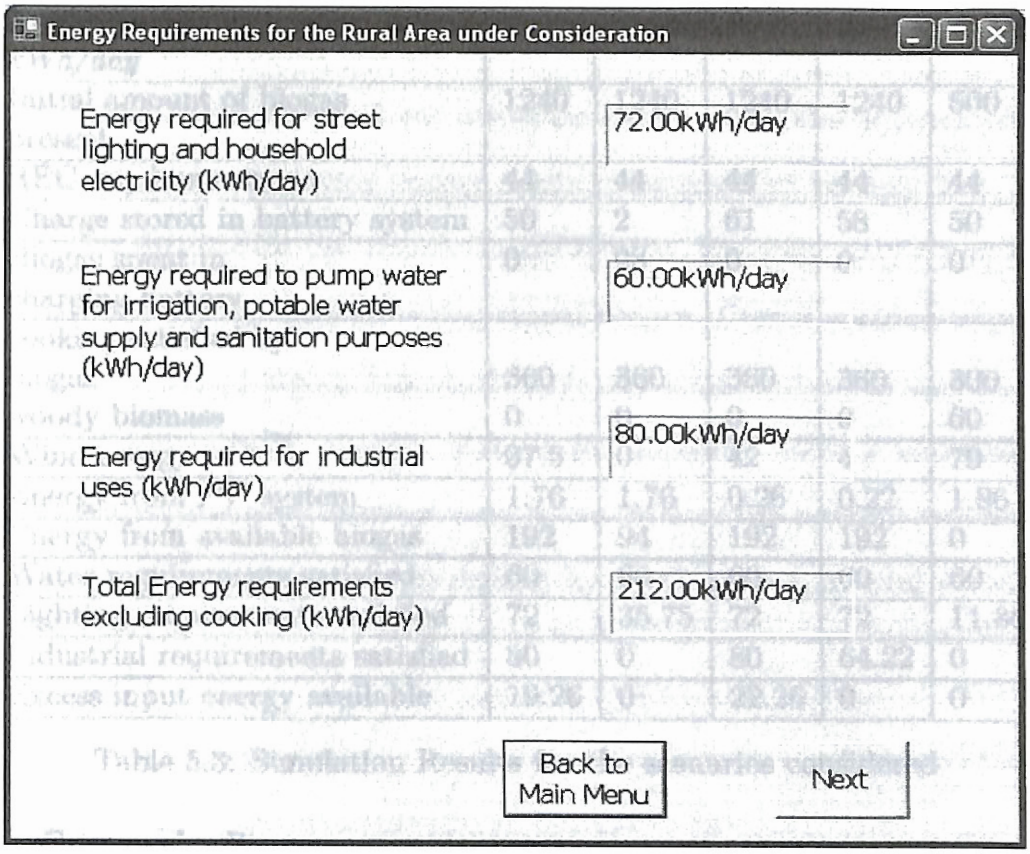

Figure 5.3: Module for energy requirements

5.2.2 Scenario 2

This scenario assumes a poor wind regime. As a result, wind electric conversion system is not useful to satisfy any needs. Cooking, REC and water requirements are satisfied completely using stored biogas. In this case, initial charge present in battery storage system is quite low. As a result, battery energy system is charged using the stored biogas. Energy available from the insolation/PV system is quite insignificant as compared to all other inputs. Since the energy needs exceeds available input energy, the prioritization module is set to action. As a result, water requirements are satisfied completely whereas only a part of the lighting requirements (about 50%) are met. Energy required for industrial activities goes unmet.

Requirements kWh/day	*1*	*2*	*3*	*4*	*5*
Initial amount of biogas present	1240	1240	1240	1240	500
REC requirements	44	44	44	44	44
Charge stored in battery system	50	2	61	58	50
Biogas spent in charging battery	0	98	0	0	0
cooking satisfied by					
biogas	360	360	360	360	300
woody biomass	0	0	0	0	60
Wind energy	37.5	0	42	4	70
Energy from *PV* system	1.76	1.76	0.26	0.22	1.86
Energy from available biogas	192	94	192	192	0
Water requirements satisfied	60	60	60	60	60
Lighting requirements satisfied	72	35.75	72	72	11.86
Industrial requirements satisfied	80	0	80	64.22	0
Excess input energy available	19.26	0	22.26	0	0

Table 5.3: Simulation Results for the scenarios considered

5.2.3 Scenario 3

In this scenario, a heavy cloud cover is assumed to be present during the entire day. Therefore, only a very small amount of energy is obtained from *PV* system. However, sufficient energy from wind and stored biogas are available to satisfy all the energy needs of the rural area.

5.2.4 Scenario 4

Both a poor wind regime and heavy cloud cover are assumed to exist for the entire day in this scenario. Cooking, REC, water, lighting and a portion of the small-scale industrial requirements are satisfied solely using energy from stored biogas.

5.2.5 Scenario 5

This is the least attractive of all the scenarios considered. The amount of biomass resources available for satisfying energy needs is assumed to be very low. REC requirements are satisfied by the battery energy system. However, only a portion of the cooking requirements are satisfied using stored biogas. Unmet cooking requirements must be satisfied using a woody biomass reserve, since this activity is very basic to the human living environment. Energy required for pumping water is satisfied entirely using available wind energy, whereas only about 16% of the lighting requirements is satisfied by electricity. Energy requirements for small-scale industrial activities goes unmet.

CHAPTER 6

Conclusions and Scope for future work

A priority based strategy for the operation of rural energy centers has been proposed and developed in this thesis. REC utilizes locally available resources such as wind, insolation and biomass to satisfy the primary needs of the rural area under consideration. Although small hydro is a possibility, it is very site-specific and therefore is not included in the energy mix considered in this study.

The primary needs of the people in rural areas include energy for cooking, household electricity, street lighting, pumping water for potable, domestic and irrigation purposes, communication and educational devices, cold storage and small-scale industrial activities. These needs are then classified according to a set of priorities, forming the base for the priority based strategy. Simulation results for various scenarios involving the priority based strategy are presented and discussed in this thesis.

Simulation results indicate that of all the renewable resources available, stored biogas is the most critical one. Since biogas is readily available and is most economical, it is the most preferred resource to satisfy the cooking needs. The rest of the needs should be satisfied by the remaining biogas (if any) and other available resources. Also, the available wind energy is primarily used to satisfy energy required for pumping water for potable, domestic and irrigation purposes as it is highly cost effective.

There are a few other scenarios, with a low possibility of occurrence that have not been considered in this thesis. In the case of a scenario comprising of poor wind regime combined with low availability of stored biogas, it is quite possible that most of energy and other needs of the rural areas may go unmet. In a situation like this, if sufficient battery charge is not present to power REC, even the REC might be forced to shut down.

In areas which have a poor wind regime and do not have sufficient cattle and other livestock population, it might be essential to install PV systems of higher ratings. This might aid in satisfying some of the needs of the rural area, but at a very high cost.

One of the future investigations in this field would involve the development of suitable sensor systems. In this thesis, we have assumed that sensors placed at various locations provide the REC with the necessary information to carry out its operation. Future work would involve determining the exact locations of the sensors and developing an infrastructure for their connection with the REC. Also, further work is needed in the field of processing the information provided by the sensors in order for the REC to make proper use of the inputs. In this thesis, we have proposed a priority based approach for the operation of rural energy centers, which is quite elementary in nature. A more sophisticated form of intelligent control using neural networks and fuzzy logic could be developed for the operation of rural energy centers in future.

Another important area of development could be the implementation of such a system in a real life situation. Data for energy needs of an actual rural area could be obtained. Using IRES-KB, appropriate ratings for PV and WECS systems could be obtained, depending on the energy needs. After selecting the ratings for all the components, the priority based strategy could be implemented for such a system in order to analyze its working in real time.

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APPENDIX A

Calculation of stored biogas energy

The Rural are under consideration has a cattle population of 200 and other livestock (sheep, pigs, chicken etc) population of about 100.

- Input of dry dung per day = 2.05 kg per animal per day.
- Total dung yield per day = 615 kg/day
- Production of gas = At 27°C, 0.38 m^3 of gas/kg of dung.
- Total gas production = 234 m^3 of gas.
- Calorific value of gas = 5.3 kwhr/m^3 of gas.
- Total amount of stored biogas available = 1240 kWhr/day.
- Burning efficiency of biogas stoves = 60% approximately.
- Efficiency of IC engine/generator set = 30% approximately.

APPENDIX B

VB.net code for Priority Based Strategy

B.1 Splash screen

```
Public Class frmmain
    Inherits System.Windows.Forms.Form

#Region " Windows Form Designer generated code "

    Public Sub New()
        MyBase.New()

        'This call is required by the Windows Form Designer.
        InitializeComponent()

        'Add any initialization after the InitializeComponent() call

    End Sub

    'Form overrides dispose to clean up the component list.
    Protected Overloads Overrides Sub Dispose(ByVal disposing
     As Boolean)
        If disposing Then
            If Not (components Is Nothing) Then
```

```
            components.Dispose()
        End If
    End If
    MyBase.Dispose(disposing)
End Sub

'Required by the Windows Form Designer
Private components As System.ComponentModel.IContainer

'NOTE: The following procedure is required by the Windows Form Designer
'It can be modified using the Windows Form Designer.
'Do not modify it using the code editor.
Friend WithEvents Label1 As System.Windows.Forms.Label
Friend WithEvents btnOK As System.Windows.Forms.Button
<System.Diagnostics.DebuggerStepThrough()> Private Sub
InitializeComponent()
    Me.Label1 = New System.Windows.Forms.Label
    Me.btnOK = New System.Windows.Forms.Button
    Me.SuspendLayout()
    '
    'Label1
    '
    Me.Label1.Location = New System.Drawing.Point(112, 32)
    Me.Label1.Name = "Label1"
    Me.Label1.Size = New System.Drawing.Size(360, 88)
    Me.Label1.TabIndex = 0
    Me.Label1.Text = "Priority Based Approach for Operation
     of
    Rural Energy Centers"
    Me.Label1.TextAlign = System.Drawing.ContentAlignment.
    MiddleCenter
    '
```

```
        'btnOK
        '
        Me.btnOK.Location = New System.Drawing.Point(440, 384)
        Me.btnOK.Name = "btnOK"
        Me.btnOK.Size = New System.Drawing.Size(96, 48)
        Me.btnOK.TabIndex = 1
        Me.btnOK.Text = "ok"
        '
        'frmmain
        '
        Me.AutoScaleBaseSize = New System.Drawing.Size(8, 20)
        Me.ClientSize = New System.Drawing.Size(560, 454)
        Me.Controls.Add(Me.btnOK)
        Me.Controls.Add(Me.Label1)
        Me.Font = New System.Drawing.Font("Tahoma", 12.0!,
         System.Drawing.FontStyle.Regular,
         System.Drawing.GraphicsUnit.Point,
          CType(0, Byte))
        Me.Name = "frmmain"
        Me.StartPosition = System.Windows.Forms.
        FormStartPosition.CenterScreen
        Me.Text = "Main Screen"
        Me.ResumeLayout(False)
    End Sub
#End Region

    Private Sub btnOK_Click(ByVal sender As System.Object,
     ByVal e As System.EventArgs)
     Handles btnOK.Click
        Dim menu As New frmmenu
        menu.Show()
        Me.Hide()
```

```
    End Sub
    Private Sub frmmain_Load(ByVal sender As System.Object,
     ByVal e As System.EventArgs)
     Handles MyBase.Load
    End Sub
End Class
```

B.2 Main Menu

```
Public Class frmmenu
    Inherits System.Windows.Forms.Form

#Region " Windows Form Designer generated code "

    Private Sub btnBatteryCharge_Click(ByVal sender As System.Object,
     ByVal e As System.EventArgs) Handles btnBatteryCharge.Click
        Dim battery As New frmBatteryCharge
        battery.Show()
        Me.Hide()
    End Sub

    Private Sub btnExit_Click(ByVal sender As System.Object,
     ByVal e As System.EventArgs) Handles btnExit.Click
        Me.Close()
    End Sub

    Private Sub btnCookingRequirements_Click(ByVal sender As System.Object,
     ByVal e As System.EventArgs) Handles btnCookingRequirements.Click
        Dim cooking As New frmcooking
        cooking.Show()
        Me.Hide()
    End Sub
```

```
    Private Sub btnEnergyRequirements_Click(ByVal sender As System.Object,
    ByVal e As System.EventArgs) Handles btnEnergyRequirements.Click
        Dim energy As New frmEnergyRequirements
        energy.Show()
        Me.Hide()
    End Sub

    Private Sub btninput_Click(ByVal sender As System.Object,
     ByVal e As System.EventArgs) Handles btninput.Click
        Dim energy As New frmenergyavailable12am
        energy.Show()
        Me.Hide()
    End Sub

    Private Sub btnPrintResults_Click(ByVal sender As System.Object,
     ByVal e As System.EventArgs) Handles btnPrintResults.Click
        Dim priorty As New frmprioritization
        priorty.Show()
        Me.Hide()
    End Sub
End Class
```

B.3 Module for Battery Charging

```
Public Class frmBatteryCharge
    Inherits System.Windows.Forms.Form

#Region " Windows Form Designer generated code "

        Dim objRandomObject As Random = New Random
    Private Sub btnNext_Click(ByVal sender As System.Object,
```

```
 ByVal e As System.EventArgs) Handles btnNext.Click
    Dim cooking As New frmcooking
    cooking.Show()
    Me.Hide()
End Sub

Private Sub btnBack_Click(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles btnBack.Click
    Dim menu As New frmmenu
    menu.Show()
    Me.Hide()
End Sub

Private Sub Button1_Click(ByVal sender As System.Object,
 ByVal e As System.EventArgs) Handles btnCharge.Click
    mdecBatteryCharge = objRandomObject.Next(0, 101)
    txtCharge.Text = CDec(mdecBatteryCharge) & "kWh/day"
    If mdecBatteryCharge > mdecErec Then
        mdecBatteryChargeRemaining = mdecBatteryCharge - mdecErec
        mdecBiogasCharging = 0D
        mdecBiogasremaining = mdecEbiogas
        lblChargeRemaining.Text = CDec(mdecBatteryChargeRemaining)
         & "kWh/day"
        lblBiogasUsed.Text = CDec(mdecBiogasCharging) & "kWh/day"
        lblBiogasRemaining.Text = CDec(mdecBiogasremaining)
         & "kWh/day"
    Else
        mdecBiogasCharging = mdecBatteryChargeMax -
        mdecBatteryCharge
        mdecBatteryCharge += mdecBiogasCharging
        mdecBatteryChargeRemaining = mdecBatteryCharge -
        mdecErec
```

```
            mdecBiogasremaining =((mdecEbiogas*mdecICengineefficiency)
            - mdecBiogasCharging)
            mdecbiogasremaing = mdecBiogasremaining/mdecICengineefficiency
            lblChargeRemaining.Text = CDec(mdecBatteryChargeRemaining)
             & "kWh/day"
            lblBiogasUsed.Text = CDec(mdecBiogasCharging) & "kWh/day"
            lblBiogasRemaining.Text = FormatNumber(mdecBiogasremaining, 2)
             & "kWh/day"
        End If
        'btnNext_Click(sender, e)
    End Sub

    Private Sub frmBatteryCharge_Load(ByVal sender As System.Object,
     ByVal e As System.EventArgs) Handles MyBase.Load
        lblErec.Text = CDec(mdecErec) & "kWh/day"
    End Sub
End Class
```

B.4 Module for Cooking Requirements

```
Public Class frmcooking
    Inherits System.Windows.Forms.Form

#Region " Windows Form Designer generated code "

    Private Sub btnBack_Click(ByVal sender As System.Object,
     ByVal e As System.EventArgs) Handles btnBack.Click
        Dim menu As New frmmenu
        menu.Show()
        Me.Hide()
    End Sub
```

```
Private Sub btnNExt_Click(ByVal sender As System.Object,
 ByVal e As System.EventArgs) Handles btnNExt.Click
    Dim energy As New frmEnergyRequirements
    energy.Show()
    Me.Hide()
End Sub

Private Sub frmcooking_Load(ByVal sender As System.Object,
ByVal e As System.EventArgs) Handles MyBase.Load
    lblCookingRequirements.Text = CDec(mdecCooking) &
    "kWh/day"
End Sub

Private Sub btnBiogasAvailable_Click(ByVal sender As System.Object,
 ByVal e As System.EventArgs) Handles btnBiogasAvailable.Click
    Dim decbiogasavailable As Decimal
    lblBiogasAvailable.Text = FormatNumber(mdecBiogasremaining
    *mdecCookingEfficiency)
    decbiogasavailable = mdecBiogasremaining *
    mdecCookingEfficiency
    If decbiogasavailable >= mdecCooking Then
        mdecBiogasremaining = (decbiogasavailable - mdecCooking)
        /mdecCookingEfficiency
        lblBiogasRemaining.Text = FormatNumber(mdecBiogasremaining)
        lblMessage.Text = "Cooking Requirements are met"
    Else
        mdecBiogasremaining = 0D
        lblBiogasRemaining.Text = FormatNumber(mdecBiogasremaining)
        lblMessage.Text = "Partial Cooking requirements are  met.
         Use reserve woody biomass for satisfying remaining
         cooking requirements"
```

```
        End If
    End Sub
End Class
```

B.5 Module for Energy Requirements

```
Public Class frmEnergyRequirements
    Inherits System.Windows.Forms.Form

#Region " Windows Form Designer generated code "

    Private Sub btnBack_Click(ByVal sender As System.Object,
     ByVal e As System.EventArgs) Handles btnBack.Click
        Dim menu As New frmmenu
        menu.Show()
        Me.Hide()
    End Sub

    Private Sub btnNext_Click(ByVal sender As System.Object,
     ByVal e As System.EventArgs) Handles btnNext.Click
        Dim energy12am As New frmenergyavailable12am
        energy12am.Show()
        Me.Hide()
    End Sub

    Private Sub frmEnergyRequirements_Load(ByVal sender
    As System.Object,
     ByVal e As System.EventArgs) Handles MyBase.Load
        lblLight.Text = FormatNumber(mdecLight) & "kWh/day"
        lblWater.Text = FormatNumber(mdecWater) & "kWh/day"
        lblIndustries.Text = FormatNumber(mdecIndustries)
```

```
        & "kWh/day"
        mdecTotalEnergyRequirements = mdecLight + mdecWater
         + mdecIndustries
        lblTotal.Text = FormatNumber(mdecTotalEnergyRequirements)
         & "kWh/day"
    End Sub
End Class
```

VITA

Harinarayan Subramanian Iyer

Candidate for the Degree of

Master of Science

Thesis: PRIORITY BASED APPROACH FOR OPERATION OF RURAL ENERGY CENTERS

Major Field: Electrical Engineering

Biographical:

Education: Received the B.E. degree from University of Mumbai, Mumbai, India, in 2000, in Electrical Engineering; Completed the requirements for the Master of Science degree with a major in Electrical Engineering at Oklahoma State University in July, 2004.

Experience: Research Assistant at Oklahoma State University from June 2002 to July 2004;

Professional Memberships: IEEE Student member since 2002