INTEGRATED RENEWABLE ENERGY SYSTEM FOR A REMOTE RURAL AREA

Ph.D. THESIS

by

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ABSTRACT

In the recent years, renewable energy resources based power generation in decentralized mode at the end user has received considerable attention for use in remote rural areas. This is because of adverse environmental impacts and high fuel cost associated with conventional energy generation. These renewable resources have enough potential for power generation in the future, because of their environmental, social and economic advantages apart from public support and government incentives. However, these resources are highly site-specific and contradictory in nature, as some of the energy sources are available in abundance during winter and others during summer. In order to make best use of such resources it is needed to utilize the strength of one resource to overcome the weakness of the other. Therefore, single technology approach, whether it is SPV system, wind, biomass, micro hydro power or any other system cannot adequately meet the demands for long period due to high cost of system as well as storage subsystem. Therefore, in order to overcome these problems, the concept of Integrated Renewable Energy System (IRES) has been propounded in meeting the energy demands of remote rural areas. These areas are far away from the utility grid and having the energy potential of locally available renewable energy resources.

Renewable energy systems generally entail high capital costs, low operation and maintenance (O&M) costs and fuel costs. It is therefore, an economic analysis is required to determine the optimum cost and benefit ratio in order to arrive at the least possible unit price of the system. In order to utilize the available renewable energy resources efficiently and economically, optimal models need to be developed. However, the modeling of an IRE system is a complicated task which requires the development of mathematical models for each component of the system. Such modeling requires optimal designing of system components to minimize the total annual cost of the IRE system.

Integrated renewable energy system is designed in appropriate and cost effective manner based on optimal modeling of locally available renewable energy resources and energy demand of a remote rural area. Therefore, IRES offers energy conservation and high energy conversion efficiency through the combination of renewable energy resources.

Based on an extensive literature review carried out under the present study, it is found that, most of the studies have focused on solar/wind/battery or solar/wind/diesel with battery storage based integrated energy systems. However, the inclusion of micro hydro power (MHP) and biomass/biogas based electricity generation system as the component of IRES is still available quite limited in literature. It is therefore, there is a scope to develop models for IRES for remote rural and far-flung areas having MHP and other renewable energy sources.

Further, the energy demand of remote area is normally kept fixed for year round application and accordingly, the sizing of renewable energy systems are carried out. The variations of load profiles, based on different seasons with different cost of appliances were not taken into account during sizing of IRE system. Also, renewable energy potential differs across geographical regions. Manufacturers consider the random potential in a geographical region while manufacturing systems for the area.The possible combination of different device types such as solar panel, wind turbine, battery system etc. having diffirent specifications were not considered in most of the stduies for desinging for IRE system. Also, in many studies different investment scenarios based appliances with demand side management strategy have not been considered during size optimization.

Keeping this in view, a cluster of 26 numbers of un-electrified villages of chamarajanagar of district of Karnataka state of India has been selected as the study area. The selected un-electrified villages are categorized into four zones based on availability of energy resources and population density of the study area. The study proposes stand-alone integrated renewable energy system to meet the energy demand of the study area based on locally available renewable energy resources such as solar, wind, micro hydro power, biogas and biomass.

A field survey was conducted for collecting data of energy resources. It has been found that potential of biomass source in the study area is found maximum followed by biogas, micro hydro, wind and solar energy. The estimated potential of all considered resources is proposed to generate electricity for all the zones considered in the study. The potential of different renewable energy resources in the study area estimated is as given in Table 1.

Table1: Estimated potential of different renewable energy sources in the study area.

Renewable Energy Resource	Zone 1	Zone 2	Zone 3	Zone 4
MHP Energy (kWh/yr)	52560	-	131400	140160
Biogas yield (m^3/yr)	74460	150380	149285	160965
Biomass Energy (kWh/yr)	145455	289425	289424	289261
Wind Energy (kWh/m^2/yr)	1097	2730	2410	2816
Solar Energy (kWh/m^2/yr)	1944	1919	1975	1925

Further, the load assessment for all four zones has been done on the basis of four different load sectors such as domestic, community, commercial and small industrial load. The load demand has been estimated by considering the total number of appliances, power ratings of each appliance and operating hours of appliances in a day in all seasons separately. Using Homer software, the total annual loads of zone 1, zone 2, zone 3 and zone 4 are estimated as 296389 kWh/yr, 394467 kWh/yr, 737810 kWh/yr and 752755 kWh/yr respectively.

The objective of the present study is to develop an optimal IRE model in stand-alone mode through optimum sizing of micro hydro system, biogas digester system and biomass gasifier (forest foliage), SPV system and wind system. In order to satisfy the energy needs in different load sectors of four different zones considered in Chamarajanagar district of Karnataka state in India, the optimum sizes of different system components with battery storage.

To solve the optimization problem, objective function with constraints, variables and constants has been defined in M-file (MATLAB code) and genetic algorithm has been used to determine the fitness function of the optimization problem. The reliability parameter has been considered based on the concept of energy index ratio (EIR) and expected energy not supply (EENS). These factors are considered as a probability reliability index to assess the feasibility of the IRE system.

Energy management strategy in remote rural area plays an important role in satisfying energy demand by utilizing the IRE system efficiently. In order to fulfill the energy requirement of the study area, an integrated renewable energy system optimization model (IRESOM) has been developed with battery storage system.

Based on the developed IREOM model with battery system, the total net present cost (TNPC) has been computed for energy index value (EIR) of 1. Three scenarios based optimal IRE model with minimum total net present cost and cost of energy have also been obtained considering optimum time scheduling of biomass generator and suitable devices of solar, wind and battery system for all the four zones. The three scenarios considered are described below;

- Scenario 1- Combination of device types

Renewable energy potential differs across geographical regions; a power source may be more dominant in one region than another. Manufacturers also consider the random potential in a geographical region while manufacturing systems for the area. Keeping this in view, the proposed study considers three device types as solar panel, wind turbine and battery system. Each device type are taken for two diffirent specifications. The eight possible combinations are obtained from 2^n base as 2 and integer *n* as the exponent of value 3. Results of eight such combinations are obtained in terms of optimal size, total net present cost and cost of energy for the proposed study area.

Optimal number of SPV panels, wind turbines and battery storage systems are found for all the four zones considering total area required by the solar PV panel, total swept area occupied by the wind turbine and SOC of the battery system for EIR value of 1.

Based on the results obtained for the considered scenarios, it is found that, solar modules each of 230 W_P rating and having area of 1.63 m^2 (Type 1), 1.4 kW wind turbines each having swept area of 4.26 m^2 (Type 2) and 24V battery rating having of 150 Ah are suggested for zone 1, zone 2 and zone 4. Wind turbine generator (WTG) of 1 kW having swept swept area of 3.14 m^2 along with Type 1 solar module and battery are suggested for zone 3. SPV and BS are common for all zones while wind turbine varies and is different for different zones.

- Scenario 2- Time scheduling of biomass generator

As load demand varies during the 24 hours in a day, the total hours in a day categorized as peak and off peak hours to represent load demand. The period between 6:00 pm -11:00 pm is considered maximum peak hours and the hours between 1:00 am - 6:00 am are considered minimum peak hours. For optimal power scheduling purpose, the 24 hours of the day categorized into two shifts of 12 hours each, are considered in the present study. To arrive at the optimal power generating schedule of the biomass generator, two different time schedules as 1:00 am to1:00 pm (TS1) and 1:00 pm to1:00 am (TS2) are considered.

Based on the time schedules of TS1 and TS2 for biomass generator, the time schedule during 1:00 pm to 1:00 am (TS2) is found to be most feasible for all four zones. This is because during this time, power generation matches peak load demand and requires less power for energy storage. This results in decrease in the system cost as number of batteries required is less.

For this scenario, a total number of 96 batteries each having 3.6 kVA rating for zone 1, 202 batteries for zone 2, 213 batteries for zone 3 and 236 batteries for zone 4 are found to be suffucient to fulfill the load demand of the study area.

- Scenario 3- Different resources combination with battery storage system

Characteristics of renewable energy resources are random in nature. Thus, to arrive at a feasible power generating solution in a region, it is necessary to consider the availability of the resources and combine them (resource combination) optimally to achieve the desired power generation at the least possible cost. Out of the five resources considered, micro hydro, biomass and biogas generated energy are considered non decision variables and the total annual energy generated by these sources is considered as fixed. On the other hand, solar and wind energy are considered decision variables as the degree of their inclusion in the system can be controlled. Their total annual energy generation depends on active area of PV panels and swept area of wind turbine. The combination of MHP, BMG, BGG and battery system with SPV and/or WTG are considered. Based on considered scenario of different resources combination with battery storage system, optimization results of three scenarios based IREOM models have been obtained. Out of the three, scenario-S2 (MHP-BMG-BGG-WTG-BS) for zone 1, scenario-S1 (BMG-BGG-SPV-WTG-BS) for zone 2, scenario-S1 (MHP-BMG-BGG-SPV-WTG-BS) for zone 3 and scenario-S2 (MHG-BMG-BGG-WTG-BS) for zone 4 are found to be more feasible for the study area. Optimal time schedules, resource combinations and device types for all zones have also been determined.

Further, considering the varying load demand and patterns of energy consumption in the four zones, three investment scenarios have also been developed. Hourly load demand has been computed for all the three scenarios for different ratings of appliances. Three different ratings of appliances as (i) high investment with low rating (HILR) appliances (ii) medium investment with moderate rating (MIMR) appliances (iii) low investment with high rating (LIHR) appliances are considered.

Simulation results of optimal sizes, total net present cost (TNPC) and cost of energy (COE) have been obtained based on with and without demand side management (DSM) strategy. Results of three scenarios with DSM strategy are compared with those of without DSM strategy. Net saving cost with DSM strategy is found to be more as compared to without DSM strategy. Further it has been observed that for zone 1 and zone 2, HILR is found to be more feasible as it involves least system cost. However, MIMR for zone 3 and LIHR for zone 4 are found to be more suitable.

Summarizing, an optimized IRESOM model comprises of SPV, WTG, MHG, BGG, BMG with battery storage system has been developed in order to meet load demand of different load sectors in Chamarajanagar district of Karnataka state of India. The developed IRESOM model has been found to be most cost effective and suitable solution to meet out the energy demand of the considered area and the model may be useful for the other similar isolated areas.