OPTIMAL PLANNING OF INTEGRATED RENEWABLE ENERGY SYSTEMS

Ph.D. THESIS

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ABSTRACT

Energy is the vital input for the sustainable development of a nation. With the rising population, the demand has increased manifold. This rising energy demand led to the evolution of some new and alternative energy resources. Unlike conventional resources, these resources are not only renewable but also environment friendly. These renewable energy resources include solar, wind, hydro and biomass. Despite having several advantages, these resources have certain limitations which constrained their dissemination. Their utilization in an integrated manner complements each other and the individual short coming can be overcome. This led to the development of integrated renewable energy systems (IRES).

Integrated renewable energy systems are the systems comprising two or more renewable energy resources supplying different energy needs in tandem. The intermittent nature of renewable energy resources like solar and wind can be overcome in these systems. With the increase in the reliability of the system, the cost of the system also increases. This led the researchers to focus on developing an optimum trade-off between the reliability and the cost of the system. In addition to the increase in reliability, the major advantage of these systems is the availability of resources even at the farthest and remotest site. The supply of energy to these sites otherwise would either be not possible or economically not viable. That's why, the development of IRES would result in the development of remote rural areas by supplying energy.

Different combinations of resources as integrated renewable energy system have been reported in the literature. These combinations include solar, wind, hydro and

biomass energy resources. In context of Indian rural energy scenario, the three most widely available energy resources are solar, wind and biomass energy resources.

The solar and wind energy resources are considered to be the most complex resources as far as their mathematical modeling is concerned. Various mathematical models have been found in the literature. The mathematical models discussed in the literature were, in general, based on either deterministic approach or probabilistic approach. Besides, techniques based on statistical and non-statistical approaches are also found in literature. These techniques, basically, are used for the development of time series models. Nowadays, the development of time series model for solar and wind energy resources has substantial scope in these types of systems.

To develop a time series model, it is important to have a series of historical data of solar radiation and wind speed. The continuous data recording, in Indian context particularly for rural areas, is a tedious task. The limited availability of solar and wind energy resources' data restrict the scope of classical statistical regression techniques and presents a good opportunity for the application of non-statistical techniques in this area. The non-statistical techniques based on artificial neural network are emerging as the good techniques for solar and wind energy modeling to overcome the data availability constraints.

Most of the work reported in the planning of IRES was focused on the sizing of resources. As far as planning of integrated system is concerned, besides sizing, the operational strategy plays an important role in analyzing the economics of the system. This left a substantial scope for the development of time-ahead operational strategy with the application of time series modeling of solar and wind energy resources.

As far as optimization techniques are concerned, various optimization techniques were reported in the literature. Classical techniques have limitations of search area and initial value definition. In the similar manner, evolutionary based algorithms have limitations of excess time and complexity. These limitations led to the emergence of hybrid techniques. Different hybrid techniques have been discussed in the literature. The application of these techniques was limited to sizing problems. This opened up a good amount of scope for hybrid techniques for the optimal planning of integrated renewable energy systems.

In this study, a rural remote site has been considered and an integrated system has been developed for supplying different demands of rural area. The considered site is a small village, named *Tapri*, with a population of 800 persons in the Kinnaur district of Himachal Pradesh, India. The main occupation of the natives is apple farming. The rural energy demands considered for the site are thermal energy for cooking, electrical energy for lighting and other uses and mechanical energy for water pumping. These demands have been estimated for the site through primary as well as secondary data collection. The thermal demands mainly comprises of cooking twice a day. The electrical demands include residential as well as common area lighting and other commercial activities. The mechanical demands include water pumping requirements for the apple farming. To estimate the demand, the entire year has been divided into four seasons, that are, December to February as season I, March to May as season II, June to August as season III and September to November as season IV.

The resource assessment is another important aspect of the problem. The solar radiations and wind speeds have been predicted using ANN based techniques. Different networks and training algorithms have been reviewed with the input and output parameters considered. Radial basis function network is then used to predict the solar radiations and wind speeds. The developed model for wind speed and solar radiations is then validated through their regression coefficient values (R-values) and root mean square error values. The R-values of solar radiations for season I-IV are found as 0.93, 0.96, 0.96 and 0.93 respectively. Similarly, the R-values of wind speeds for season I-IV are found as 0.88, 0.84, 0.98 and 0.86 respectively. The obtained models are then applied to determine the solar radiation and wind speed values in a day-ahead scenario.

The next step, after the determination of resource and load, is to obtain an optimal operational strategy such that the operational cost of the system comes out to be minimum. IRES has been worked out with different load – resource combinations. For this system, the operational strategy problem has been formulated. The objective function includes the cost of operation of different energy conversion facilities and a cost of energy not served is also included in the function. The operation cost includes the cost of generating electrical energy, thermal and mechanical energy from solar, wind and biomass energy resources cost of energy conversion from one form to another form. Various demand balance constraints for thermal, electrical and mechanical demands have been considered along with their upper and lower bounds. Mechanical load is considered as deferrable load and can be supplied at any time segment of the day. Initially, the sizes of different energy conversion facilities are assumed. This is a linear programming optimization problem and there are 266 variables with 23 equality constraints and 52 inequality constraints. The problem has been solved through Optimization Toolbox of MATLAB. The operational strategy for a typical day has been obtained different factors (α_{TL})ratio of thermal energy served to the total thermal load, (α_{EL}) ratio of electrical energy served to the total electrical load and (α_{ML}) ratio of mechanical energy served to total mechanical load are included to check the energy not served for different demands. It was found that value of 0.56kWh of thermal energy gets unserved and 0.63kWh of electrical energy remains unserved for a typical day.

For planning of IRES, it is necessary to work out the optimal sizes along with operational strategy. For optimal planning, the overall cost of the system should be minimum. Hence, the overall cost has been considered in objective function which comprises of capital as well as operational cost. The capital cost is governed by the size of energy conversion facility, while the operation cost is governed by power output at different instant of time. Hence, the developed formation has both the discrete as well as continuous variables. A hybrid EP-LP based approach under MATLAB environment has been proposed to solve the developed formation. A discrete size selection has been made through evolutionary programming (EP) and with the help of these sizes, the operational strategy has been worked out with minimum operational cost using linear programming technique. The fitness function has been evaluated by combining operational cost and capital cost.

Summarizing, the study carried out may be useful for the planning and development of IRES for a remote and unelectrified site. However, this study has wide scope of research in future. The dispatch strategy has theoretically been coined out. There is a scope of realization of proposed operational strategy by designing an adaptive controller. Besides, there is a need for reliability analysis with the inclusion of some storage devices as well as dump load.