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Hybrid Energy Assessment for Remote Areas

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ABSTRACT
Hybrid energy system is an excellent solution for small rural and remote areas. Hybrid energy system can be used to reduce dependency on either conventional energy sources or single renewable sources. Integration of one or more energy sources with energy storage device can fulfill the energy demand of remote areas. The objective of hybrid energy system is to minimize total system size, cost and fully utilize renewable sources. This paper discusses the tools available for hybrid energy assessment and a brief overview of hybrid renewable energy system and energy storage devices. A typical example of test model is simulated in HOMER software. The model includes PV, battery, convertor, load and grid is simulated and optimized.

Keywords – Hybrid Renewable Energy System, Energy Storage Devices, Software Tools.

I. INTRODUCTION

Electricity is a backbone and crucial condition for a country to be developed in terms of economy and good quality in terms of lifestyle. In many developing countries several billions of people do not have access of electricity because of geographic allocation. For example isolated and remote places where national grid is not available or a chance of reaching grid is less. At the same time due to depletion of conventional energy sources which meets most of the world energy demand and their combustion products are causing global warming, green house effect and air pollution which are posing great danger for our environment and human life [1].

Therefore, it is necessary to find alternative source of energy to fulfil the energy demand. The renewable energy resources such as solar, wind, small hydro and biomass and energy storage devices can meet demand in remote areas. But the main drawback of these renewable energy sources is that they are not available at all time in a day to throughout the year. Therefore, hybrid power generation is more efficient to generate power in remote and rural villages. [1-2]

Hybrid energy system is combination of two or more energy sources such as solar, wind biomass, generator and energy storage devices such as capacitors, batteries, pumped hydro storage, flywheel, fuel cell etc. It provides high efficiency, reliability of energy supply and reduce energy storage requirement compared to single source of energy system. But with the increased complexity in comparison with single source of system, optimum design of hybrid system is required to reduce size of system, cost of system and full use of renewable energy sources.

The important criterion in designing the hybrid system is to reduce size and capital cost of system in order to improve the efficiency. For this detail study of climatic condition for solar, wind hydro energy at a particular site is needed. This paper will concentrate on reviewing the different tools available to design hybrid energy system for remote areas and it is useful for user who intends to design hybrid system. In this paper at first, hybrid renewable energy system is discussed. Then different software available for hybrid system is presented.

II. HYBRID RENEWABLE ENERGY SYSTEM

The term HRES describes a system having different energy sources integrated to power the customers demand. HRES can be a combination of renewable energy sources and energy storage device like solar, wind, biomass and energy storage device like batteries, capacitors, flywheel, fuel cell etc.

Hybrid renewable energy system can provide power to remote areas. There are many advantages of HRES such as, Small hybrid systems are cheaper than conventional system, no any form of emission, It is best suited for off grid electrification, reliable operation, availability of abundant fuel for hybrid system free and exhaustible. A brief overview of renewable energy sources is outlined below. Banosa et al [3] gave detail analysis of various research work done in various alternative source of energy.

a. Solar energy

It is the energy radiated by the Sun, which is converted in to electricity by using photovoltaic's system. PV system consists of photovoltaic's array which converts the light photon falling on it to electrons, this generates a DC current which can be boosted by using convertors and then inverted to supply AC power to the load. There are different types of PV cells as polycrystalline, mono crystalline and thin film PV cells. The PV cells are grouped to form modules, these modules are connected in series and parallel to form array. Its output is expressed as,

$$P_P = Y_P \; f_P \left(\frac{\overline{G_T}}{\overline{G}_{T,S}}\right)\left[1 + \alpha_p\left(T_C - T_{C,S}\right)\right]$$

Where,

Y_P – rated capacity of the PV array

f_P – PV derating factor [%]

G_T – Solar radiation incident on the PV array in the current time step [kW/m^2]

$\overline{G}_{T,S}$ –Incident radiation

T_C – PV cell temperature

b. Wind Energy

Now, wind power is second fastest growing source of electricity across the world. USA and China have highest installed capacity of wind power installation capacity. According to fiscal 2014 – 2015 the total electricity generation through wind is 9.521 GWh with about a 15 % capacity utilization factor. Wind turbine converts kinetic energy in the wind in to the mechanical energy. Then, mechanical energy is converted in to electricity using generator. Wind turbine is connected to the generator through a gear box and capacitor bank provided as DC link. Mostly double fed induction generator and permanent magnet synchronous generator are used to generate electrical power.

Mechanical power output can be expressed as,

$$P = \frac{1}{4}\, \varrho A(v_1^2 - v_2^2)(v_1 + v_2)$$

Where, v_1 is the undelayed free-stream velocity, the wind velocity, before it reaches the converter, whereas v_2 is the flow velocity behind the converter

III. ENERGY STORAGE DEVICES

a. Battery

Battery is a device consisting of one or more electrochemical cells. It converts chemical energy in to electrical energy. When battery is charging, it store energy in the form of chemical and while discharging it converts chemical energy in to electrical energy [1, 6].

Mostly lead acid batteries are used in PV system. It is oldest form of rechargeable battery which is widely used. The range of batteries is from 100 watt to 20 MW [6]. The power capability of batteries can be increased by connecting series and parallel combination depending on the required application.

b. Capacitors

Capacitors charge and discharge almost instantaneously, capacitors store energy as electrostatics charge and capable of long term storage of energy with minimum losses. Double layer capacitor is used as storage device other form of capacitor like super capacitor and ultra capacitor also used. The advantages of super capacitor and ultra capacitors are long life with little degradation over hundred of thousand of charge cycle, low cost per cycle high output power, it has high power density, shorter charging time as compared to conventional batteries. The storage power capability of super capacitor is up to the 250 KW and high power density but high self discharge loss [1, 6].

c. Fuel cell

Fuel cell is similar to the battery. Both fuel cell and battery are electro chemical cell converts fuel in to electricity. It contains two electrodes separated by an electrolyte material. The hydrogen cell is mostly used. The maximum power capability of hydrogen cell is 20 MW. Features of hydrogen cell are very low maintenance, produces low emission and continuous running etc. However fuel cells are very costly[1, 6].

d. Pumped hydro storage

In pumped hydro storage plant water is stored in two reservoirs at different height. During peak periods, electricity is generated and water flows from higher reservoirs to lower reservoirs at low demand. During off peak periods water is pumped back from lower reservoirs to higher reservoirs which further generation. Therefore it is very efficient and economically in case of peak and off peak periods electricity prices and the provision of ancillary services such as load balancing, energy storage and frequency control as load changes within second etc. pumped storage plant will respond [6].

e. Flywheel energy storage system

Flywheel stores K.E. energy by using mechanical motion of a mass around a fixed axis. In this motor or generator set is used to first drive a flywheel accelerating it to a high speed and energy is stored in the form of rotating kinetic energy and this stored energy in flywheel is directly proportional to square of rotating speed and its inertia. Currently the maximum capacity of single flywheel storage system 360 MJ energy and 5 MW rated power. The charging and discharging time is very short, high efficiency and longer life. [6]

To achieve various objectives discussed in section 1 many different types of software tool have been developed and practiced. A brief overview of software is given below.

IV. SOFTWARE TOOLS FOR HYBRID SYSTEM

a. HOMER

HOMER (Hybrid Optimization of Multiple Electric Renewable) is used for technical and economical assessment and simulation of hybrid power system. HOMER was developed by national renewable energy laboratory (NREL) of the USA. HOMER performs optimization over a wide range of energy sources, convertors and load.

HOMER can simulate any system configuration which is defined by user such as solar, wind, biomass, small hydro and energy storage devices etc. It requires six types of data to simulate and optimize the model metrological data, load profile, equipment characteristics, search space, economical data and technical data. The above input data are fed in to software over time interval up to one minute [7 – 8].

Simulation and optimization

Simulation and optimization stages are done at each plan from search space. The main objective function is to minimize the constraint. The objective function of each plan is total net present cost and it is the present value of difference of total cost and sum of revenue. Total cost include initial cost, operation and maintenance cost, replacement cost and fuel cost. The revenue includes revenues from energy sold to the grid and salvage value.

Power balance constraint is the technical constraint of generator and transaction of energy with grid etc. For the given output is calculated such as NPC, operation result, generation, batteries and converter size, energy sold and purchase to the grid and emission produced [8].

Sensitivity analysis

To manage the uncertainty and to determine robustness of given optimal configuration sensitivity analysis is performed. There are some uncertainties such as solar radiation, wind speed, fuel price, variable loads, expected life time etc. has some effect on simulation and optimization stage. All these parameter are fed to HOMER with different values. After feeding these values simulation and optimization stages are repeated and new feasible and best optimization results are obtained [8].

b. iHOGA

Improved hybrid optimization by genetic algorithm is a program developed in C++ language for simulation and optimization of hybrid renewable energy system of any size. It consists of PV, wind, generator, H_2 tank, fuel cell, batteries, inverter, charge controller, Electrolyzer etc.

System optimization

The aim of optimization is to minimize total system cost throughout whole lifetime. The program allows two objective optimization functions. One is multiobjective optimization and another is mono objective optimization function. In mono objective optimization function it calculates total cost during system life time and calculates the cash flow for each year and updated with initial time and in multi objective optimization function it looks for solution with low NPC and low CO_2 emission [9]

System simulation

The system is simulated for one year, for each combination of components and control variable. The results obtained in the simulation for one year are considered to be same for the rest of life time. The procedure of simulation is similar to HOMER except some parameters are different which discussed in HOMER [9].

c. HYBRID2

HYBRID2 software is useful for long term prediction of hybrid power system performance. This software is very flexible and easy to use for power system developers to assists in the evaluation and design of rural and off grid electrification projects, hybrid software was developed by NREL and university of Massachusetts for simulation and optimization of hybrid power system.

This software contains four main parts; graphical user interface (GUI), simulation module, economics module and graphical result interface (GRI). GUI allows the user to construct project easily and maintain organized structure to all current project. Simulation and economics module allows the user to run simulation with relative ease and include error checking of input. GRI allows the user to view detail output data in graphical form.

It also requires time series data to run simulation. Time series data includes wind, solar, temperature resources, primary load, deferrable load etc. it provides output from both simulation engine and optimization package. Simulation engine includes summation of all power flow, performance of individual components, fuel usage and fuel saving. The output from economics package provides all economics figures such as payback period, internal rate of return and economics input that go in to the analysis [10 – 11].

V. TEST CASE

While simulating the case test, grid is supplying rated energy and PV produces nominal power throughout the project life time. Hybrid system consists of PV, load, battery, converter and grid connected system. Fig. 1 shows the simulation of selected case and table shows the load profile.

Solar resources used for case test at location of 18.1577° N latitude and 73.3208°E longitude was taken from Indian metrology department and ISRO website. Daly load profile and monthly solar radiation and clearance index is shown in fig.2 and fig.3 respectively.

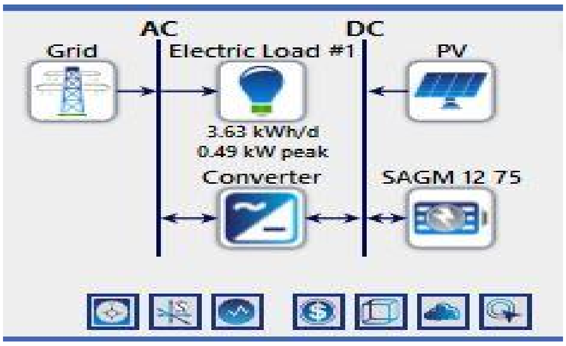

Fig 1: Simulation of test case

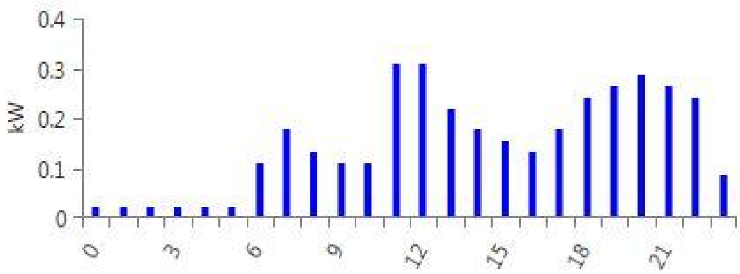

Fig 2: Daily load profile

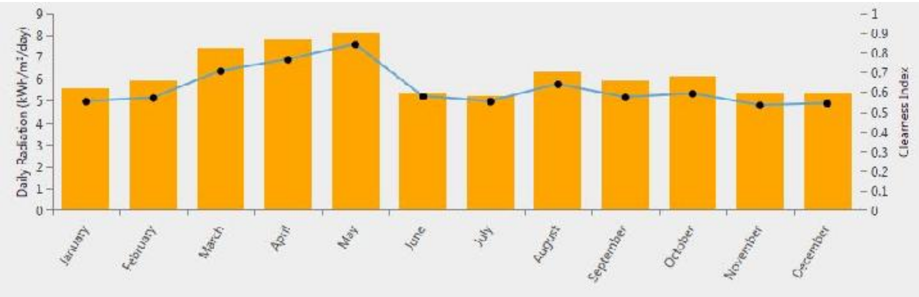

Fig 3: Daily solar radiation and clearance index

Table 1. Load demand

Metric	Baseline	Scaled
Average (kWh/d)	3.63	3.63
Average (kW)	.15	.15
Peak (kW)	.49	.49
Load Factor	.31	.31

Load Type: AC DC

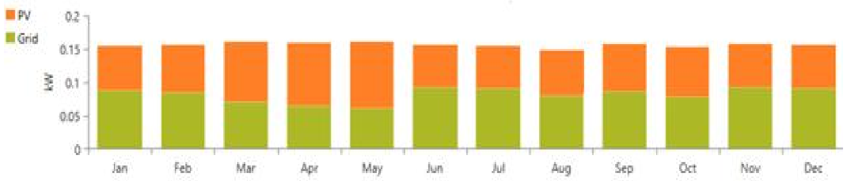

Fig 4: PV output and grid output for load

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VI. RESULT AND DISCUSSION

Table 2 shows optimization results, during optimization the number of configuration are simulated. In HOMER, different component are combined and subject to constraint like minimum renewable fraction, PV output, converter output.

Table 2. Optimization result

Architecture				Cost				System	PV		Converter		Grid
PV (kW)	Grid (kW)	Converter (kW)	Dispatch	COE (₹)	NPC (₹)	Operating cost (₹)	Initial capital (₹)	Ren Frac (%)	Capital Cost (₹)	Production (kWh)	Rectifier Mean Output (kW)	Inverter Mean Out (kW)	Energy Purchased (kWh)
	9,99,999		CC	₹ 3.25	₹ 43,154	₹ 4,306	₹ 0.00	0					1,325
0.00521	9,99,999	0.00130	CC	₹ 3.25	₹ 43,175	₹ 4,290	₹ 182.68	0.350	182	9.43	0	0.000529	1,320
0.366	9,99,999	0.326	LF	₹ 4.13	₹ 54,970	₹ 3,350	₹ 21,298	46.3	12,801	662	0	0.0700	712
	9,99,999	0.00313	LF	₹ 4.56	₹ 60,565	₹ 5,205	₹ 8,401	0.0538			0	0.0000814	1,324

VII. CONCLUSON

This paper has summarized on various tools available for hybrid energy assessment for remote and rural areas. A brief study of hybrid renewable energy system and different energy storage is presented. The current weakness of hybrid system is energy storage, with an accelerated research; the efficiency and life time of storage device have been improved to ensure optimal utilization. It is important to observe that various storage systems offer different benefits and hence selection of a proper system has to be done judiciously depending on requirement.

Out of discussed software tools, HOMER software has been used for assessment of typical hybrid system as a case study as discussed. The result as seen from table 2 and fig. 4 clearly indicate that for a given location and data series the output is quiet satisfactorily. Thus it can be concluded that HOMER software is likely to give correct assessment for a given location.

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