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Hybrid power systems- a comparative analysis

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Abstract: The present study investigates the possibility of using a Diesel Generator/SPV Power system for low-cost production of electricity which can satisfy the energy load demands of a typical remote and isolated rural area. For this the optimal dimensions to improve the technical and economical performances of the hybrid system are determined according to the load energy requirements of particular area, the solar and other available resources and the importance of supply continuity. The proposed system's installation and operating costs are simulated using the Hybrid Optimization Model for Electric Renewable (HOMER) with the solar radiation and the system components costs as inputs; and then compared with other supply option of diesel generation.

Key words: Hybrid power systems; SPV; Diesel generators; Micro grid

1. Introduction

Energy usage is considered as an important factor for development of any country. The developing countries like India have large part of its population residing in villages or rural parts of country. These places do not have proper connectivity from cities or dense populated areas, but they are rich in natural resources. For the energy needs in these rural areas, only availability resources are biomass, sun, wind or water. But these sources cannot cater direct energy needed to run various appliances i.e. electricity. Therefore, electrification in these rural areas is need of hour and can play a very important role in India's development. Such initiatives result in improvement of social and economic status of the people living in these rural areas (Chaurey, 2011). Despite the various efforts to increase the electricity production through grid connectivity, only around 56% of the total rural Indian population, has access to electric supply. Of the total un-electrified villages, large numbers are located in some of the remotest places in India. As they are far from the grid, an alternative process needs to be evolved for utilization of local resources to get electrical energy. Various renewable energy resources such as solar, wind, biomass etc. are available in these areas which can be converted to electrical energy. The only need is to evolve an energy conversion and control system which assesses the energy demand and availability of resources, and makes a hybrid system comprising of these renewable energy sources in such a way that these areas get uninterrupted electricity supply all the time. Sush systems may also have support of diesel generator for the situations when no other alternative source is available or viable (Upadhyay et al., 2015). Hybrid energy systems have received more attention from past few years because of its flexibility in selecting different resource with the application of economically feasible, reliable and hazard free alternatives, compared to commercial energy generating systems (Kusakana et al., 2009; Nehrir et al., 2011; Zhou et al., 2010; Rubio et al., 2012).

This paper presents an analysis of hybrid energy system consisting of solar photo-voltaic (SPV) energy conversion systems and diesel generation (DG) system for Jogikheri and Khandidhar villages of Chakrata tehsil in Dehradun District of Uttarakhand (India) which has location as 30 degrees 69 minutes North and 77 degrees 86 minutes east. The objective of analysis is to get a cost effective solution with uninterrupted electric power supply during the day & night throughout the year.

The paper focuses on the assessment of power demand in the designated area and available potential of the renewable energy (i.e. solar energy) and selection of the best possible configuration comprising of SPV system, storage devices and diesel generator using HOMER software. The obtained results are compared with the stand-alone Diesel Generator based power system.

2. Demand analysis

The energy demand analysis is the key factor for designing any energy supply or generation system. It requires complete assessment of the current demand as well as the future growth possibilities depending on the nature of the people residing in that area and local culture & habits. In this work, the energy demand is estimated by considering the necessary household load i.e. light lamps, TV, fan,

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radio), commercial load for shops as light lamps and fan; and community office load (Gram Panchayat office, Temples etc.). Fig. 1 shows the seasonal load profile data based on the present practices as collected during different months of year. The estimated baseline data of the probable load for all household loads, commercial load and community load is given in Table 1 for further analysis.

Table 1: Base line of the load

Metric	Baseline
Average Energy (kWh/d)	141.46
Average Power (kW)	5.89
Peak load	16.56
Load factor	0.36

3. Solar energy potential

The designated area is in the Dehradun district of Uttarakhand state and it receives very high level of solar radiation throughout the year which varies between 3.23 and 6.9 kWh/m^2 (Tyagi et al., 2009). For the selected site, i.e. Jogikheri village the annual average daily radiation, clearness index and stream flow as collected from various available sources during various months of the year are summarized in Table 2.

Table 2: Month wise solar radiation

Month	Clearness Index	Daily Radiation (kWh/m2/day)
January	0.618	3.559
February	0.628	4.419
March	0.633	5.521
April	0.635	6.486
May	0.619	6.892
June	0.586	6.711
July	0.498	5.598
August	0.527	5.509
September	0.587	5.342
October	0.678	5.033
November	0.668	4.002
December	0.614	3.287

Annual Average (kWh/m^2/day)=5.20

4. HOMER

The HOMER (Hybrid Optimization of Multiple Energy Resources) is simulation software for designing and deploying microgrids and distributed power systems that can include a combination of renewable energy sources, storage, and fossil-based generation (either through a local generator or a power grid) whether remote or attached to a larger grid. HOMER's optimization and sensitivity analysis algorithms allow to evaluate the economic and technical feasibility of a large number of technology options and to account for variations in technology costs, electric load, and energy resource availability.

5. SPV/diesel hybrid system

Since the domestic load requirements are during days as well as nights, the hybrid system to be proposed must have provisions for economically viable energy in the nights. Due to this reason, a combination of SPV and DG systems is proposed to be analyzed with and without battery storage system. Figs. 2 and 3 show these two combinations of the hybrid systems, namely SPV-Diesel generator with battery storage and SPV-Diesel generator without battery storage.

5.1. SPV system

Solar power is the conversion of the energy from the sun to usable electricity. The most common source of solar power utilizes photovoltaic cells to convert sunlight into electricity. Solar energy is a resource that is not only sustainable for energy consumption, it is indefinitely renewable. Solar energy is environment friendly and no pollution is created in the process of generating electricity. Solar panels also require little maintenance. After installation and optimization they are very reliable due to the fact that they actively create electricity in just a few millimeters and do not require any type of mechanical parts that can fail. India's theoretically calculated solar energy incidence, on its land area alone, is about 5,000 trillion kilowatt-hours (kWh) per year. As of 31 August 2015, the installed grid connected solar power capacity is 4,229.36 MW. India expects to install an additional 10,000 MW by 2017 and a total of 100,000 MW by 2022 under the Jawaharlal Nehru National Solar Mission (JNNSM) (Wikipedia).

The PV window of HOMER allows entering the cost, performance characteristics and orientation of an array of solar photovoltaic (SPV) panel as well as to choose the sizes which HOMER shall consider for optimal system. Both flat panel and concentrating PV technologies can be represented by the SPV components. A sample analysis taking size of 50 kW is shown in Table 3.

Table 3: PV characteristics

Lifetime(year)	25
Size(kW)	50
Normal operating cell temp. (oC)	18
Efficiency at standard test condition (%)	30
Slope	30.967

Solar module is the heart of a photovoltaic system. Many solar cells are wired together to form a solar module. They are composed of silicon having different structures based on which the solar modules can be of three types, namely mono-crystalline, poly crystalline and thin film (website altenergy).

Mono-crystalline solar cells are made of silicon ingots which are cylindrical in shape. They have highest efficiency but are the most expensive of all. Poly-crystalline cells are made of square shaped ingots and consist of small crystals. They are less expensive with a bit lower efficiency than the mono-crystalline cells.

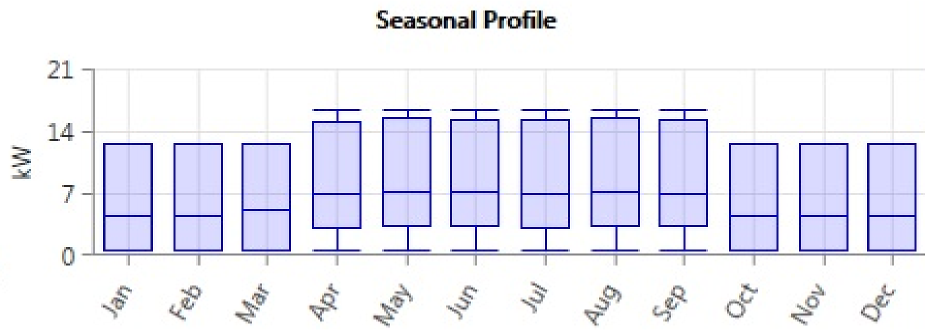

Fig. 1: Load profile (Seasonal)

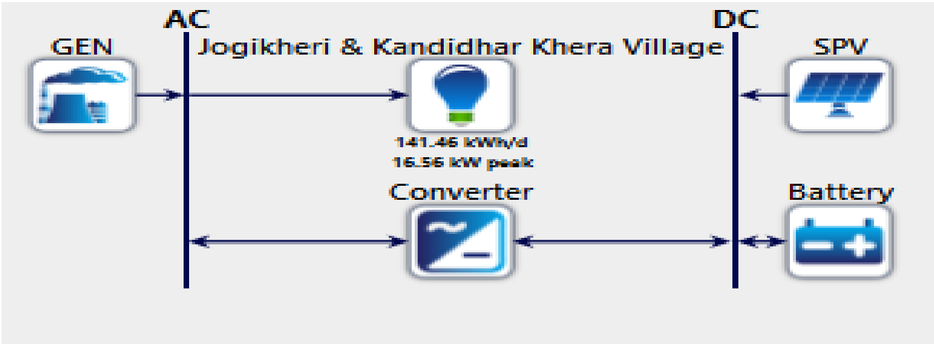

Fig. 2: Proposed hybrid SPV/DG system with battery storage

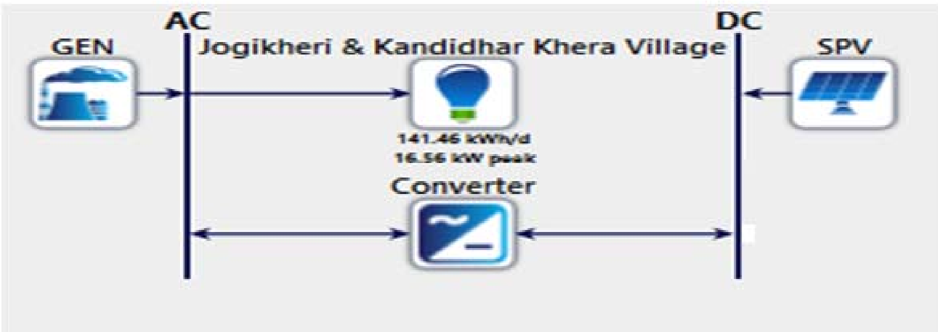

Fig. 3: Proposed hybrid SPV/DG system without battery Storage

Thin film cells are made by depositing several thin layers of photovoltaic material onto a substrate such as glass or metal. They are least expensive but have lowest efficiency as compared to others. Poly-crystalline silicon solar modules will be used here owing to their lesser cost and good efficiency. The efficiency of the solar module will be approximately 16%.

With an average of 5 sunny hours in a day and about 300 clear sunny days, the total energy generated per year by the photovoltaic plant will be 1500 kWh/sq.m per kW. Considering a 1 MW installed SPV plant, the total generated electricity shall be 1500000 kWh in year.

The total carbon dioxide emission reduced by the use of 1 MW solar plant is about 34,419.5 tonnes [website spin-grid]. One ton of carbon dioxide is equivalent to 1 carbon credit. The cost of one carbon credit is approximately 110. In an year, the total carbon credits saved are 1376.78 which will amount to 1,51,445.8 per year. Over a lifetime of 25 years, the total carbon credits saved are 34419.5 and thus the total amount will be 37,86,145. For polycrystalline solar panels, the cost per watt is about 42. Thus for one solar panel of 300W, the cost considered is 12,600.

5.2. Diesel generator

A diesel generator is simply a normal electric generator driven by a diesel engine (prime mover). The Generator window of HOMER allows feed the cost and sizing characteristics of a generator. It also provides access to the fuel resources, fuel curve, emissions, maintenance and schedule which shall be used in HOMER software. In this work, a diesel Generator of 20 KW rating is considered because diesel generators operate most efficiently when running between 70-90% of their rated capacity and become less and less efficient as the load decreases below 70% or increases above 90%. This effect can increase the maintenance requirements of diesel generators i.e. around double the normal cost and can halve their operating life (El-Hefnawi, 1998; Trihadi, 2001; El-Shafy et al., 2010).

Table 4: Generator characteristics

Company name	KIRLOSKAR
Model	KEC-E25-II
Rating(kw)	19
Cost	296000

5.3. Battery storage system and converter

A stand-alone photovoltaic energy system requires battery storage to meet the energy demand during periods of low solar irradiation i.e. night time. A Battery storage system consisting of a single string (20kW-72kW) and AC/DC converter for charging or supplying power supply to load is considered. The Converter window in HOMER software allows defining the costs of the converter as well as specifying inverter and rectifier parameters.

The converter is used to convert the DC power received from SPV Modules to usable AC power for connected loads. For maximization of power utilization, multiple maximum power point tracking (MPPT) controllers are used for these systems. The cost of such converters is considered at about 16 per watt.

6. Results and discussion

The optimum system configuration and component sizes that meet load requirements at the lowest cost are obtained by using HOMER sizing tool. The inputs treated by the software describe the solar resource availability and Diesel generator configuration; the load power and energy demand and the hybrid system component costs.

6.1. For a SPV and DG based hybrid system

For A SPV and DG based hybrid system without battery, the cost of energy comes out to be 12.97, which is quite high. In this case, the solar power contribution is 28% only as in the night time solar power shall not be available and DG has to be used for the power supply because of no storage device i.e. battery. Hence the overall efficiency of SPV and DG based hybrid system without battery shall be low.

The base values considered for the SPV and DG based hybrid system with battery storage are,

1. Net Present Cost- 48,52,261
2. Cost of Energy- 7.27

When SPV and DG based hybrid system with battery storage is used the cost of energy comes out to be 7.27. The solar resource is available only during day time. The solar component has two functions: to supply the load and to provide power that will charge the battery. The power from the battery bank is mostly used via the converter during night, peak power demands and during the time when there is no solar power available. In this case, the solar power utilization increases to 64% and rest of energy demand is met by DG sets. Thus from the month of November to February, the contribution of the SPV is low and also the load is low, SPV is used to meet the demand during the day, whereas, the DG set is to be used from 5pm to 9pm together with the battery storage system. Whereas from March to October, the generation of SPV is quite high and it is used to meet the high energy demand during the day from 6 am to 7 pm and peak demand from 7 pm to 9 pm. The simulation result is shown in Fig. 4 for the proposed system

6.2. For a DG based stand-alone system

To have comparison of the proposed system, analysis and simulation of a DG based stand-alone system in HOMER is carried out. The base values considered for the DG based stand-alone system are,

3. Net Present Cost- 90,59,565
4. Cost of Energy- 13.57

In this case, the cost of energy is 13.57 which are quite high as compared to SPV and DG based hybrid system with battery storage. Also a large number of pollutants shall be emitted as only Diesel generator is being used to meet the energy demand. Table 5 shows the list of pollutants emitted by using the diesel generator rather than the hybrid system. These pollutants will have negative effects such as global warming, cancer or mutations, depletion of ozone layer and problem of acidification.

The simulation result of the DG based stand-alone system is shown in Fig. 5 with all the data demonstrated by HOMER.

SPV (kW)	GEN (kW)	Battery	Converter (kW)	Dispatch	COE (₹)	NPC (₹)	Operating cost (₹)	Initial capital (₹)	Ren Frac (%)
50.0	19.0	1	30.0	CC	₹7.27	₹4.85M	₹212,191	₹2.11M	64
50.0	19.0		30.0	CC	₹12.97	₹8.66M	₹507,496	₹2.10M	28

Fig. 4: System simulation results of proposed SPV and DG based hybrid system

			GEN (kW)	Battery	Converter (kW)	Dispatch	COE (₹)	NPC (₹)	Operating cost (₹)	Initial capital (₹)	Ren Frac (%)
			19.0	1	30.0	CC	₹13.57	₹9.06M	₹667,604	₹429,100	0.0
			19.0			CC	₹15.85	₹10.6M	₹796,675	₹281,200	0.0

Fig. 5: Simulation results of DG based stand-alone system

Table 5: Diesel generator emissions

Pollutant	Emission(Kg/Yr)
Carbon dioxide	49841
Carbon monoxide	123.02
Hydrocarbons	13.63
Particular Matter	9.27
Sulfur dioxide	100.02
Nitrogen oxides	1097.8

7. Conclusion

The analysis and simulation of data for solar photo voltaic (SPV) and diesel generator (DG) based hybrid system with and without battery storage has been carried out to demonstrate the effectiveness of the renewable energy based micro grid system for a remote rural village electrification. The aim of this paper was to show that a SPV and DG based hybrid system with battery energy storage, satisfactorily meets the energy needs of remote areas, even at peak load in mornings and evenings with available solar radiation in the selected area.

For the selected site the proposed hybrid supply option, composed of 50kW SPV and 19kW Diesel Generator has a cost of energy (COE) of 7.27 per kWh. The diesel generator has 20kW rated output and has an annual consumption of 18927 Ltr with COE of 13.57 per kWh, which is higher than the proposed SPV and DG based hybrid system with battery energy storage. For this specific site, the hybrid system is the best option to provide cost-effective and clean electricity as compared to the other options such as grid extension or diesel generation. These results open up the ways to extract energy from other renewable energy sources available in that area such as micro/small hydro, biomass and biodiesel.

It is hoped that the presented results of this study shall be useful for deployment of hybrid SPV and DG based systems to supply cost effective electricity to customers while protecting the environment in remote rural areas where solar resources is available.

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