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Feasibility analysis of a renewable hybrid energy system with producer gas generator fulfilling remote household electricity demand in Southern Norway

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ABSTRACT

Hybrid energy system is increasingly emerging as an option to produce energy for the remote areas. This paper presented an economic feasibility analysis of a single standalone house operating with a hybrid power plant consisting of a fixed capacity producer gas generator (2 kWe) and other renewable energy sources (Photovoltaic and wind). The National Renewable Energy Laboratory's Hybrid Optimization Model for Electric Renewable (HOMER) was employed which evaluated techno-economic analysis based on the criteria of net present cost and levelized cost of electricity. Taking the site specific daily average solar radiation, average wind speed and load data into account, renewable hybrid model consisting of Bio/PV (Photovoltaic)/wind/battery/capacitor was found feasible giving 19,866 kWh/yr. of energy with a levelized cost of electricity of 0.306 kWh/yr. While comparing the hybrid system with a diesel or, natural gas generator alone, the maximum savings from CO_2 emissions worth 22,626 kg/yr. was achieved. The sensitivity analysis over a range of diesel/natural/producer gas price (0.1 \$/L to 1 \$/L or, 0.1 \$/m^3 to 1.0 \$/m^3) showed that in addition to the environmental benefits hybrid energy configuration could result economic advantages when the producer gas price does not exceed the threshold of 0.1 \$/m^3.

1. Introduction

Energy is a single most commodity mankind deals every day. Yet, its ceaseless availability is not always guaranteed and the production is often associated with familiar issues like carbon footprint, low efficiency and resource depletion. To reverse these challenges and to enhance reliability, energy needs be produced from alternative sources such as from wind, solar and biomass and the access should be achieved through viable pathways so that demands both at centralized and decentralized levels are feasibly met.

As a country, Norway has an exemplary share of renewable energy worth ~95% of the total production capacity due thanks to its wealth of hydroelectricity [1]. Although hydropower is one of the most promising sectors of renewable energy, the nation is also blessed with other potential sources such as wind and biomass [2]. With the availability of blend of renewable resources, Norway as a Kyoto ratified country is nicely shaped to fulfill its commitment towards reducing 30% CO_2 emissions by the year 2020 [3]. The drive towards meeting the targeted CO_2 reduction could be directed in multiple areas at several scales and levels where the integration of various forms of renewable energy would be the key.

In terms of the availability of various forms of renewable energy, Southern Norway, especially Grimstad (58° 20′ 25″ N, 8° 35′ 36″ E) is particularly attractive. Due to the preferential geographical locations, this area is heavily endowed with high solar irradiation with annual horizontal insolation of around 900 kW h/m^2 [4]. It also has wide range of forest resources [5] as well as abundant wind [6]. However, the electricity production from solar energy in Grimstad, likewise entire Norway, is not significant [7]. Total electricity generation from wind is also far too small compare to the demand because of the lack of initiative and investment. Although solar and wind contain a huge potential to be converted into energy, the major constraints regarding these sources are unreliability and unpredictability [8]. A stand-alone renewable energy plant operating 100% with solar energy may be unrealistic, as power cannot be produced during the cloudy days when sunlight is unavailable. Alternatively, a stand-alone system operating solely with wind turbine is also infeasible throughout the year due to the unusable production of power when wind speed goes below 3 m/s or,

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above 20 m/s (for the wide range of wind turbine capacity) [9]. Thus, to avoid this problem, hybrid energy system can offer a valuable alternative which involves two or, more sources of energy for fulfilling a particular demand. Typical hybrid energy system for instance can combine a fossil fuel generator either with solar or, wind energy or, both. A number of documented researches have demonstrated that hybrid energy systems are more suitable than single source energy systems in terms of economic feasibility and reliability. In fact, renewable hybrid energy systems have been a topic of investigation in many contemporary works. For example, a Biomass gasification/PV hybrid energy system was modeled and validated by Ref. [10] for power supply to a decentralized section of a renewable energy research building in Congo for which the optimum size and cost of the power plant units were determined. The results indicated that hybrid energy system as an isolated unit is feasible to satisfy the power demand of an independent research center in Congo. In another work [11], a standalone hybrid system consisting of wind/PV/fuel cell (FC) was modeled to determine the power demand management of a remote area in a Pacific Northwest region in the USA using real climatic data both for winter and summer scenarios. The results showed that the proposed hybrid system is effective for regulating round the year power demand of the remote municipalities. In addition to the small scale plants, hybrid energy systems of large scale capacity providing power for a remote hotel located in subtropical coastal area of Queensland, Australia, was assessed in a study by Ref. [12] for several combinations of renewable energy system. Feasibility analysis revealed that hybrid plant based on wind energy conversion system (WECS) exhibited potential long-term advantages in terms of Net Present Cost (NPC) for tourist resorts requiring stand-alone electricity. Further, Ashok K [13] modeled and analyzed the several configurations of renewable hybrid systems capable to provide electricity demand of a remote village in south Kerala, India. The main objective of the study was to find an optimum combination of energy sources which are attractive in terms of least life cycle cost. It was concluded that micro-hydro-wind was optimum in terms of both economics and environments, provide electrification to the rural remote community at a unit cost of 6.5 R s/kWh. Lately, Khan et al. [14] proposed a technique where renewable hybrid configuration featuring PV/biogas digester/membrane distillation (MD) was considered for a purpose of producing energy as well as of supplying pure drinking water to the inhabitants of a remote village (Panipara) located in Bangladesh. After feasibility analysis it has been concluded that hybrid energy plant offers a clear economic advantage in a case when including with the utilization of renewable electricity the by-products from the biogas digester is used as fertilizers for on-farm application.

Based on these facts, techno-economic analysis of a renewable hybrid energy system meeting energy demand of a standalone house in Southern Norway is proposed in this paper which, to the best of the author's knowledge, has not been investigated in the past. The other aspect of this work which is the addition of wood gas generator in hybrid system has been scarcely explored in the previous literature and hence making the context of this study interesting both in regard to the local bioenergy as well as to the standalone renewable electricity.

2. Methods

To evaluate the suitability of producer gas (PG) generator in meeting a single household electricity demand, first an energy system comprised of a fossil fuel generator was designed followed by analysis in terms of cost, energy and emissions. Subsequently, a series of hybrid configurations consisting of producer gas generator and one or, two other renewable energy options was developed and the techno-economic parameters were evaluated. The results obtained from all the configurations afterwards were compared and the optimum solution was identified.

The average consumption of electricity for a typical household in Norway was assumed as according to the data provided by the study [15] and presented in Fig. 1 while the demographic and the energy data as relevant to calculation were used from a reliable statistical reference such as Statistics Norway [16] and the cost of energy devices were carefully estimated as according to the current market prices and pertinent literature sources. The design, simulation and optimization of the energy systems were carried out by using a simulation tool HOMER developed by the National Renewable Energy Laboratory (NREL) allowing free access to the users over a definitive period. HOMER analyzes feasible energy system configurations from among number of possibilities based on the ascending net present cost (NPC).

The details of the energy systems including cost and other parameters as considered in this study are given in the following subsections.

2.1. System architecture

2.1.1. Mono energy system

Mono energy system model was developed based on the conventional energy devices such as diesel or, natural gas generator capable of supplying the entire household electricity demand round the year. One configuration for each fuel with a generator (2.5 kWe), battery (2 units, 2.16 kW h each) and a converter (1 kW) was designed and corresponding simulation was performed. The simulation results were subsequently optimized based on the least plant cost and best match energy supply scenarios.

The sensitivity analysis was additionally performed as against the range of diesel and natural gas prices between 0.1 and 1.0 $/kWh with a step of 0.1 $ increase. The design of mono-energy system in the HOMER platform is presented by Fig. 2.

2.1.2. Hybrid energy system

Hybrid energy model for several combinations was formulated by keeping producer gas generator as a mandatory option. The producer gas generator was assumed to be integrated with an existing gasification plant capable to produce minimum 2 kW of electricity. In this case, the gasification facility available in the University of Agder was considered as a model gasification plant which can produce maximum 5 kW of electricity.

Besides producer gas generator, the other components added to

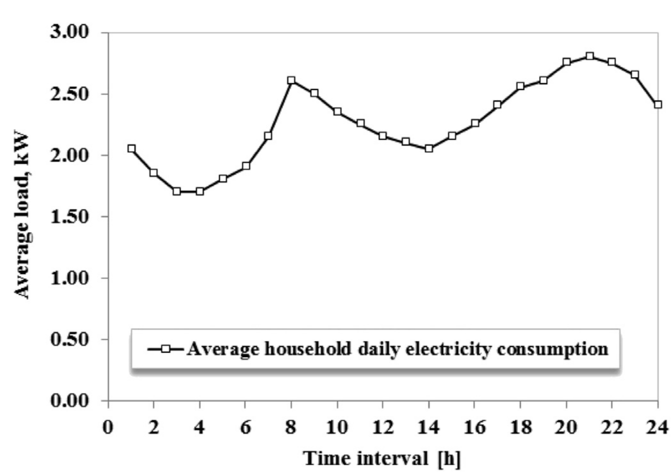

Fig. 1. Average electricity consumption of a typical household in Southern Norway.