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An economic analysis of a stand-alone and grid-connected cattle farm

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ABSTRACT

This paper presents an economic study of electricity supply to a dairy cattle farm of 50 livestock units. We compared a stand-alone battery-wind-diesel hybrid system with an only-grid connected system and we analyzed four locations in Spain with different average wind speeds. The farm's electricity demand is 63 kWh/d and the hybrid system designed for its supply is made up of a 20 kW wind turbine, a diesel generator and a battery. All simulations were made with the HOMER© (Hybrid Optimization Model for Electric Renewables) software. Through a sensitivity analysis we can determine the economic viability of different options and sizes of the components of the installation.

In locations with an average wind speed higher than 7.39 m/s, a stand-alone system is profitable as long as the distance to the grid is higher than 7 km, the price of electricity is 0.192 €/kWh and diesel price is 1.8 €/L. If 800 Ah-battery is used instead of 200 Ah, the COE will be reduced by 18% in location with 7.39 m/s average wind speed.

Contents

1. Introduction

The EU is committed to reducing emissions of greenhouse gases by up to 80–95% below 1990 levels by 2050 while ensuring energy supply and competitiveness. These objectives imply a permanent development of all renewable energy sources and especially wind power. Currently is the leading technology in electricity generation and will provide in 2050 from 32% to 49% of total electricity consumption [1].

The International Energy Agency appeals to governments to encourage actions that accurately reflect the real cost of energy production and consumption. The low carbon electricity should be the core of any sustainable energy system since it can produce drastic reductions in carbon dioxide emissions in industry, transport and services sector [2]. Since the cost of wind energy is still higher than the market price of electricity from conventional energy sources, many countries (Denmark, Germany, Spain, etc.) have introduced feed-in-tariffs that use them as a very important instrument to develop electricity from renewable sources.

There is an increase in the market of small wind turbines for off-grid installations that make decentralized electricity generation a competitive solution. Hybrid systems have a huge potential to substitute fossil fuels in the current energy systems and will cause a considerable reduction in the cost of infrastructures [3].

In recent years, wind turbine technologies have advanced considerably in power control systems and in wind field modeling as important part of a structural analysis of wind turbines. There are still obstacles to the diffusion of stand-alone and small grid-connected systems, such as unfavorable regulations and price settings that lead to the undervaluing of grid-connected systems.

Lundsager et al. [4], based on previous experiences, emphasize various general recommendations for the installation of isolated

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wind energy projects and between us we emphasize that these projects should be part of a concerted plan of action within a national program. Also we underline that it is desirable to avoid further difficulties, study in detail the feasibility of the project.

There are several tools to design hybrid systems as Hybrid Optimization Model for Electric Renewable (HOMER), Hybrid2 software package (HYBRID2), Hybrid Optimization by Genetic Algorithms (HOGA) and Transient Energy System Simulation program (TRNSYS). The ideal tool is highly dependent on the specific objectives that must be fulfilled, of the applications, and combined with other factors such as the energy-sectors considered, technologies accounted for, time parameters used, tool availability, and previous studies [5].

One of the reasons for the high costs of electricity supply can be attributed to the dependence on centralized energy systems and operating mainly fossil fuels and also require large investments for setting transmission and distribution networks to reach remote regions [6]. The stand-alone systems have disadvantages like excess battery costs, low capacity factor and finite capacity to store electricity forcing to throw away the extra energy generated [7]. Economic feasibility and load factors, besides the environmental factors, help decide between a grid-connected system in front of other stand-alone system. Therefore, it is critical to examine the conditions under which both systems are profitable.

Hybrid solar or wind energy systems are an alternative to energy supply by electricity network. Several procedures have been used to optimize the size of their components [8–17]. Taking into account the duration of the batteries, diesel generators and fuel price uncertainty, for sizing of a wind–diesel hybrid system, it was concluded that the optimal solution is close to many sub-optimal solutions characterized with good economic costs but also depends on the operating conditions of the system adopted [18].

Stand-alone electric generation hybrid systems are more appropriate than those that only have one power source for off-grid supply, but the design, control and optimization of hybrid systems are usually very complex [19]. Celik [20] states that the choice of scenarios based on the worst months can lead to a less optimal choice of solar–wind hybrid system in terms techno-economic. While providing a high level of autonomy, the system cost is too high and the same level of autonomy could be obtained at less cost by introducing a third power supply.

Kaldellis et al. [21] develop an algorithm for the estimation of the maximum wind energy that can be absorbed by an autonomous system from the knowledge of the restrictions of an autonomous electricity network.

The importance of storage on the economics of hybrid wind-diesel power systems in Saudi Arabia is assessed. The percentage fuel savings by using hybrid 100 kW system is 27% as compared to diesel-only situation [22]. Dalton et al. [23] compared the technical and economic feasibility of various renewable energy hybrid systems compared to the option of supplying electric power to the network in a hotel in Australia and shows that are competitive in certain cases studied. Stand-alone systems with renewable energy sources require their oversizing and to fulfill significant energy storage requirements, which will cause relatively high costs. Kaldellis et al. [24] propose an integrated technical–economical methodology for the evaluation of wind and photovoltaic stand-alone power systems.

Lujano-Rojas et al. [25] use a strategy for charge control to minimize the energy supplied by the diesel generator and the battery and to optimize the use of renewable energy, subjected to restrictions imposed by user behavior and the charges work cycle. Notton et al. [26] developed a methodology that allows determining the optimal configuration of an isolated system according to the percentage of the connected load and taking into account physical and economic cost considerations. Elhadidy and Shaahid [27] study the impact caused by the installation of a battery in a wind–solar hybrid system.

The small diesel generators, up to 100 kW, are only 25–35% of efficient, because the fuel costs in remote off-grid communities are higher [28]. In Canada are identified 89 villages with at least 5 m/s that could be considered as candidates for remote wind power. Without any incentive, a maximum of 10 villages are possible candidates for wind–diesel projects economically viable and an incentive rate of 0.15 $/kWh extend this number to 62 potential candidates for such project [29].

This paper is structured as follows. Section 2 presents the data analysis and the methodology used, Section 3 presents the results and conclusions are included in Section 4.

2. Material and methods

We analyzed four possible locations for a dairy cattle farm with 50 livestock units with electricity supplied by a small wind turbine. The criteria for the choice were the annual average wind speed and the operation hours of the small wind turbine. Both parameters were different for each location. Some specifications for the locations are shown in Table 1. The main advantage of analyzing the four locations is the possibility of importing the results to other locations with similar characteristics.

We used a 20 kW Westwind turbine. Table 2 shows some specifications of the chosen model and Fig. 1 represents its power curve. It is worth noting that the turbine starts at 4.5 m/s and is efficient in situations of low speeds, since many dairy cattle farms are not located in the most suitable locations. The price of the wind turbine includes the price of the turbine and the tower, as well as the cost of the installation, which is estimated at 30% of the wind turbine's cost. The price of replacement of the components of the hybrid system is estimated at 75% of the initial cost and the operation and maintenance cost is estimated at 3% [30].

According to all of the above, we simulated the system with HOMER software tool, developed by the National Renewable Energy Laboratory (NREL) [31]. HOMER is a global standard for economic analysis of sustainable remote micro-grid systems and creates a computer-generated system as close to reality as possible by considering the effect of the variation of the values with the time of electric charge and wind speed.

The criteria of evaluation used are the net present cost (NPC), the cost of energy (COE) and the renewable fraction (RF) percentage. NPC of the system is the total cost of installing and operating the system over its lifetime, with future cash flows discounted to the present. The NPC includes the costs of the initial construction, the component replacements, maintenance and fuel for the project lifetime of 25 years. HOMER uses the following equation to calculate the total NPC. The NPC estimation in HOMER also takes into account salvage costs, which is the residual value of the power system components at the end of the project lifetime.

$$\mathrm{NPC} = \frac{C_{ann,\,tot}}{\mathrm{CRF}(i, R_{proj})} \quad (€) \tag{1}$$

where, $C_{ann,tot}$ is the total annualized cost [€/yr], *CRF* is the capital recovery factor, and R_{proj} is the project lifetime [yr].

The capital recovery factor (CRF) is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows):

$$\mathrm{CRF}(i, n) = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{2}$$

where i is the annual real interest rate (4%) [32] and n is the number of years (25).

HOMER assumes that all prices escalate at the same rate and this method allows inflation to be factored out of the analysis The