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Cost–benefit analysis of remote hybrid wind–diesel power stations: Case study Aegean Sea islands

J.K. Kaldellis*, K.A. Kavadias

Laboratory of Soft Energy Applications & Environmental Protection, Mechanical Engineering Department, TEI Piraeus, P.O. Box 41046, Athens 12201, Greece

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Abstract

More than one third of world population has no direct access to interconnected electrical networks. Hence, the electrification solution usually considered is based on expensive, though often unreliable, stand-alone systems, mainly small diesel-electric generators. Hybrid wind–diesel power systems are among the most interesting and environmental friendly technological alternatives for the electrification of remote consumers, presenting also increased reliability. More precisely, a hybrid wind–diesel installation, based on an appropriate combination of a small diesel-electric generator and a micro-wind converter, offsets the significant capital cost of the wind turbine and the high operational cost of the diesel-electric generator. In this context, the present study concentrates on a detailed energy production cost analysis in order to estimate the optimum configuration of a wind–diesel-battery stand-alone system used to guarantee the energy autonomy of a typical remote consumer. Accordingly, the influence of the governing parameters—such as wind potential, capital cost, oil price, battery price and first installation cost—on the corresponding electricity production cost is investigated using the developed model. Taking into account the results obtained, hybrid wind–diesel systems may be the most cost-effective electrification solution for numerous isolated consumers located in suitable (average wind speed higher than 6.0 m/s) wind potential regions.

Keywords: Hybrid wind–diesel station; Stand-alone system; Cost–benefit analysis; Energy production cost; Variable maintenance cost; Sensitivity analysis

1. Introduction

Most European and North American consumers cover their electrification needs by large capacity and robust interconnected electrical networks, supported by nuclear and fossil fuel-fired power stations of considerable size (e.g. 1000 MW). In these cases the free market competition leads to reliable network operation and minimum production cost (Feretic and Tomsic, 2005), achieving unit electricity costs of generation down to 0.03 €/kWh. On the other hand, United Nations estimate (Jensen, 2000) that almost two billion people have no direct access to electrical networks. Hence, their only electrification possibility should be based on autonomous stand-alone systems (Kaldellis, 2002b; Kaldellis et al., 2003). Otherwise one should invest on expensive (Tanrioven, 2005) grid-extensions, whenever possible.

In actual fact, the great majority of rural consumers had no other choice than small diesel-electric generators, while only in limited cases small wind converters, photovoltaic generators or micro-scale hydro-systems contribute in the electricity generation (Beyer et al., 1995; Bhuiyan and Ali Asgar, 2003, U.S. (DOE), 1997; Kaldellis et al., 2005). The utilization of diesel engines presents minimum first installation cost (Hunter and Elliot, 1994) but substantial maintenance and operation (M&O) cost (Fig. 1). On the contrary, wind power installations are capital intensive, presenting however low M&O cost (Kaldellis and Gavras, 2000). As a result, one may find an appropriate combination of a small diesel-electric generator and a micro-wind converter that guarantees the remote consumer electrification at a rational (minimum) initial and long-term cost (Bowen et al., 2001; Elhadidy and Shaahid, 2004; Kaldellis and Vlachos, 2005). Such a system may also use an appropriate battery bank, in order to improve the system reliability. The extreme cases of such a generalized stand-alone solution appear to be either the diesel-only (no wind

*Corresponding author. Tel.: +30 210 5381237; fax: +30 210 538134.
E-mail address: jkald@teipir.gr (J.K. Kaldellis).

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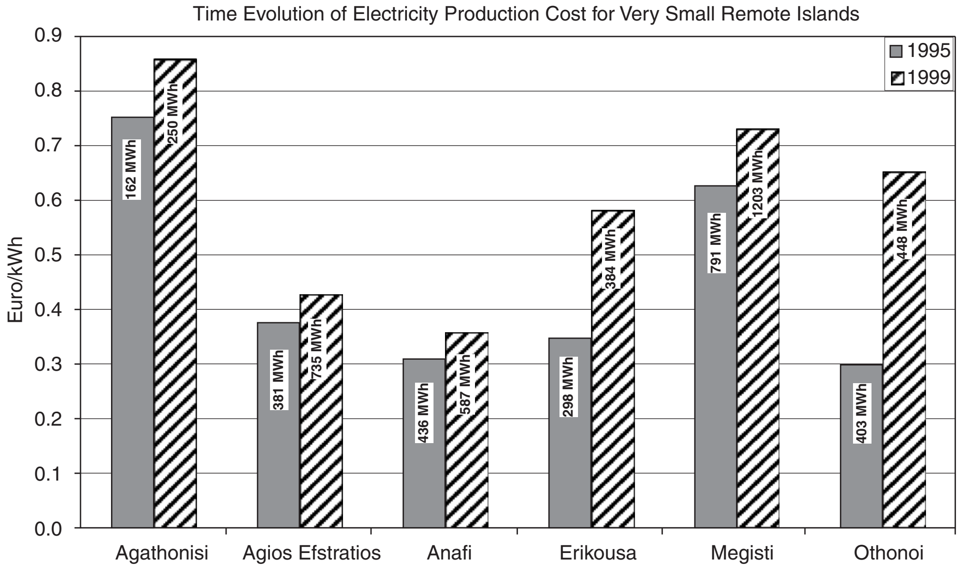

Fig. 1. Electricity production cost time-evolution for remote consumers located in small Greek islands.

turbine and/or energy storage) or the stand-alone wind power (zero diesel-oil contribution) configuration. The possibility of biofuel utilization is not included here (Sakkas et al., 2005).

In this context, the present study is concentrated on a detailed cost–benefit analysis (Kaldellis and Gavras, 2000; Kaldellis et al., 2005) of an optimum sizing wind–diesel–battery stand-alone system used to meet the electrification requirements of a typical remote consumer, generation capacity up to 15 kW. Accordingly, the corresponding electricity production cost value is predicted using an integrated methodology and is subsequently compared to existing electrical market price. Finally, an extensive sensitivity analysis is carried out in order to improve the proposed analysis reliability.

2. Proposed solution

Based on previous works by the authors (Kaldellis, 2002b; Kaldellis et al., 2003; Kaldellis and Vlachos, 2005) a representative small wind–diesel–battery stand-alone power system (up to 15 kW) able to meet the electricity requirements of remote consumers consists of (Fig. 2):

(a) a micro-wind converter of rated power N_o (kW);
(b) a small internal combustion engine of N_d (kW), able to meet the consumption peak load demand N_p (i.e. $N_d \geqslant N_p$);
(c) a lead-acid battery storage system with total capacity of Q_{max}, operation voltage U_b and maximum depth of discharge DOD_L;
(d) an AC/DC rectifier of N_o kW and U_{AC}/U_{DC} operation voltage values;
(e) a DC/DC charge controller of N_o rated power, charge rate R_{ch} and charging voltage U_{CC};
(f) a (uninterruptible power supply) (UPS) of N_p (kW), frequency of 50 Hz, autonomy time δt and operation voltage 220/380 V;
(g) a DC/AC inverter of maximum power N_p (kW) able to meet the consumption peak load demand, frequency of 50 Hz and operational voltage 220/380 V.

This system should be capable of facing a remote consumer's electricity demand (e.g. a four- to six-membered family), with rational first installation and long-term operational cost. The specific remote consumer investigated is basically a rural household profile (not an average load taken from typical users) selected among several profiles provided by the Hellenic Statistical Agency (Kaldellis, 2002b), see also (Lazou and Papatsoris, 2000; Notton et al., 1998). In order to minimize the electricity requirements of the remote consumer special emphasis is laid on the efficient and rational use of the available energy resources. In this context, the numerical load values vary between 30 W (refrigerator load) and 3300 W. According to the consumption profile approved, the annual peak load N_p does not exceed 3.5 kW, while the annual energy consumption E_y is around 4750 kWh per year.

Additionally, the corresponding wind potential and ambient temperature and pressure are also necessary (PPC, 1986) to integrate the system sizing calculations. Finally, the operational characteristics of all components (e.g. wind power curve at standard day conditions, diesel-electric generator specific fuel consumption, inverter efficiency, battery bank characteristic etc.) composing the stand-alone system under investigation are also required (Fig. 2).

For estimating the appropriate configuration of the proposed wind–diesel hybrid system, three governing parameters should be defined: the rated power N_0 of the wind turbine used, the battery maximum necessary capacity Q_{max}