



# Feasibility study and sensitivity analysis of a stand-alone photovoltaic–diesel–battery hybrid energy system in the north of Algeria

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## ABSTRACT

This paper aims to study the techno-economical feasibility of a photovoltaic–diesel–battery hybrid energy system (HES) destined to electrify a research unit (UDES) located in the north of Algeria. For this aim several scenarios have been studied for a photovoltaic penetration varying from 0% to 100% including a stand-alone diesel system and a stand-alone photovoltaic system. For each scenario, the power system has been designed and optimized to get a maximum output power at a low cost. The performance of these systems has been analysed based on some determinant criteria such as net present cost, the cost of energy, energy excess, load satisfaction, fuel consumption savings, maintenance and operation costs of diesel generators, CO<sub>2</sub> and pollutants saving rates. The impact of the storage battery bank size on the total cost of the power system has also been studied; it has been found that this parameter is a decisive factor that determines the optimum share of the solar resource in the hybrid system. Results showed that 25% PV–diesel–battery HES is the optimal configuration, which presents the best compromise between PV penetration efficiency, energy cost and the system stability. A sensitivity analysis has been performed on the optimal HES in order to study the effect of some parameters' variation (global solar radiation, diesel price, real interest rate and load consumption) on its total cost, the cost of energy, photovoltaic resource penetration and fuel intake.

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## Contents

1. Introduction	1135
2. Background	1136
3. Hybrid energy system description	1138
3.1. Photovoltaic modules	1138
3.2. Battery bank	1138
3.3. Power converter	1138
3.4. Diesel generators	1138
4. HOMER software	1138
4.1. Description	1138
4.2. Economic assessment criteria	1139
4.2.1. Net present cost	1139
4.2.2. Total annualized cost	1139
4.2.3. Capital recovery factor	1139
4.2.4. Annual real interest rate	1139
4.2.5. Levelized cost of energy	1139
5. Homer input parameters description	1139
5.1. Load profile	1139

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5.2.	Solar radiation data .....	1139
5.3.	Diesel .....	1139
6.	System dispatch strategy .....	1139
7.	Simulation results .....	1139
7.1.	Stand-alone diesel system .....	1141
7.2.	Hybrid energy system scenarios .....	1142
7.2.1.	Technical and electrical analysis .....	1142
7.2.2.	Economic analysis .....	1143
7.2.3.	Environmental impacts of hybridization .....	1145
8.	Sensitivity analysis .....	1146
8.1.	Global solar radiation and diesel price .....	1146
8.2.	Load consumption .....	1147
8.3.	Real interest rate .....	1147
9.	Concluding remarks .....	1148
	Acknowledgments .....	1149
	References .....	1149

## 1. Introduction

Global energy consumption is experiencing a drastic increase in both developed and developing countries (1% and 5% per year, respectively) [1] because they need permanently more energy for their industrial and technological development and to provide residential comfort for the growing populations in general [2]. The global yearly consumption has been estimated to be an averaged primary power of 16.9 TW [3] and it is expected that the production capacity should be doubled in the next 40 yr to cover our energy needs [4].

Modern civilization is heavily dependent on energy which is met throughout conventional sources, such as nuclear energy and fossil fuels (coal, oil and gas) [5]. As reported in Ref. [6], about 80% of total energy is produced by burning fossil fuels; the combustion of these substances leads to the emission of tons of pollutants and greenhouse gases (GHG) (carbons (CO<sub>2</sub>), sulfur dioxide, nitrogen oxides, and unburnt hydrocarbons) that harm the atmosphere, the environment and induce adverse effects on the health of the populations [7]. High concentrations of CO<sub>2</sub> in the atmosphere have contributed to the global climate warming phenomenon [8] and an increase of 3–6 °C of the earth's temperature is expected by the end of the century [6]. As a response to climate change, the KYOTO protocol was adopted in December 1997 where 38 of the industrialized countries committed to reduce the emission of six greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, N<sub>2</sub>O, HFCs, PFCs and SF<sub>6</sub>) by 5.2% on an average between 2008 and 2012 compared to the 1990 levels [9,10].

Nowadays, about 1.4 billion people around the world in remote communities and rural areas are still not connected to the grid and are totally deprived of a steady electrification network [11]. Owing to geographical, economical and technical obstacles, the grid is no more considered as an appropriate means of electrification for these sites, of low population rates, due to high costs of investments needed for setting up substations and extending electrical lines, high costs of maintenance and lines losses [4].

Decentralized production systems based on diesel power generators are the most widespread means for rural electrification since they exhibit reliability and availability and for their low investment costs compared to the grid [12,13,14]. However, these systems have some drawbacks such as high costs of operation due to high fuel consumption, high costs of maintenance, emission of GHGs and pollutants in the local atmosphere [14]. Furthermore, for low load levels, 40–50% of the rated power of the diesel generator (DG), the oil is not burnt in a fit manner in the diesel engine which causes carbon build-up; in this case the DG becomes inefficient which increases its maintenance costs [15,16].

Renewable energies (REs) are considered as a good alternative to fossil fuels that would help in mitigating their hazardous effects on the atmosphere and compensate for their depleting nature as they use clean and regularly regenerating flows of energy (sun, wind, water, etc.) [17]. Currently, there is a growing recognition of the importance of integrating REs in the energy sector of countries that aim to achieve the goals and objectives of a sustainable development.

The potential of REs is enough to cover the entire of the universal energy demand [2] and it is well distributed across the globe unlike fossil resources. As indicated in Ref. [18], the global wind resource potential estimated at about 72TW is much greater than the global daily electrical consumption; this capacity allows the production of over five times of the global energy needs and over 40 times of the global electrical consumption of the year 2011. Similarly, solar energy (SE) received at the ground on an annual average is estimated to be about 75,000 GToe, which is equivalent to 0.9 billion of TWh of the electricity. This energy is 6000 times the current annual global energy consumption [19,20].

Currently, the generation of electricity from REs is approximately estimated at 17% of the total electricity mix [21]. The major problem responsible for slowing the rate of investments in this field is the difference between the cost of electricity generated from REs and that generated from alternative resources.

The stochastic nature of REs (diurnal and seasonal cycles) is responsible for a mismatch between the demand and supply of electrical power [21]. In this case solar and wind power systems need to be backed up by other sources of energy, generally a combination with either a DG or a reversible electric storage (batteries) or with both is used in one system such as a hybrid energy system (HES) [15,22].

The use of batteries as a backup system increases the initial investments of solar and wind stand-alone systems especially when it comes to high capacities [4], in this case the use of a DG is beneficial mainly economically by supplying electrical energy at a low cost [23].

Generally, the combination of renewable and conventional sources of energy allows the optimization of power generation systems both from technical, economical and environmental viewpoints by providing continuous and stable power, reducing operation and maintenance (O&M) costs of DGs, minimizing the dependence on fuel and curtailing harmful emissions and pollutants [24–26]; for these reasons HESs are progressively used as distributed systems to produce electricity locally in remote areas and communities.

The sizing of HESs is complicated as their performances are strongly affected by the design and the type of the components,

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