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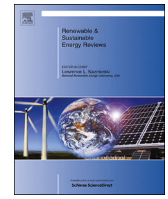

Optimization of a PV–wind hybrid system under limited water resources

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A B S T R A C T

Water plays a vital role in various economic sectors, including energy production. It is required in various stages of the energy production chain including fuel acquisition, processing and transportation. However, there are growing concerns about the mounting demand for water arising from population and industrial growth, especially in water-stressed regions. Climate change and environmental pollution are exacerbating the situation, and the exploitation of renewable energy resources is perceived as one pillar of mitigating the negative effects of climate change. In this regard, solar photovoltaic (PV) and wind power plants are promising renewable energy technologies, and previous studies have demonstrated that these two energy technologies are less water-intensive. However, the effect of available water on the optimization of a hybrid PV–wind system has not been extensively explored. In this study, a model for investigating water-efficient optimization of PV–wind hybrid systems has been proposed. The demand for water, in the production of energy from PV and wind power plants was expressed as a linear function of the numbers of PV panels and wind turbines. The proposed model was applied to the design of a grid-connected PV–wind hybrid system, using meteorological data from Bonfoi Stellenbosch weather station (33.935°S, 18.782°E) in South Africa. The hybrid system was designed to generate about 100,000 MW h/year under the prevailing meteorological conditions. In addition, the Levelized Cost of Energy (LCOE) was optimized with (60,000 m^3) and without a water constraint. It was found that the water-constrained scenario reduced water demand by 24%. The optimal LCOE of the system declined by 23% when available water was increased from 60,000 m^3 to 75,000 m^3. It is therefore concluded that water availability is an important factor in the economic optimization of a hybrid PV–wind system.

Contents

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1. Introduction

Clean water is essential for the social and economic development of any nation. It is also known that a large proportion of the available water on the earth's surface is, however, saline [1]. In addition, the pressure on available water resources is increasing due to population and economic growth, and will be exacerbated by climate change, with some regions experiencing a reduction in the supply of water [2,3]. Consequently, there is need for efficient use of the available water resources in various economic sectors, including the energy sector.

Water plays a vital role in the energy production chain [4]. In conventional thermal power plants (which commonly use coal, nuclear, oil and gas fuels), energy production involves various stages including fuel acquisition, processing and transportation. Water is required in the mining, washing, beneficiation and transportation of coal, and in plant construction and power generation. Similarly, water is used in nuclear power for uranium mining, milling, conversion, enrichment, fuel fabrication, power plant construction, power generation and fuel disposal. Extraction, purification, transportation and storage processes also demand water in the production of energy from natural gas or oil. Water is withdrawn (W_w), consumed (W_c), recycled (W_r), and discharged (W_d) at any given stage of the energy production process, as illustrated in Fig. 1. Increasing the level of W_w reduces the water that is available for other economic activities. Moreover, the consumed water is no longer available for other applications and, in some cases, discharged water is heavily contaminated. In view of this, there has been growing interest to assess water withdrawal and consumption in the energy production chain.

Damerau et al. [5] investigated the costs of reducing water in a concentrated solar power case study in North Africa, where insolation is abundant but water is scarce. It was found that wet cooling was unlikely to be sustainable, an observation that is in agreement with concerns raised by Stambouli et al. [6]. Macknick et al. [7] reviewed water withdrawal and consumption factors for generating electricity from different technologies and found that non-thermal renewable energy technologies such as PV and wind exhibited the lowest water demand. Li et al. [8] used a life cycle analysis technique to investigate water use in the wind power sector in China; their findings suggest that wind energy requires a very low volume of water. A cleaning system for PV panels was developed by Moharram et al. [9], who found that the use of water with surfactants was more effective in removing dust from PV panels than cleaning the panels with water only. Other investigators have also reported low values of water usage in PV and wind technologies [4,10]. These two renewable energy technologies clearly have potential to save water.

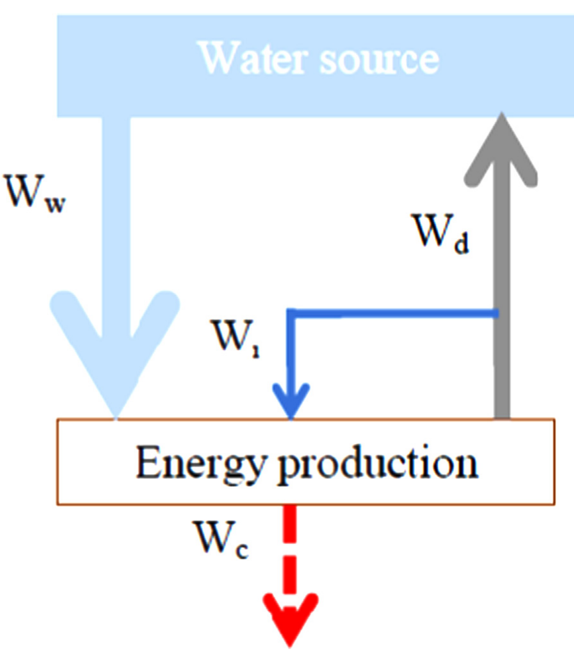

Fig. 1. Water usage in the energy production process.

Nevertheless, both solar and wind resources are intermittent [11], thereby rendering them unattractive to many investors. One way of overcoming this limitation is through hybridization [11,12]. In a hybrid system, several energy sources are integrated to provide the required amount of energy—thus, PV and wind resources can be combined to sustain energy supply to a load when one of these resources is not available. The deployment of energy storage (such as batteries) enhances the reliability of the PV–wind hybrid system but it increases the cost of the system. A PV–wind hybrid system may be stand-alone or grid-tied. The former system is not connected to a grid utility while the latter is connected to a grid utility (which often takes in alternating current (AC) power). Nevertheless, PV panels generate direct current (DC) power, and so an inverter is used to convert DC to AC power.

PV and wind technologies have different water demands, with PV systems exhibiting a higher demand [4]. Consequently, their shares would influence the overall water demand, and it is necessary to take into consideration water requirements when optimizing PV–wind hybrid systems in order to curtail water requirements.

Optimization of hybrid solar–wind power generation plants has been extensively investigated. Nogueira et al. [13] developed a method for optimal sizing of PV–wind system with battery storage. They used simulation tools and linear programming to determine the minimum cost of the system, and found that their method always yielded the lowest cost. Yang et al. [14] used a genetic algorithm to minimize the annualized cost of a stand-alone PV–wind hybrid system and found good optimization of the system. Other researchers have also investigated the problem of optimizing the cost of the PV–wind hybrid system [15–17]. Nevertheless, most of these and other studies have minimized the cost of electricity without taking into account the possible scarcity of water. The objective of this study was to develop a model that includes a water constraint for optimization of the Levelized Cost of Energy (LCOE) generated by a grid connected PV–wind hybrid system exploited under water constraints. It is found that optimization of the PV–wind hybrid system with a water constraint reduces the water demand in the energy production chain. The LCOE declines with increasing the available water. These findings can assist in energy planning in regions where water is scarce to ensure sustainable development. However, this study did not consider backup and storage components of the system. Consequently, further work is required to establish the implication of