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Upper-limit solar photovoltaic power generation: Estimates for 2-axis tracking collectors in Nigeria

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ABSTRACT

Energy generation by solar PV (photovoltaic) systems can be improved by incorporating tracking mechanisms, with the highest improvements resulting from 2-axis tracking. Peak energy generation levels (from PV collectors with 2-axis tracking) have been determined in this study, for locations in Nigeria. The spatial domain of interest was discretized into a grid of 1° latitude by 1° longitude cells. For each cell, monthly average daily irradiation on horizontal surfaces and ambient temperatures were obtained from the web-based NASA meteorological data service. With these, irradiation on tilted surfaces, system performance ratios, r_p, seasonal and annual energy generation potentials, E/P_k, and improvements in energy generation potentials, $\Delta E/P_k$, were determined. An approach for estimating r_p is suggested, which accounts for effects of varying temperature and insolation levels on performance. r_p values obtained by this approach are conservative relative to the fixed value of 0.75 which is presently in common use. The highest seasonal E/P_k (446–648 kWh/kWp) and $\Delta E/P_k$ (32%–62%) occur in the December-January-February season, and the least (249–590 kWh/kWp and 10%–26%, respectively) in the June-July-August season. E/P_k generally increased with latitudes. The additional E/P_k obtained with tracking (20%–40% annually) could offset additional costs due to tracking.

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1. Introduction

The quantity of solar energy received by solar collectors can be enhanced to varying extents by the incorporation of mechanisms that enable them track the sun's trajectory. The motivation for tracking lies in the fact that the energy output of solar PV (photovoltaic) collectors is affected to the largest extent by the amount of solar radiation incident on their surfaces. Tracking mechanisms alter the slope of collectors in order to minimize the angle of incidence of beam solar radiation. The motion of tracking collectors could be either about one axis (1-axis tracking) or two axes (dual- or 2-axis tracking). Of these available tracking modes, the 2-axis tracking mode delivers the highest irradiation to a solar collector. In this tracking configuration, the collector is rotated about two perpendicular axes parallel to the earth's coordinate axes—the east–west and north–south axes as shown in Fig. 1. This enables the collector's orientation to be continuously altered in such a manner as to maintain its surface always normal to the beam solar radiation. Hence, the power output from a 2-axis tracking PV system represents the upper limit of possible PV power generation at any location. This has been validated by a number of studies in which the power outputs of PV systems, employing different tracking configurations, were predicted and compared. The 2-axis tracking configuration has been invariably shown to offer the highest power outputs.

Investigations on Europe-wide outputs of solar PV collectors have been conducted by Huld et al. [1–3]. The outputs of two 1-axis tracking PV collectors (one with optimally inclined modules rotating about a vertical axis, and the other with modules rotating about an optimally inclined axis directed north–south) were found to be comparable to the outputs of 2-axis tracking collectors, and were predicted to be higher than the outputs of fixed optimally inclined collectors by up to 30% in southern Europe, and as much as 50% in northern Europe [2]. Experimental investigations of energy production from fixed collectors, 1-axis tracking collectors, 2-axis tracking collectors, and CPV (concentrating PV) collectors, at locations in Spain, were conducted by Gómez-Gil et al. [4]. The systems with 2-axis tracking had the highest energy production, followed by the 1-axis tracking systems, then the CPV systems and finally the fixed systems. The

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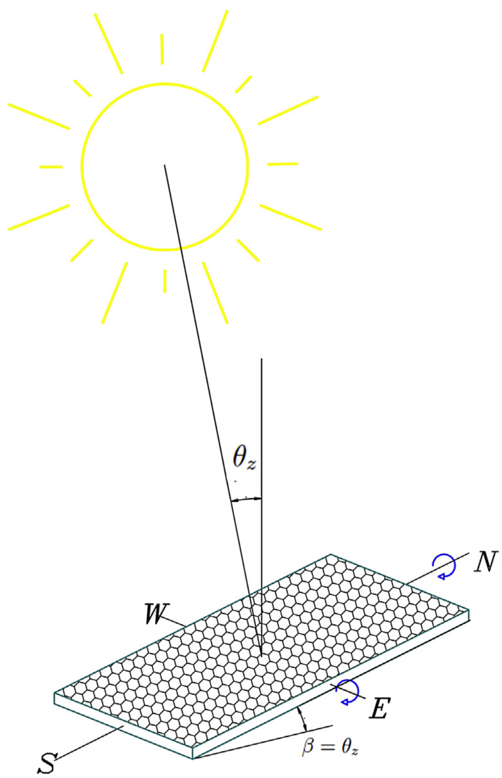

Fig. 1. Illustration of a 2-axis tracking PV collector surface, showing rotation about the cardinal axes.

outputs of the 2-axis systems were about 25.2% greater than the outputs of the fixed systems. Elsewhere, the performances of fixed PV installations in Morocco have been reported by Barhdadi and Zakey [5] and in Nigeria by Njoku [6]. In the latter study, the energy production potentials of fixed optimally tilted PV systems were found to be between 2.35 and 6.45% greater than those of fixed horizontal PV systems in Nigeria. Studies on PV systems in Brisbane, Australia have also been performed by Yan et al. [7]. Using a simplified linear model that relates the energy generation to product of sunlight intensity, incident angle, number and area of PV panels and an efficiency term, estimates of energy generation for different collector tilt angles and orientations were computed and the tilt angle and orientation which maximized energy output at the location were obtained. The model was also used to obtain 4 year forecasts of energy generation for the location.

The estimation of the energy output of solar PV systems is not a trivial task and numerous methods for performing this task have been put forward. Rus-Casas et al. [8] presented a detailed discussion on existing methods, classifying them broadly into direct methods and indirect methods. With direct methods, energy output is obtained using parameters which characterize the PV generator, such as DC performance ratio and conversion efficiencies, whereas indirect methods involve the determination of instantaneous power generation and subsequent integration over the desired duration of operation. The indirect methods were further divided into those that first calculated the PV generator I–V curve and those that directly calculated the generator's power output. The latter methods do not accounted for second order effects in detail by resulting in marginal loss of accuracy. They are however most easily applied in practice.

The quantity of additional power that may be obtained from PV collectors with the addition of tracking mechanisms is strongly dependent on the systems' location. This is because tracking systems track the beam component of solar radiation, which depends strongly on sky clearness index, which in turn is also strongly location dependent. Thus, the margins of improvement in PV outputs determined for locations that have been studied may not be obtainable in all other locations. In this study, the maximum solar PV power generation potentials that exist at locations in Nigeria

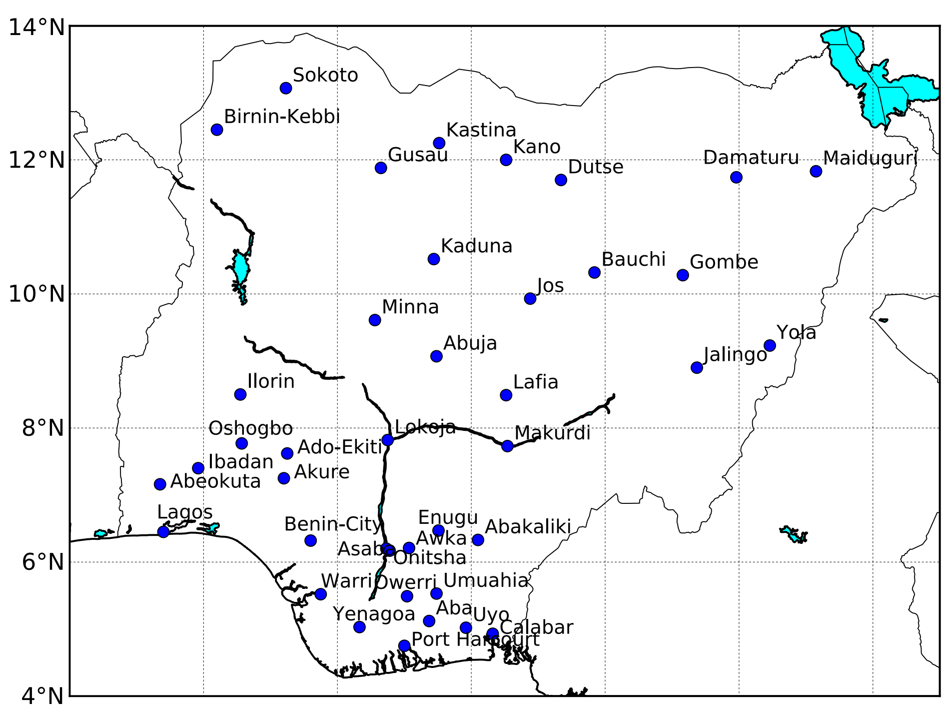

Fig. 2. Map of Nigeria indicating the locations of major urban centers.

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