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Tracking strategy for photovoltaic solar systems in high latitudes

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ABSTRACT

Several studies show that from about 20% to 50% more solar energy can be recovered by using photovoltaic systems that track the sun rather than systems set at a fixed angle. For overcast or cloudy days, recent studies propose the use of a set position in which each photovoltaic panel faces toward the zenith (horizontal position). Compared to a panel that follows the sun's path, this approach claims that a horizontal panel increases the amount of solar radiation captured and subsequently the quantity of electricity produced. The present work assesses a solar tracking photovoltaic panel hourly and seasonally in high latitudes. A theoretical method based on an isotropic sky model was formulated, implemented, and used in a case study analysis of a grid-connected photovoltaic system in Montreal, Canada. The results obtained, based on the definition of a critical hourly global solar radiation, were validated numerically and experimentally. The study confirmed that a zenith-set sun tracking strategy for overcast or mostly cloudy days in summer is not advantageous.

1. Introduction

The current demand for energy is constantly on the rise despite a relative "status quo" in the western hemisphere [1]. Hence, attention is increasingly being focused on energy security and environmental impacts of energy consumption [2]. In this context, renewable energy resources have also received increasing attention as the share of renewables in total power generation will rise from 21% in 2012 to 33% in 2040 [3]. Among these renewable energy resources is solar power, which when harvested can be used to generate electric power. When implementing this technology, one can either rely on fixed or tracking panel installations. In general, fixed installations can either be mounted on roofs where the panels are appropriately oriented and inclined or be part of the building itself, known as building integrated photovoltaics (BIPV) or building added photovoltaics (BAPV) in the case of a retrofit. Tracking installations are used in so-called solar farms, mainly for energy production.

1.1. Tracking the sun increases the amount of energy harvested

Although some may argue that the tracking strategy will eventually peter out, because of ever decreasing production costs, it is currently commonly-used worldwide. It has been demonstrated that tracking significantly increases the average yearly energy production over a fixed position. Indeed, according to the review proposed by Mousazadeh et al. [4], using sun-trackers can increase the collected energy between 10% and 100% depending on the period of time and geographical conditions. More recently, a 30-day experimental study highlighted that by using sun-trackers, the amount of energy produced significantly increases by 12–20% [5]. The same results were obtained by Eke and Senturk and their results demonstrated than after one year of operation, about 30% more energy is obtained by a dual-axis sun tracking system than the latitude-tilt fixed system [6]. Similarly, models developed by Ismail et al. [7] and experimental work conducted by Abdallah [8] estimated the gain in yearly energy production to be 20.4% and 43.9% respectively, by using a double axis tracker compared to an optimally-inclined fixture.

1.2. Tracking strategies

Sun-tracking systems can be either one-axis or dual-axis: (1) one-axis implies that the solar panel can pivot east and west. This design is rather simple, but a certain south–north

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Nomenclature

A_i	anisotropic index
E	hourly electrical energy produced by the solar PV array (W h)
G	solar irradiance on a surface (W/m^2)
I	hourly solar radiation (W h/m^2)
k_t	hourly clearness index
LST	local solar time
R	effective ratio of the total solar radiation on a tilted surface to that on a horizontal surface
R_b	ratio of the beam solar radiation on a tilted surface to the beam solar radiation on the horizontal surface
R_d	ratio of the diffuse solar radiation on a tilted surface to the diffuse solar radiation on the horizontal surface
TA	tracking advantage

Greek symbols

β	surface slope (°)
ρ_g	ground reflection coefficient

Subscripts

b	direct beam
c	critical
d	diffuse
DTS	pointing directly toward the sun
H	horizontally oriented
r	reflected
T	tilted or inclined
$T-60°$	tilted 60°

Abbreviations

PV	photovoltaic
c-Si	crystalline silicon
MPP	maximum power point
MPPT	maximum power point tracking
I–V	current–voltage
BIPV	building integrated photovoltaics
BAPV	building added photovoltaics
PSO	particle swarm optimization
PDPSO	performance dependant particle swarm optimization

misalignment could result in decreased efficiency in comparison to a dual-axis design, even in tropical regions; (2) dual-axis sun-tracking enables both east–west and south–north alignment. This ensures that the panel always remains normal to the sun's beam radiation, thus maximizing the amount of energy intercepted by the surface. This is the relevant strategy for high latitude locations. Moreover, sun-tracking modes are divided into passive and active tracking: (1) passive sun-tracking determines or predicts sun movement by calculation and/or statistics, so that the orientation and angle of the solar panel changes slowly according to a predetermined path. This method requires long term statistics, and the longitude and latitude of different regions are included in the calculations so as to obtain the optimal movement orientation and angle. Such a method is proposed herein; (2) active sun-tracking uses optical sensors to determine the sun's position. The direction of the sun is identified according to the feedback from error signals measured by sensors, and then the solar panel is turned toward the sun. Taherbaneh et al. [9] developed a method based on the simultaneous use of two fuzzy controllers to maximize the generated output power while Roth et al. [10] constructed and tested a tracker that uses the signal of a sun-detecting linear sensor to control the pointing, and Chin et al. [11] proposed both a MATLAB/Simulink model and compact solar tracker, which "operates at different modes to provide flexibility to accommodate different weather conditions and preferences for different users".

1.3. Passive tracking strategies

Among the studies on passive sun-tracking systems, Al Nabulsi et al. [12] suggested in 2010, a system-efficiency optimization method for a 150 W photovoltaic panel using a dual-axis maximum point power tracker (MPPT) [12]. In 2011, Seme et al. proposed an efficient system [13], which calculates the inclination and azimuth of the sun, and uses a dual-axis sun tracking system to follow the sun's movement. Still in 2012, Colli and Zaaiman [14] tested three solar panels using different forms of crystalline silicon in three different locations in Italy. They proposed a maximum power verification method for solar panels that was applied to the bracket and a one-axis sun tracking systems [14]. The study showed that the one-axis tracking system could intercept more irradiance than the fixed bracket system and produce 19% more energy. In 2012, Dolara et al. proposed a one-axis tracking system performance analysis [15]. Their results showed that the system could effectively increase the output power of solar panels when compared to fixed systems.

1.4. Active tracking strategies

In 2011, Solihin et al. [16] used particle swarm optimization (PSO) to look for the optimal parameters of the PID controller. The authors used a PID controller for the DC motor. The search results of four objective functions were compared. In 2011, Dongsheng et al. [17] suggested a novel type of PSO to look for PID parameters, retaining the advantages of traditional PSO. The PSO equation was included in the calculation of the average worst solution. Still in 2011, Verma and Jain [18] proposed a performance dependant particle swarm optimization (PDPSO) to look for DC motor PID controller parameters. The application program of PDPSO is almost identical to the traditional PSO, but it provides faster response time. In 2012, Altinoz et al. [19] used chaotic PSO to look for PID parameters. After one PSO search in the logistic chaos map, the positions of particles were put in chaos to look for better positions, so as to prevent PSO from earlier convergence.

1.5. Tracking strategies in cloudy conditions

Given that in overcast or cloudy conditions over 90% of the solar radiation may be diffused [20], tracking the sun could be ineffective as the albedo of the environment is generally lower than that of the clouded sky itself. Hence, in partially cloudy conditions, as a function of the clearness index, tracking the sun could be either effective or unnecessary. Lazaroiu et al. [5] recommended the need for further research to limit the energy consumption of the photovoltaic (PV) solar tracking during "partially clear sky" and "cloudy sky" days.

Knowing in which conditions it is more advantageous to track the sun is an important issue for solar panel operation optimization in any climate. But this is especially relevant in Canadian weather conditions as the presence of snow, both on the ground and on the panel itself, will affect the panel's performance.

Not surprisingly, studies on tracking strategy optimization in cloudy conditions are sparse and relatively recent, because