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Performance Evaluation of Sun Tracking Photovoltaic Systems in Canada

Mostafa mehrtash[1], Guillermo quesada[2], Yvan dutil[3], Daniel rousse[4]

[1]Industrial research chair in energy and energy efficiency, École de technologie supérieure; mostafa@t3e.info
[2] Industrial research chair in energy and energy efficiency, École de technologie supérieure; guillermo@t3e.info
[3] Industrial research chair in energy and energy efficiency, École de technologie supérieure; yvan@t3e.info
[4] Industrial research chair in energy and energy efficiency, École de technologie supérieure; daniel@t3e.info

Abstract
This study is performed to investigate the performance of photovoltaic (PV) systems with different types of solar trackers in Northern climates. To this end, four PV systems were simulated; horizontally fixed, inclined fixed, azimuth tracking, and a dual-axis tracking. The simulations have been carried out by use of PVSOL Pro for daily, monthly, and annual periods. The analyses have been done for climate conditions prevailing in Montreal, Canada. Annual analyses show an increase of solar irradiation upon a tilted system, azimuth tracker system, and dual axis tracker system as compared to the horizontal system. This yearly increase is 16.8%, 50.1%, and 55.7% respectively. The results from daily analyses show, as expected, that in clear days the dual axis tracker PV system provides the highest performance, but in overcast conditions all systems perform almost similarly and the optimum position is horizontal. The results indicated that a dual-axis tracking array is the optimum system if it goes to the horizontal position in overcast condition.

Keywords: solar energy, photovoltaic (PV), solar tracking, performance

Introduction

In recent years, energy has become a significant issue in the world. Fossil fuel resources are decreasing while the world energy consumption is increasing considerably. Moreover, the consumption of fossil fuels causes air pollution. An obvious solution for energy problem is utilization of renewable energies like solar, wind, geothermal...etc. Solar energy has the largest potential among all renewable energy resources. Today, solar energy is captured essentially by photovoltaic (PV) modules, solar thermal collectors, solar dryers, solar cookers, and solar water pumps fed by PV. PV modules convert the solar irradiation into electricity and they evolved considerably in recent years.

Solar irradiation impinging on a surface consists in direct, diffused, and reflected radiations. Although the largest fraction of the solar irradiation is direct, both diffuse and reflected radiation must be taken into account for the systems operation analysis. Solar irradiation on PV modules varies with the modules position; the solar irradiation takes its maximum value when the modules are perpendicular to the direct radiation since the main part of solar radiation is direct [1]. The location on earth and local weather conditions are other important parameters in determining solar irradiation amounts. According to the literature, the yearly optimal angle to absorb the maximum amount of solar radiation by fixed PV modules is equal to the local latitude at low latitude locations and up to 14° less than latitude at high latitude areas [2].

Solar trackers are utilized to keep the solar collector surface perpendicular to the Sun and allow collecting a higher amount of solar radiation than with a fixed module. There are two main types of trackers, single axis and dual-axis, which usually operate using either a passive or active mechanism. Although dual-axis trackers follow the sun more precisely, they increase the initial cost and complexity of the system.

Many authors have been studied solar tracking systems. Salah Abdallah [3] designed, constructed and studied four tracking systems for Amman, Jordan: dual-axis, single axis vertical, single axis east-west and single axis north-south. The power generation by each system is greater than that of a fixed system tilted at 32° by 43.9%, 37.5%, 34.4%, and 15.7% for the dual-axis, east-west, vertical, and north-south tracking system, respectively. In [3], the continuous test was made during a day. Helwa et al. [4] compared four PV systems: fixed system facing south and tilted at 40°, vertical axis tracker, tracker with 6° tilted axis (north-south tracker), and dual-axis tracker. The comparison is based on one year measurement of solar irradiation and their power output. The comparison's results show annual increase of collected radiation by azimuth, north-south and dual-axis trackers by 18%, 11% and 30%, respectively, over the fixed system. Abu-Khader et al. [5] compared and evaluated different types of tracking. Four systems have been constructed and studied: fixed, vertical axis tracking, north-south tracking, and east-west tracking. Pyranometers, installed on panels, measured the solar irradiance. Experiments result showed that the north-south tracking was the optimum one. The north-south tracking system produces 30-45% more output power than the fixed system tilted at 32°.

Koussa et al. [6] measured and modeled PV systems with different types of sun trackers. Their measurements were based on 18 typical days and located in north of Algeria with latitude of 36.8°. The hourly direct normal radiation, horizontal global radiation, diffuse radiation, and temperature were measured. Electricity production for each system – that depends on solar tracker electricity consumption, sky state, and day length – was evaluated. The obtained results show that during clear days, tracking the sun is very useful, during cloudy days it is unnecessary, and during partially clear days based on clearness index, it could be unnecessary or useful.

Systems descriptions

Four different configurations of PV systems have been studied: horizontally fixed, fixed at the latitude angle, single axis azimuth tracking with tilt angle of 55°, and dual axis tracking PV system. Simulations were made for the situation and weather conditions of Montreal, Canada. Each system consisted of 48 PV modules with the total power of 11.04 kW. Three 4.60 kW inverters have been employed for each system to convert the current from DC to AC form. The first system is kept horizontally to act as a comparison reference. Christensen and Barker [7] defined a parameter (w) as the difference of latitude and optimum tilt angle. They found that w is ranged from 0° to 16°, with higher values in high latitudes and lower annual average clearness index. Therefore, the second system is tilted at 45° since the Montreal's latitude is 45.5°. The third system is an azimuth tracking system which tracks the Sun from east to west with the panels tilted at 55°. This angle is annual optimum, calculated by PVSOL, for azimuth tracking in Montreal. The fourth system is a dual-axis tracking PV array.

Simulation

These systems have been analyzed on daily, monthly, and annual bases. Figure 1 shows the arrays irradiation over a year. Dual-axis tracking PV array absorbs more radiation than other arrays but it has almost the same performance as azimuth tracking PV array. The irradiation on tilted fixed array is considerably higher than on horizontal fixed array, except in summer since the Sun moves across the sky through a path nearly overhead and a horizontal plane is perpendicular to the direct radiation.

In November and December, we observed the minimum amount of radiation, while the average of electricity consumption arises in winter.

Figure 2 shows the arrays irradiation for a clear day in winter. As it can be seen from the graph, the dual axis tracker receives more radiation than the others.

Figure 3 shows arrays irradiation during a clear day in summer. Here again, the dual-axis tracking system receives more radiation. The azimuth tracking array absorbs almost the same amount of radiation as the dual-axis tracking array, but at noon, when the sun is overhead at the sky, it has the lowest performance since the module is not perpendicular to solar beam radiation. In a clear summer day, the fixed systems also receive almost the same amount of radiation. The efficiency of the PV panels is increased due to a decrease in the ambient temperature.

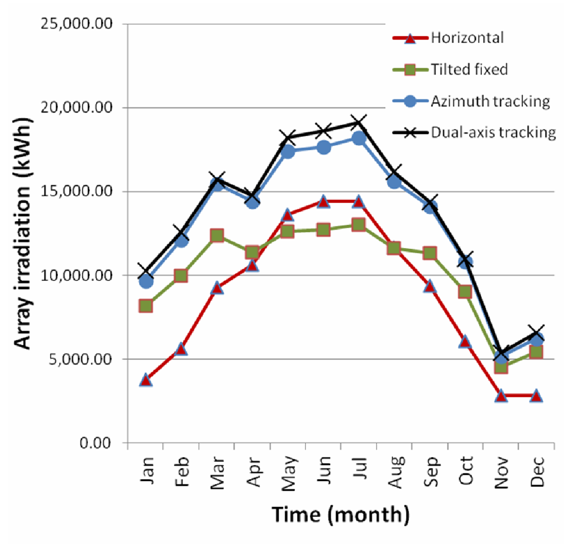

Figure 1. Annual array irradiation

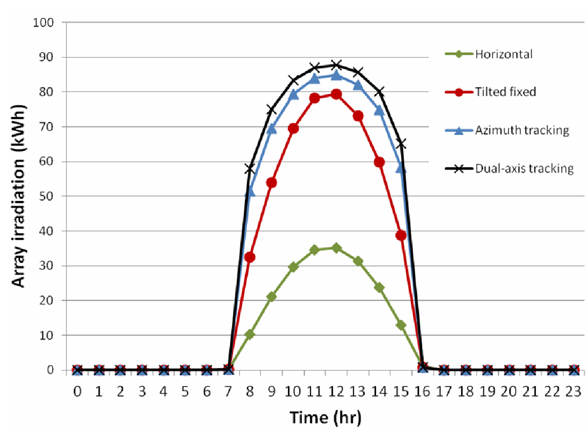

Figure 2. Array irradiation in a clear day in winter

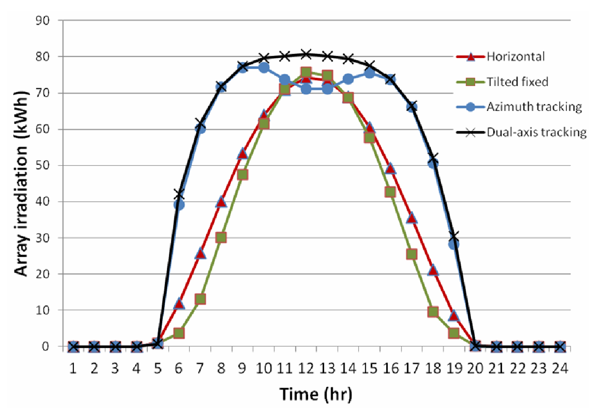

Figure 3. Array irradiation on a clear day in summer

Figure 4 shows the array irradiation in an overcast day in which the major part of the radiation is diffuse. On a cloudy day, these systems have almost the same performance; however, the horizontal position is optimum.

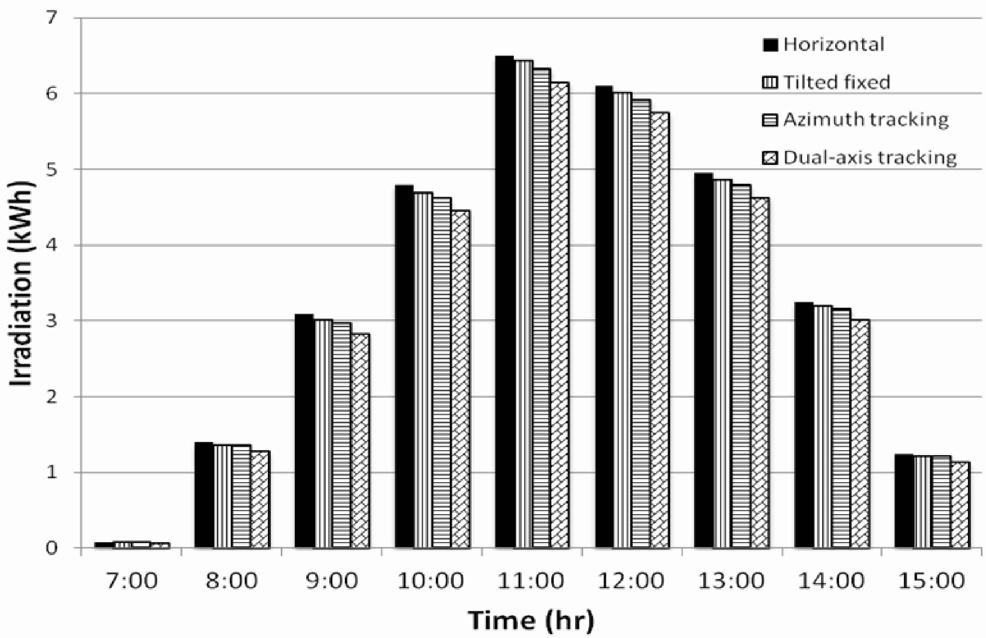

Figure 4. Array irradiation on an overcast day

Results and discussion

Important results from the simulations are shown in Table 1. Annual analysis shows an increase of array irradiation of up to 16.8%, 50.1%, and 55.7% for tilted fixed, azimuth tracking, and dual-axis tracking arrays, respectively, as compared to the horizontal fixed array.

The total energy production of systems as compared to the horizontal array are 23.22%, 65%, and 71% for tilted fixed, azimuth tracking, and dual-axis tracking systems, respectively. The array irradiation percentage increase is not equal to energy production percentage increase since the correlation between irradiation and relative efficiency of the PV system is not linear.

Dual-axis tracking and azimuth tracking array have the highest efficiency among these systems. The annual efficiencies of fixed arrays are 11% and 11.7% for horizontal and tilted fixed arrays, respectively, while the azimuth and dual-axis tracking systems have the same efficiency of 12.2%.

In Figure 5, these systems compared in three different typical days. In clear days, both in summer and winter, the highest irradiation belongs to the dual-axis tracking. On an overcast day, all the systems receive almost the same amount of irradiation approximately, but the horizontal position is the optimum angle for these conditions.

In Figure 5, arrays irradiations for three typical days are shown. On an overcast day, the irradiation is obviously shown to be very low as compared to clear day's irradiation.

Finally, according to all analyses, the dual-axis tracking array has the highest performance among the investigated systems. The optimum strategy for tracking the sun is to use a dual-axis tracker in clear conditions and to move to the horizontal position when the weather is overcast. Although the dual-axis tracking system has the highest performance, it increases the initial cost, complexity of the system, and the maintenance cost. Furthermore, the azimuth tracking provides 94% of the energy production of dual-axis tracking array, while it is cheaper and simpler to implement [5].

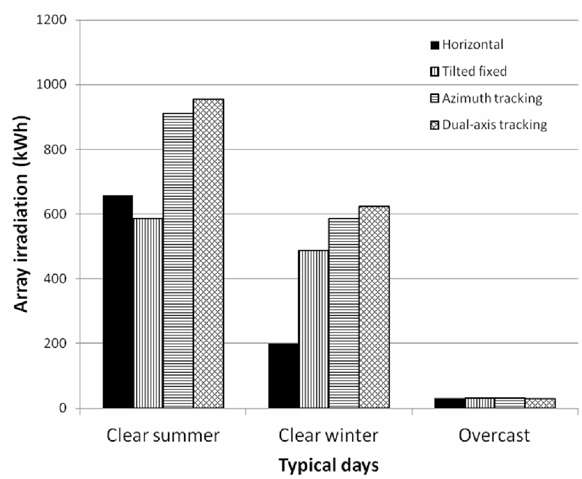

Figure 5. Array irradiations in different typical days

Conclusion

In this study four different PV arrays were analyzed: horizontal, fixed tilted, azimuth tracking, and dual-axis tracking. These are operating under climate conditions of Montreal, Canada. The results of the PV Solve Pro simulations show that the dual-axis tracking array provides the best performance. It receives 55.7% more solar radiation and generates 71% more electricity than the horizontal system over a year. Although the azimuth tracking system receives less solar radiation and generates less electricity than the dual-axis tracking array, it has the same average efficiency.

Table ١. Overall comparison

Array	Annual irradiation (MWh)	Energy production (MWh)	Efficiency (%)	Cloudy day irradiation (kWh)	A Clear winter day irradiation (kWh)	A Clear summer day irradiation (kWh)
Horizontal fixed	104.5	11.6	11	31.4	200.6	659
Tilted fixed	122.1	14.3	11.7	30.8	486.4	586
Azimuth tracking	156.9	19.1	12.2	30.4	585.7	910
Dual-axis tracking	162.7	19.9	12.2	29.3	623.8	954

Furthermore, the azimuth trackers are single axis and therefore much cheaper and simpler than dual-axis trackers. The dual-axis tracking system receives only 3.7% more solar radiation and produces only 4% more electricity than the azimuth tracking array. The consumption of the trackers is proportional to the tracking accuracy. While tracking the Sun is useful in clear days, it is counterproductive in overcast days. Consequently, the optimum method of sun tracking is using dual-axis tracker to follow the sun completely in clear sky conditions and go to the horizontal position in overcast conditions. These results are supported by previous studies [8].

The upcoming work will be experimental as a dual-axis tracking system has been installed in Hawkesbury, Ontario. This array will be monitored during winter 2012 to investigate its behavior in the drizzle, snow, and ice conditions.

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