A Comprehensive Financial Analysis for Dual-Axis Sun Tracking System in Iran Photovoltaic Panels

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Abstract— **Renewable energy sources are defined as free and clean sources of energy, which encourage investment in electricity production industry to move from conventional power plants to renewable energy sources such as photovoltaic (PV) systems. Regarding to the geographical characteristics, solar panels can be used widely around the most populated cities of Iran. One of the most important factors, which affects the amount of harvested energy by panels, is the adjustment of tilt angle of the panels. In this paper, the cost effectiveness analysis (CEA) of installing the dual-axis sun tracking system in comparison to single-axis sun tracking system is carried out. The analysis is accomplished on three currently available panels installed in Iran cities, as case studies including Yazd, Semnan and Tehran. Financial analysis is conducted based on solar radiation, inflation rate, temperature, and characteristics of solar panels such as degradation effect on solar panel efficiency. The investigations are developed by simulation results, which show that although the dual-axis sun tracking system can increase the produced energy, the total investment and maintenance cost is greater than the profit of extra energy attained using the dual-axis system with respect to the single-axis system considering the financial indexes and geographical situation of case studies in Iran.**

Keywords— Sun tracking system, financial analysis, photovoltaic system, power system planning

I. INTRODUCTION

Solar energy as a clean source of energy can respond to the world increasing demand for the electrical energy considering increment of population and development of societies. On the other hand, by gradually depletion of fossil fuels as one of the main sources of electrical energy generation, the need for a consistent source of electrical energy is defined as a challenging issue for power system operators and researchers [1, 2]. The use of solar energy has become pervasive all over the world, which has attracted remarkable efforts in recent years [3]. Utilizing solar energy in different points of the world such as Saudi Arabia has been dramatically increased in last years [4]. This is due to the fact that this source of energy has the high potential of harvesting in mentioned area [5]. Local climate conditions and orientation of photovoltaic (PV) panels with respect to the horizon are considered as effective factors which affect the absorbed energy of such systems [6, 7].

Recently, several investigations are conducted in different places around the world for analyzing the impact of installing the solar tracking systems. In this context, the assessment of solar energy with considering the optimum tilt angel are performed for Sindh, Pakistan [8]. Also, harvested energy from a flat plate collector at various tilt angle positions is calculated for Basrah. Moreover, the procedure for optimizing the tilt angle is discussed in this study. The results show that by adjusting the tilt angle eight times per year, the harvested energy by panels is almost equal to the harvested energy by daily adjustment [9]. The economic analysis of installing PV systems in State of Kuwait is studied in [10], where the cost-benefit analysis of implementation of PV systems proved that such project is beneficial in Kuwait considering positive characteristics of solar radiation. A similar research is accomplished as a PV park for Cyprus in [11], where different parameters such as PV park orientation and capital investment, and pollutant gas emission trading system price are considered. The authors in [12] studied integration of PV and electrical energy storage systems considering the energy storage management and grid-connected characteristic of the system. In [13], the financial analysis and environmental aspects of large-scale PV systems installation in United Arab Emirates is studied. The cost-benefit analysis shows that implementation of PV systems is not beneficial due to high initial costs and low power purchase price. The authors in [14] investigated economic benefits of grid-connected residential PV systems in United Kingdom and India proposing prosumer electricity unit cost (PEUC) parameter to evaluate the benefits from installing such systems.

The cost analysis of PV systems has attracting considerable interest in recent publications. The harvested electrical energy from the modules is maximized using time-varying evolution

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particle swarm optimization to find optimum tilt angle of PV modules for several cities in Taiwan [15]. Although, the heuristic methods may lead to more accurate results, a simply method for optimizing the tilt angle is proposed in [16] requires low computational load. The reported results prove that the harvested energy by solar panels installed in Saudi Arabia by adjusting the tilt angle daily and monthly are almost equal. Various solar radiation models are investigated and compared for optimum tilt angle adjustments of PV panels in [17] and a global optimum value is proposed without any need for monthly adjustment. Further, an estimation of the optimum tilt angle for four different adjustment regimes for south-facing PV surfaces in Tabass, Iran is carried out. Additionally, a diffuse solar radiation model from three different categories is established to determine the optimum tilt angle.

To the best knowledge of the authors, the sun tracking issue is not investigated considering cost effective analysis of dual axis sun tracking system in comparison with single axis. This paper is concerned with the cost beneficial analysis of substituting the dual axis solar tracking systems with the installed east-west (EW) single axis solar tracking system in Iran PV panels. Practical and environmental factors, which can affect the efficiency of the panels, are studied in details considering the financial analysis. In addition, time series method as an effective tool for forecasting the economic indices in life cycle context of solar tracking system is implemented in this research. The extra harvested energy by finding the daily optimum tilt angles using dual axis sun tracking system for available panels are estimated based on available data for these regions. Then, the financial analysis is conducted to evaluate the cost-effectiveness of installing the dual axis sun tracking systems based on the economical characteristics of country.

The rest of the paper is organized as follows: In section II, a model for the cost effectiveness analysis of dual/single axis sun tracking system is developed. The proposed model for the cost effectiveness analysis of dual/single axis sun tracking system is studied in Section III. The results of simulations are discussed in Section IV. Finally, the paper is concluded in Section V.

II. Modeling

The absorbed solar radiation by dual axis solar tracker systems consists of two elements. The first element is due to changing the panels orientation toward west and east, which is defined as EW solar tracking systems. The second element, which is possible for only dual axis, is increasing the absorbed radiation by changing the tilt angle. In this study, the authors aim to calculate the difference of absorbed radiation because of changing the tilt angle. Typical scheme of the dual axis solar tracking system is demonstrated in Fig. 1.

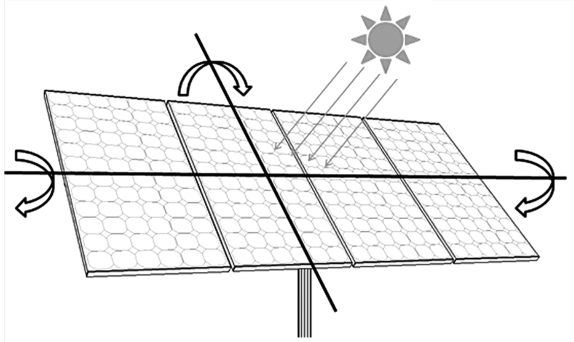

Fig. 1. Dual axis solar tracker

The solar radiation can be categorized into direct, diffuse and reflected radiation. Direct radiation is also called "beam radiation" refers to the portion of solar radiation traveling on a straight line from sun to the surface of the earth or solar panel. The beam radiation on tilted surface is calculated as follows [16]:

$$H_d = h_d . R_{b,t} \tag{1}$$

where, h_d is the direct radiation on a horizontal surface, $R_{b,t}$ is monthly average ratio of beam radiation on the tilted surface to a horizontal surface defined as follows for northern hemisphere:

$$R_{b,t} = \frac{\cos(\phi-\beta)\cos\delta\cos\omega_{ss} + \frac{\pi}{180}\omega_{ss}\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\cos\omega_{sr} + \frac{\pi}{180}\omega_{sr}\sin\phi\sin\delta} \tag{2}$$

where, ϕ is latitude, β is the surface angle, δ is declination, ω_{sr} is the sunset hour angle and ω_{ss} is the sunset hour angle for the tilted surface which can be stated as:

$$\begin{aligned} \omega_{ss} &= \min[\omega_{sr}, \cos^{-1}(-\tan(\phi-\beta)\tan\delta)] \\ \omega_{sr} &= \cos^{-1}(-\tan\phi\tan\delta) \end{aligned} \tag{3}$$

In addition, there is another main radiation beside the direct radiation called "Diffuse Radiation". When the sunlight is scattered by particles and macules this radiation is formed. Although, the amount of the diffuse radiation depends on the various factors like the density of suspended particles in atmosphere, sun position in sky, humidity etc., it is always less than the direct radiation portion. The diffuse radiation on tilted surface is calculated using following equation [7]:

$$H_{dif} = h_{dif} \cdot \left(\frac{1+\cos\beta}{2}\right) \tag{4}$$

where, h_{dif} is the diffuse radiation on horizontal surface. The last term of solar radiation is the reflected radiation by the non-atmospheric factors such as the ground. Actually, reflected radiation rarely accounts for a significant part of the sunlight striking panels surface. However, when the ground is covered by fresh snow, the portion of reflected radiation can be almost 25 percent of total radiation. The reflected radiation on the solar panels can be calculate as follow [7]:

$$H_{ref} = (h_{dif} + h_d).\rho.\left(\frac{1+\cos\beta}{2}\right) \tag{5}$$

where, ρ depends on the condition of ground which is approximately 0.7 and 0.2 for snow covered places and the others, respectively.

II.I. Earth declination angle

The declination angle denoted by δ, is daily changed as a result of rotation of the Earth tilted axis around the sun. The declination angle causes panels to be tilted with different angles in each day of year to get maximum radiation. An estimated formula for δ calculation is introduced as follows [7]:

$$\delta = -23.45 * \cos(\frac{360}{365}.(n+10)) \tag{6}$$

where, n is 1 for January 1st.

II.II. Degradation effect on solar panel efficiency

The panels located in the more moderate climates attained low degradation rate. As an instance, the northern United States has low degradation rate. According to the meta-analysis performed by the National Renewable Energy Laboratory (NREL), the most common rate for monocrystalline silicon, the most commonly used panel for commercial and residential PV, is around 0.7 up to 0.8 percent per year for panels made after 2000 [18]. That means, after 25 years the panels produces the energy with 80% of nominal efficiency. As a practical factor, panels degradation should be considered in cost analysis.

II.III. Temperature effect

Solar panel efficiency is affected negatively by temperature increasing. Depending on the installed location, the panels' generated power varies. The temperature effect can be considered by a coefficient. The solar cell's temperature can be calculated as follow [7]:

$$T_{cell} = T_{Air} + \frac{NOCT-20}{800} \times G \tag{7}$$

where, G is insolation in W/m^2, $NOCT$ is the nominal cell operating temperature, which is around 48°C for typical modules. The relation between cell temperature and the efficiency term related to the temperature coefficient (C_{temp}) can be defined as follows [7]:

$$C_{temp} = (1 - \frac{TC}{100}(T_{cell} - 25)) \tag{8}$$

where, TC is the temperature coefficient, and T_{cell} is the cell temperature.

III. The Proposed Model for Cost Effectiveness Analysis of Dual/Single Axis Sun Tracking System

The amount of extra absorbed solar energy in solar panels installed on dual axis solar tracker system in comparison with single axis, consists of the two elements. First, it is due to the orientation angle adjusting every 10-15 minutes, the second one is the result of daily tilt angle adjusting. The first term is the same with single axis solar tracking system however the second term increases the harvested energy by dual axis sun trackers. In this section, the authors calculate the total solar radiation on panels' surface for single axis and dual axis solar tracker system in three cities. In addition, difference between energy radiations in presence of single axis sun tracking system dual axis sun tracking system is derived. Finally, the cost effectiveness of installing the dual axis sun tracker system instead of single axis sun tracker system will be discussed.

Net present value (NPV) is the difference between the investment and net inflows in which future net cash of an investment is returned to the present value considering discount rate. Since inflation is a phenomenon which can affect the present value of future cash, it should be considered in the model. Inflation can be entered to the calculation of NPV using nominal discount rate instead of real one as follows:

$$r_n = \frac{1+r}{1+i} - 1 \tag{9}$$

where, r is real discount rate and i is inflation rate. Net present value of each year in the life time of project can be defined as follows:

$$NPV_t = \frac{R_t}{(1+r_n)^t} \tag{10}$$

where, R_t is net cash flow at time t, which can be defined as follows:

$$R_t = I_t - C_t \tag{11}$$

where, I_t is related income from installing sun tracking system considering efficiency degradation, C_t is system maintenance cost. Accordingly, total NPV of the investment can be defined as follow:

$$NPV_{tot} = C_{inv} + \sum_{t=1}^{lifetime} NPV_t \tag{12}$$

where, C_{inv} is the initial investment cost. Installing the sun tracking system would be cost beneficial if total NPV_t for system lifespan is positive.

The following equation represents total solar radiation on tilted surface.

$$H_T(t) = H_{dif}(t) + H_{ref}(t) + H_d(t) \quad (13)$$

By optimizing $H_T(t)$ for each day based on NASA data, optimum daily tilt angle for each city will be attained. A portion of solar radiation on panel surface that can be converted into the electricity depending on the panel's efficiency. Although the rated efficiency of panels in standard test conditions (STC) are listed on the manual, the real efficiency can be calculated by following formulation with regard to the installed conditions.

$$\eta_{out} = (1 - |C_m|).C_{surf}.C_{temp}.\eta_{rated} \quad (14)$$

where, C_m refers to the output power deviation, which is usually ± 0.05, C_{surf} is the solar panels surface's cleanliness coefficient, which is almost 0.95 for big cities and 0.98 for less polluted regions. In addition, η_{rated} is the rated efficiency available from manual. The term C_{temp} represents the effect of temperature and can be calculate as follows:

$$C_{temp} = (1 - \frac{TC}{100}(T_{cell} - 25)) \quad (15)$$

TC is the temperature coefficient and T_{cell} is the cell temperature. By daily changing the tilt angle, the harvested energy can be increased in comparison with the fixed tilt angle. However, it requires special structure and equipment for already installed panels.

IV. CASE STUDIES AND SIMULATIONS

Two different scenarios are simulated, single axis and dual axis structure for PV collectors, Matrix laboratory (MATLAB) software is used for simulation. Data for direct and diffuse radiation on horizontal surface available by NASA datasets is used for optimization process by MATLAB software. Since this is a long term planning, average values for 22 years are used for each site.

Daily average solar radiation on panels surface for three case studies including Yazd, Tehran and Semnan are demonstrated in Figs. 2.a to 2.c, respectively. Dual axis sun tracking systems are able to adjust the tilt angle daily, which may lead to greater solar radiation absorption rather than single axis sun tracker systems. The comparison of daily solar radiation during the year for three case studies proves that solar radiation is maximum using dual axis sun tracking system. Total solar radiation on tilted surface for three case studies is compared using single axis and dual axis sun tracker systems. In the first step, daily collected energy is computed using the above mentioned formulations for solar power output. Then, total harvested energy for a year is derived. The results show that the solar radiation on collectors increases 3.83 percent for Tehran, 3.93 percent for Yazd, 3.88 percent for Semnan respectively in comparison with single axis structure. The results are listed in Table 1.

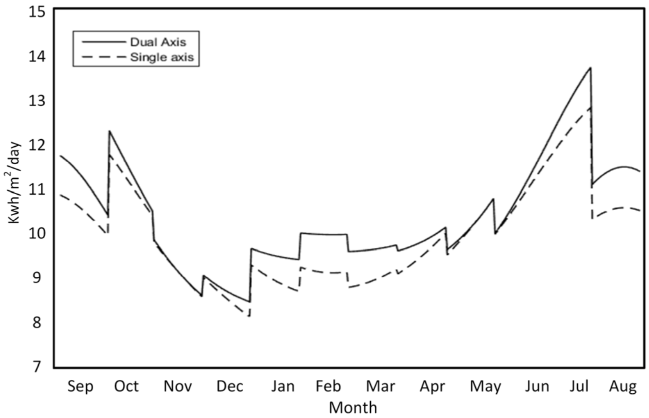

Fig. 2.a Yazd daily solar radiation on panels' surface

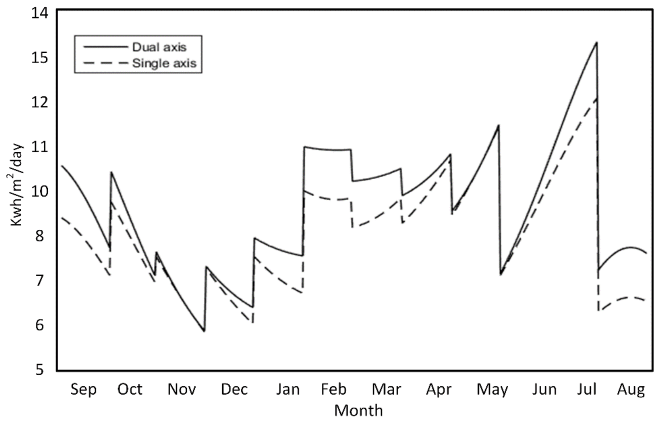

Fig. 2.b Tehran daily solar radiation on panels' surface

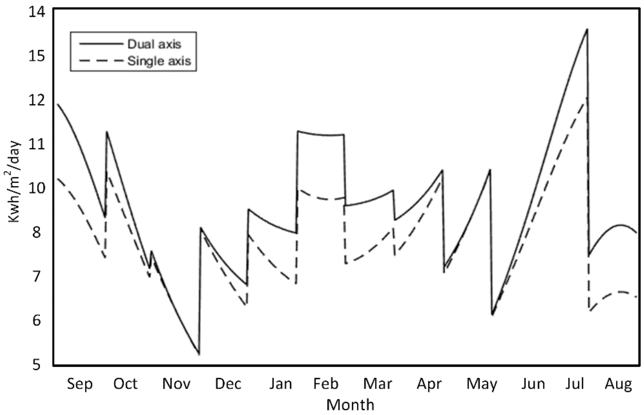

Fig. 2.c Semnan daily solar radiation on panels' surface

Table 1. Comparison of total solar radiation on tilted surface for three case studies

Total solar radiation on tilted surface (kWh/m^2/year)	Tehran	Yazd	Semnan
Dual axis sun tracker	3.436×10^3	3.698×10^3	3.467×10^3
Single axis sun tracker	3.309×10^3	3.558×10^3	3.48×10^3

In this study, the authors aim to conduct a financial analysis to evaluate the cost-effectiveness of installing dual/one axis sun tracing system on solar panels. For this purpose, the economic indicators like the rate of inflation should be considered. Time series analysis and forecast is one of the suitable methods for tracking the economic variables' changes over time. In time series, forecasting the information regarding historical values and associate patterns are used for future data forecasting. In this sub-section, the authors try to predict the annual increase in inflation rate for next 30 years. The available data in [19, 20] up to 2016 is used for estimating the model then the derived model is used for forecasting the annual increase in inflation rate. Predicted inflation rates are done for 2014 to 2016 and for 2017 to 2047 including actual data and predicted data, which are depicted in Fig. 3, and is obtained using time series forecasting method. The comparison between predicted data and actual data for 2014 to 2016 shows that the prediction error is 7.56 %.

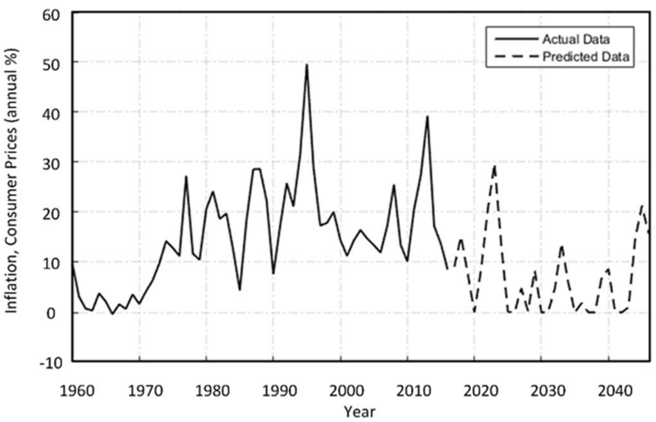

Fig. 3. Predicted inflation rates for 2017 to 2047

Moreover, Fig. 4 shows monthly average temperature for last 75 years provided by Iran Meteorological organization. Second, profit of using the tracking system and cost of maintenance and operation is considered for financial analysis, which are provided in Table 2. Finally, Net present values are calculated considering discount rate and estimated inflation values based on past data and cost beneficial of installing the sun tracking system is investigated for mentioned cities which are respectively -30.77$, -39.67$, and -27.52$ for Tehran, Semnan and Yazd. The energy attained for dual axis sun tracking system for Tehran, Semnan and Yazd are listed in Table 1 respectively. On the other hand, the energy attained using single axis sun tracking system for Tehran, Semnan and Yazd are listed in Table 1, respectively. The analysis shows that it is not economical to install dual-axis sun tracking systems instead of single-axis PV panels.

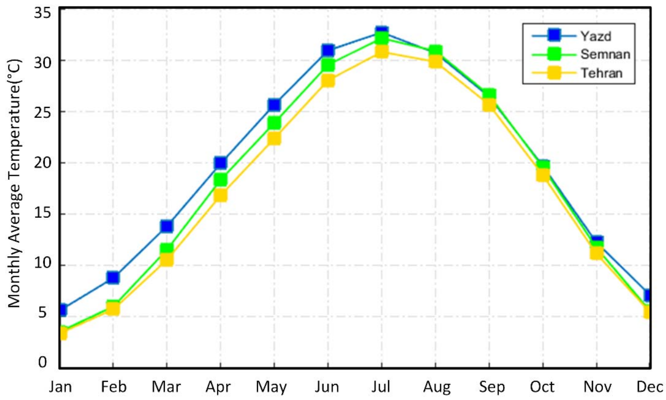

Fig. 4. Monthly average temperature for last 75 years provided by Iran Meteorological organization

Table 2. Initial and maintenance cost and characteristic of a commercial sun tracker system

Number of motion axis	Initial cost ($)	Max. dimensions of a solar panel (m^2)	Annual maintenance cost ($)	Expected life time (year)
Dual-axis	836	4 panels (19.5 m^2)	36-48	25
Single-axis	540	4 panels (19.5 m^2)	23.6-32	25

V. Conclusion

Dual axis sun tracking system can increase the solar panels' harvested energy in comparison with single axis sun tracking systems. The cost-benefit analysis of installing dual/single sun tracking system on photovoltaic panels in three cities in Iran has been investigated in this paper. For this purpose, total absorbed radiation was calculated based on 22 years' average radiation data from NASA database for these regions. The life span of solar panels should be considered in the cost analysis, which is around 25 years (normal life span of PV panels) based on degradation effect. Since the average values for radiation data are not changing notably, this data set is suitable for our analysis. Furthermore, there are other factors, which are important in this results like efficiency degradation of panels.

In addition, inflation rate for the period of investigation was predicted by time series method for cost analysis. The results show that in presence of dual axis sun tracking system, the radiation on collectors increases; however, the economic characteristic of the country makes this investment not beneficial for investors. by decreasing the Interest rate below 3.5 percent per year and increasing the purchasing price for electricity to 45 percent would make this investment cost beneficial.

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