



## Evaluation of Photovoltaic System Performance: A Case Study in East Azerbaijan, Iran

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### ABSTRACT

Solar energy is a feasible and efficient way to reduce environmental pollution which, in turn, can decrease the production of greenhouse gases. Iran with over 300 sunny days has a high potential for producing energy, including electricity through photovoltaic (PV) systems. Regarding this fact that Iran has the enormous resources of fossil fuels such as oil and gas, the government tends to expand its energy production by renewable systems, including photovoltaics. This paper is to evaluate the efficiency of photovoltaic system in one of the major provinces of Iran. In this study, a 4.8 kW photovoltaic power station in East Azerbaijan province was investigated. First, a simulation-analysis is carried out. Then the verification of the study is done using extracted experimental data. According to the results, the photovoltaic power plant generates 8334 kWh annually. Finally, the station is economically investigated. This economic analysis is carried out in accordance with the existing tariffs and policies in Iran.

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## INTRODUCTION

Environmental pollution and exhaustibility of fossil fuel have led various countries to move towards renewable and clean energy [1, 2]. Fossil fuels are yet the major resources for producing energy [3]. But using renewable energy is increasing in recent years so that the predictions show that by 2035, 16% of the world's electricity will be produced by renewable energy [4]. Renewable energies are available in many areas of the world and energy can be produced from them, even in remote areas [5].

Among renewable energies, the sun is an endless source of energy that can easily be converted into other types of energy such as thermal, electrical and chemical [6]. Photovoltaic systems are mechanisms that can be used to produce electrical energy using sunlight [7]. The use of solar energy to produce energy is an increasing trends [8, 9]. Electricity generation by photovoltaic systems is highly dependent on the environmental and geographical conditions of the site. Solar radiation intensity, temperature, humidity, dust as well as the wind are among environmental factors [10, 11].

Temperature is one of the important environmental factors which influence the efficiency of photovoltaic systems [12]. Typically, the system efficiency decreases by 0.45% per 1 °C

increase in temperature [13]. One of the solutions is use of photovoltaic thermal system. These systems are such that they reduce the heat at the surface of the panels and extract the heat obtained [14-18]. Another important environmental factor is the effect of dust. Increasing the amount of dust in the air and on the surface of the panels reduces the amount of sunlight that reaches the solar cells. This can, in turn, reduce efficiency [19, 20].

Solar energy is one of the most suitable renewable energies for Iran as a sunny country with an average of 2800 hours of sunshine annually [21]. In addition, the production of energy by renewable and clean systems can solve the problem of air pollution in the country to a remarkable extent. This has led policymakers in Iran to plan to produce 5,000 MW of photovoltaic electricity by 2021 [22].

East Azerbaijan province, located in northwestern Iran, is one of the most suitable locations for the installation of photovoltaic systems. It is true that hours of sunshine in this province are lower than many central and southern provinces in Iran, but the low average temperature in this province has resolved this problem and can increase the efficiency of photovoltaic systems.

The economic assessment of photovoltaic electricity generation depends on the supportive policies and tariffs available in each country. In Iran, the government has been

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trying to support renewable electricity generation by purchasing guaranteed electricity for 20 years.

In this work, a 4.8 kW photovoltaic system in one of the villages of East Azerbaijan province was investigated. The results are based on the performance of the system. First, the amount of electricity generated by the system compared with the calculated data using simulation. Then the simulation is validated by conducting the experiment for one year (2019 AD). Finally, an economic evaluation of the system was performed. This study is conducted according to the existing tariffs and regulations in Iran and the results were obtained.

## MATERIALS AND METHODS

In this section, the materials available for performing the tests and the methods are discussed. The software and the simulation used for the study are mentioned. Finally, the economic analyses investigated in this study are discussed.

### System description

In this study, a 4.8 kW system was investigated. The system is installed on the roof of a residential house in one of the cities of East Azerbaijan province called Darian with latitude 38.2172 and longitude 45.6305. The system comprises 15 photovoltaic panels of 320 Watts, which feed electricity into a 5 kW inverter and then into the global grid. The angle of the installation of the panels is 30 degrees relative to the horizon (Figure 1). The data of this system are recorded and evaluated by the data logger on the inverter. These data record and store the output of the panels in every 5 minutes.

### System modelling

The simulation was performed by RET Screen Expert software. RET Screen is an energy engineering software for the estimation of clean projects. This tool is used by developers to make project feasibility cheaper and more precise before the implementation section. The outputs and information of the RET Screen are in excel format [23]. A system similar to the system is simulated in this software. A system with 15 photovoltaic panels of 320 watts and a 5 kW inverter. Panels with a horizontal angle of 30 degrees are also considered. Also, the inverter efficiency is 97% and other system losses are assumed to be 2%.

### Economic evaluation

In this section, economic fundamentals are discussed. Economic concepts are considered in this study to investigate the photovoltaic system in the area. One of the most important economic theories in electricity generation is the Levelized Cost of Energy (LCOE) which is a measure of the average net



Figure 1. Photovoltaic system in Darian

present cost of electricity generation for a generating plant over its lifetime [24]. This parameter allows us to compare different methods of generating electricity economically. Payback period (PP) is another important economic parameter which refers to the amount of time it takes to recover the cost of an investment [25, 26]. Internal rate of return (IRR) is a significant parameter for appraise the amount of investment attractiveness. This is the interest rate at which the Net present value (NPV) of positive and negative cash flows for the systems are equal to zero [25-27].

## RESULT AND DISCUSSION

### Performance analysis

In this section, the given system is examined in terms of performance. First, this study is conducted by simulation. The results of the simulation will then be validated by conducting the experiment.

### Simulation

In this simulation, the energy generated by the photovoltaic system in different months is simulated. Figure 2 shows the energy generated in different months. As shown in Figure 1, the highest and lowest energy outputs are in July and December, respectively. According to the results, the energy produced through one year is 4.8 kW photovoltaic system in the desired geographical area is 8373 kW. If so, the average energy produced would be 22.93kWh/day. The capacity factor for this power plant is 19.91%.

### Experimental analysis

In this study, data on the photovoltaic system during 2019 were extracted and analyzed. The energy produced by 4.8 kW photovoltaic system is shown in Figure 3. According to the data obtained, the highest and lowest level of producing energy is in summer and winter. The months of July and December also represent the months in which the highest and lowest amounts of energy are produced. The total annual energy generated by the system is 8334 kWh. According to these interpretations, the average energy produced is 22.83 kWh per day. According to the results, the capacity factor for this plant is 19.82%.

Figure 4 shows the energy production in 365 days of 2019. To illustrate the overall behavior of the graph appropriately, a 4th-degree graph is fitted (Equation 1). As illustrated in this figure, production increased from the beginning of the year to July, reaching its peak in this month. Thereafter, production declined and as a result, production declined in December.

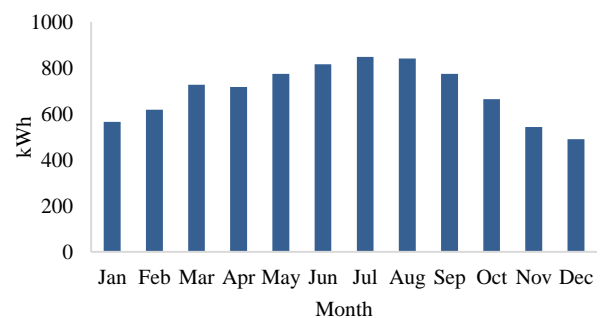
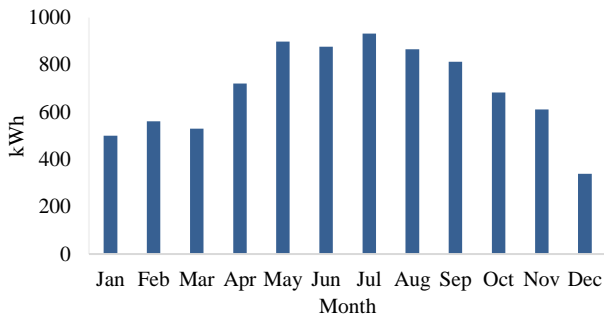
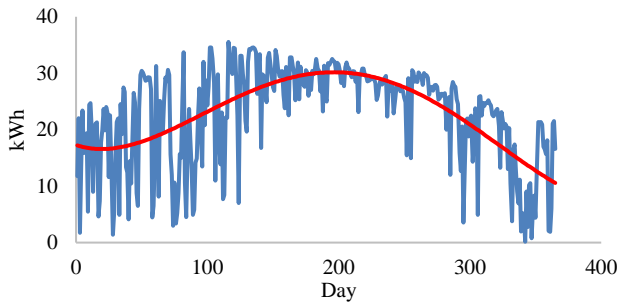


Figure 2. Calculation of energy generated by photovoltaic power plant by simulation



**Figure 3.** Calculation of energy generated by photovoltaic power plant by conducting experiments



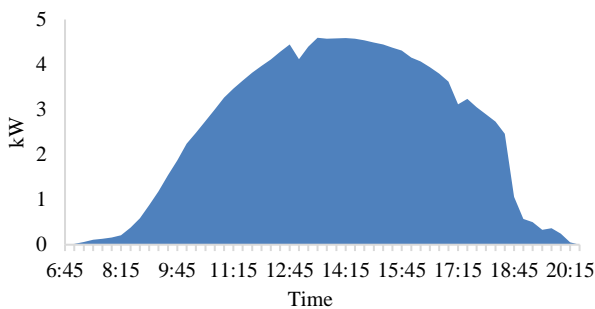
**Figure 4.** Energy production in 365 days of 2019

$$y = 1E - 08x^4 - 1E - 05x^3 + 0.0022x^2 - 0.076x + 17.27 \quad (1)$$

Among the different days of the year, most energies were produced on 24/4/2019. On this day the generated energy was 35.54 kW per hour (Figure 5). This maximum production occurred on one day of spring. On this day, the sun shined less than one summer day, but the air temperature on that day was lower than the temperature on a summer day.

**Economic analysis**

In this section, RET Screen software is used for economic investigation of the system. These calculations are based on the weather and geographical location of the site. In this study, the initial cost of \$ 1100 per kilowatt is considered. In this way, the price of a power plant is equivalent to US\$5280. The maintenance and repair price is \$ 3 per year [24]. The exchange rate of Dollar to Rials are assumed as 1:117296. Also, the inflation rate, discount rate, and the Electricity Export escalation rate are assumed to be 20%, 18%, and 10%, respectively. The electricity produced at the power plant is

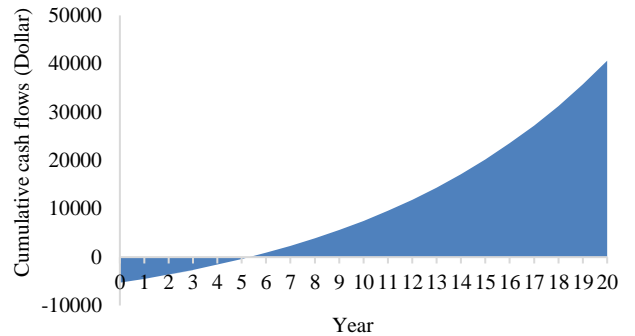


**Figure 5.** Most energy produced in one day in 2019

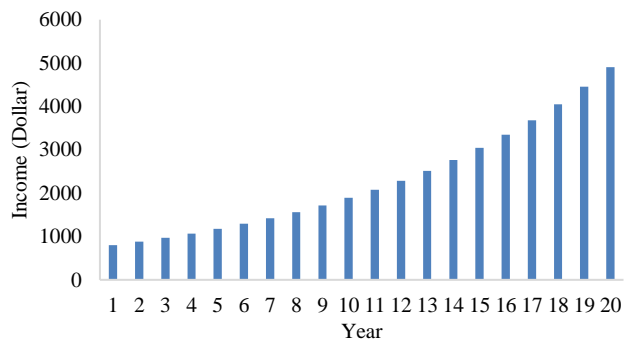
sold directly to the government and goes to the national grid. It will be sold for 20 years at 10400 Iranian Rials (US \$ 0.89) per kWh.

Figure 6 shows the Cumulative cash flows for this power plant. According to the graphs and economic calculations are carried out in this study, the PP for this plant is 5.3 years.

Figure 7 shows the power plant revenue over 20 years. IRR has been achieved 23.7%. Also, one of the most important economic parameters for investigation of technology is LCOE. LCOE for the system in this paper is equal to 13.5cents (US\$/kWh).



**Figure 6.** Cumulative cash flows for photovoltaic system



**Figure 7.** Incomes from photovoltaic systems

**CONCLUSION**

In this study, a photovoltaic system was investigated in a village of East Azerbaijan province. This study was first performed by simulation and then the results were validated by testing prototype. According to the results of the simulation, the system produces 8373 kWh of energy annually. This number is obtained by performing an 8334 experiment, which is very close to the number obtained from the simulation. The difference between the simulated and experimental data is less than 1%

In the economic sector, the IRR rate is 23.7%, which is higher than the rate of bank interest in Iran and can be attractive to investors. Also, payback period has been achieved 5.3 year. The cost per kilowatt-hour of electricity generated by the plant is estimated at 13.5 cents US\$/kWh. This is higher than the electricity generated by fossil fuel power plants, which is one of the weaknesses of photovoltaic systems. But the strengths of these plants are water

conservation, environmental pollution reduction and availability of the plant for consumers.

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## Persian Abstract

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### چکیده

انرژی خورشیدی یک راه حل کارآمد و امکان پذیر برای کاهش آلودگی زیست محیطی است که تولید گازهای گلخانه‌ای را کاهش می‌دهد. کشور ایران با دارا بودن بیش از ۳۰۰ روز آفتابی در سال پتانسیل بالایی برای تولید انرژی از جمله برق توسط سیستم‌های فتوولتاییک را دارد. با توجه به دارا بودن منابع عظیم سوخت‌های فسیلی مانند نفت و گاز دلت تصمیم بر گسترش تولید انرژی توسط سیستم‌های تجدید پذیر از جمله فتوولتاییک را دارد. هدف از این پژوهش بررسی کارایی سیستم فتوولتاییک در یکی از استان‌های بزرگ ایران است. در این پژوهش یک نیروگاه فتوولتاییک ۴/۸ کیلوواتی در استان آذربایجان شرقی مورد بررسی قرار گرفته است. این بررسی ابتدا توسط شبه سازی صورت گرفته و پس از آن توسط داده‌های تجربی استخراج شده صحت سنجی خواهد شد. با توجه به نتایج به دست آمده سیستم فتوولتاییک موجود ۸۳۳۴ کیلووات ساعت انرژی در سال تولید کرده است. در پایان این نیروگاه از لحاظ اقتصادی مورد بررسی قرار می‌گیرد. این بررسی اقتصادی با توجه به تعرفه‌ها و سیاست‌های موجود در کشور ایران صورت می‌گیرد.