# Investigation of the Effects of Photovoltaic Panel Cooling Using Hydroelectric Power Plant Discharge Water on Energy Production and System Efficiency

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***Abstract*— The performance of photovoltaic (PV) systems varies depending on panel temperature, and high temperatures cause significant efficiency losses in energy production. This study proposes an innovative hybrid renewable energy system that utilizes hydroelectric power plant discharge water to cool photovoltaic panels. The aim of the proposed system is to reduce the PV panel temperature and thus increase system efficiency by leveraging the waste water potential of an existing hydroelectric source. System performance was analyzed using simulation-based methods with HOMER Pro software under different cooling scenarios. The model considers the temperature-dependent efficiency change of PV panels, the cooling effect, and energy production parameters. The findings show that using discharge water for cooling purposes in PV systems can increase energy production and improve the economic performance of the system. This study contributes to the design of hybrid renewable energy systems and reveals the efficiency-enhancing potential of integrated energy solutions.**

***Keywords*— *Photovoltaic Systems, Hydroelectric Energy, Hybrid Renewable Energy Systems, PV Cooling, Energy Efficiency, HOMER Pro***

## I. INTRODUCTION

Increased global energy demand, environmental impacts from fossil fuels, and energy supply security issues have made it necessary to use renewable energy sources more effectively [1], [2]. In this context, solar and hydroelectric energy are among the fundamental components of energy transformation due to their low carbon emissions, high resource potential, and contributions to sustainable energy systems [3], [4]. In particular, PV systems have become one of the fastest-growing renewable energy technologies in recent years thanks to their modular structures, ease of installation, and decreasing investment costs [5], [6]. However, the performance of PV systems is significantly affected by environmental conditions. Factors such as solar radiation, ambient temperature, wind speed, panel surface temperature, and dust accumulation play a decisive role in PV output power [7], [8]. The study by Kaya et al. shows that an increase in panel temperature reduces the open-circuit voltage, leading to a decrease in PV module efficiency [9]. It is stated in the literature that the temperature coefficient in crystalline silicon-based PV models mostly varies between −0.3 and −0.5 %/°C and that every 1°C increase in panel temperature can lead to a similar rate of decrease in power output [10], [11]. This situation can cause significant losses in annual energy production, especially in regions with high solar radiation and hot climate conditions [12].

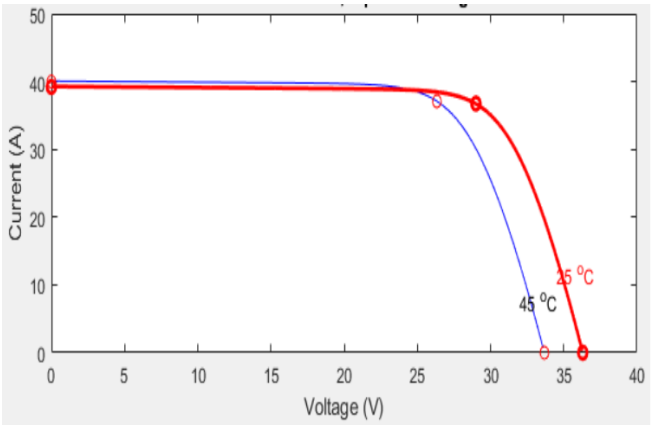


Fig. 1. Temperature-dependent current and voltage variation of PV panel [9]

Various techniques such as air cooling, water cooling, phase change materials and hybrid cooling methods have been developed to reduce temperature-related losses in PV systems [13]–[15]. Among these methods, water cooling stands out as one of the effective solutions for reducing the temperature of PV panels due to its high heat transfer capacity [16]. Experimental studies show that water-based cooling applications can increase electrical efficiency and annual energy production by reducing the temperature of PV panels [17], [18]. However, additional requirements such as pumps, boronizing, maintenance, and energy consumption in active cooling systems can affect the economic feasibility of the system [19]. Hydroelectric power plants are facilities that provide continuous and high-flow water discharge after electricity generation. Instead of simply releasing this discharge water into the natural flow after energy production, using it as an auxiliary resource for cooling PV panels can enable the secondary use of the existing water resource. In addition, installing PV systems around hydroelectric facilities makes it possible to utilize the existing energy infrastructure, grid connection, and land use potential more effectively [20], [21]. Therefore, the positioning of PV systems around hydroelectric power plants and the use of discharge water for panel cooling can be considered an innovative approach to the integrated use of renewable energy sources. In recent years, hybrid systems using hydroelectric and solar energy together

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have been investigated, especially in the context of floating PV systems and dam reservoir applications [22], [23]. These studies show that the balancing capability of hydroelectric power plants and the high daytime production potential of solar energy can be evaluated together. However, it is seen that there are limited studies in the literature on systems where hydroelectric power plant discharge water is used directly for PV panel cooling. This situation constitutes the unique contribution area of the present study. In this study, the Ilısu Dam region in Turkey was selected as the case study area and a system approach in which hydroelectric power plant discharge water is used for PV panel cooling was proposed. In the study, a grid-connected PV system with an installed capacity of 500 kW was modeled in HOMER Pro software. Annual PV energy production, renewable energy ratio, grid energy purchase and sale amounts, and system performance indicators were compared by creating two different scenarios: cooled and uncooled. Thus, the impact of hydroelectric power plant discharge water on PV system performance was evaluated from a technical perspective.that follow.

## II. Materials And Methods

This study proposes using hydroelectric power plant discharge water for panel cooling to improve the performance of PV systems that can be installed around the Ilısu Dam, one of Turkey's hydroelectric power generation facilities (Figure 2). The system is modeled as a grid-connected PV energy system. Cooled and uncooled operating conditions are compared.




Fig. 2. Ilısu Dam [24]

The main objective of this study is to investigate the effect of wastewater from a hydroelectric power plant on electricity generation by utilizing its own pressure due to the slope and reducing the temperature of the PV panel through water circulation without requiring any energy from a water pump, and to numerically determine the energy gain obtained.

### A. Modeling with HOMER Pro

The technical analysis of the system was carried out using HOMER Pro software.[25]

The following steps were followed in the modeling process: The system was obtained from the HOMER database for solar radiation and temperature data of the Ilısu Dam region, a grid-connected 500 kW PV system was defined and an annual electricity load of 730.000 kWh was created. The load value was determined to represent the consumption of a medium-sized facility that may consist of dam operation, lighting and administrative buildings. Modeling of uncooled and cooled PV system scenarios separately and comparison of energy production, grid consumption and renewable energy ratios were ensured.

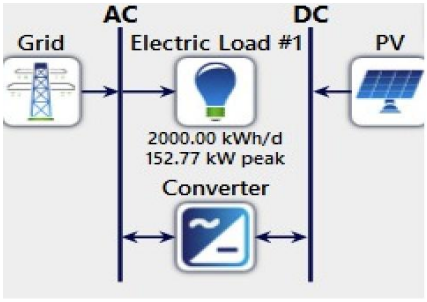


Fig. 3. Simulation Application Diagram

Meteorological data were obtained using the NASA POWER database of the HOMER Pro software. The annual average global horizontal solar radiation for the Ilısu Dam region was determined as 4.77 kWh/m²-day [26].

### B. Hydroelectric Resource Model

The energy production capacity of the Ilısu Dam was not directly analyzed within the scope of this study. It was assumed that the water discharged from the turbine outlet of the hydroelectric power plant could be used as a cooling source for the PV panels. Hydroelectric power generation is modeled as a fixed or time-dependent variable generation source in the system. Hydroelectric power generation is generally expressed by the following equation [27]:

$$P(hes) = \rho \times g \times H \times Q \times \eta_t \quad (1)$$

Here;

ρ: water density (kg/m³),

g: gravitational acceleration (9.81 m/s²),

H: water drop height (m),

Q: water flow (m³/s),

η_t: turbine efficiency

In this study, the main purpose of the hydroelectric system is to provide a cooling water source in addition to energy production.

### C. Photovoltaic System Model

The FV system was modeled using the "Generic Flat Plate PV" component within HOMER Pro. The installed power of the system was determined as 500 kW. Microcrystalline silicon panels with a nominal power of 550W were used as the basis for modeling the system. Accordingly, the system consists of approximately 909 FV panels. The FV panel output power is expressed by the following general equation [28].

$$P(FV) = P(rated) \times (G / G(ref)) \times \eta \quad (2)$$

Here;

P(rated): panel nominal power,

G: instantaneous solar radiation,

G(ref): reference radiation value,

η: panel efficiency.

Panel efficiency varies depending on temperature and the following model was used:

$$\eta = \eta ref\,[1 - \beta(\,Tcell - Tref\,)] \qquad (3)$$

In the model, β represents the temperature coefficient, which typically varies between 0.003 and 0.005 1/°C for PV panels.[29]

### *D. Cooling System and Assumptions*

In this study, two different operating scenarios were created to investigate the potential of water discharged from a hydroelectric power plant to reduce the temperature of PV panels. In the first scenario, the panels were modeled under standard operating conditions without any cooling application, while in the second scenario, the cooling effect of the hydroelectric power plant discharge water on the panel surfaces was taken into consideration.

TABLE I. PV PERFORMANCE PARAMETERS ACCORDING TO COOLING APPLICATION

| | ***Uncooled PV*** | ***Cooled PV*** |
|---|---|---|
| Panel capacity (kW) | 500 | 500 |
| Cell temperature (NOCT)(°C) | 47 | 10 |
| Panel efficiency (%) | 13 | 18 |
| Temperature coefficient (%/°C) | -0.5 | -0.3 |

Table 1 shows that in both scenarios, the installed power of the PV system is kept constant at 500 kW. Thus, the aim is to assume that the change in system performance is solely due to temperature and efficiency parameters. While the panel cell temperature is assumed to be 47°C in the uncooled scenario, this value is reduced to 10°C in the cooled scenario using hydroelectric power plant discharge water. Since the decrease in cell temperature increases the electrical conversion efficiency of the PV panels, the panel efficiency is increased from 13% to 18%. Keeping the temperature coefficient the same in both cases allows for a more accurate assessment of the effect of temperature on energy production. The scenarios created in line with these assumptions enable the quantitative determination of the contribution of hydroelectric cooling application to the PV system performance.

## III. RESULT AND DISCUSSION

This study analyzes two different scenarios for a 500 kW grid-connected PV system planned to be installed in the Ilısu Dam region. The first scenario examines PV panels under standard operating conditions, while the second scenario evaluates the situation where water discharged from the hydroelectric power plant is used for panel cooling.

Figures 4 and 5 show the distribution of hourly power outputs of PV systems throughout the year. In the graphs, the horizontal axis represents the days of the year, and the vertical axis represents the hours within the day. Increased color intensity indicates higher power output.

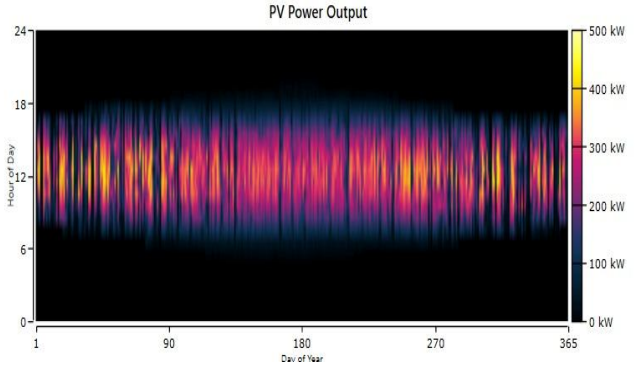


Fig. 4. Power output graph of an uncooled PV panel

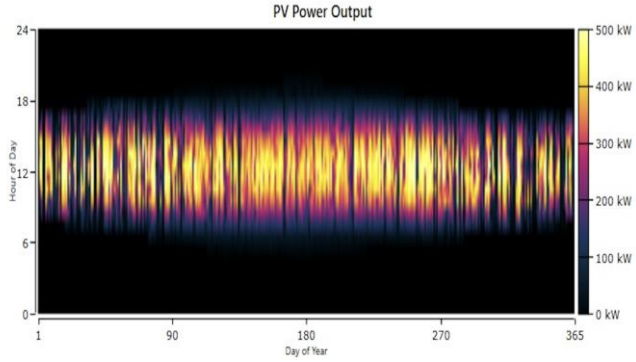


Fig. 5. Power output graph of an cooled PV panel

In the cooled PV system, it is observed that the color intensity is spread over wider areas and high power levels are maintained for a longer period. This is due to the increase in cell efficiency as the panel temperature decreases. The cooling application has enabled the PV system to produce higher output power by reducing power losses, especially during the summer months when temperatures rise.

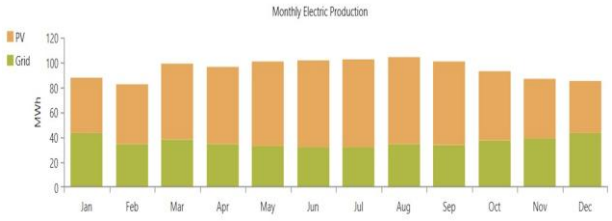


Fig. 6. Monthly energy production from uncooled PV

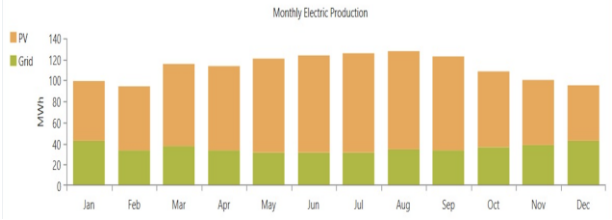


Fig. 7. Monthly energy production from cooled PV

Figures 6 and 7 show the monthly electricity production distributions of uncooled and cooled PV systems. In both scenarios, it is observed that electricity production increases in spring and summer months and decreases in autumn and winter months. This is due to the seasonal variation in solar

radiation in the Ilısu Dam region. In the cooled PV system scenario, it was observed that the amount of PV production increased especially during the May-September period, and consequently, the amount of energy purchased from the grid decreased. Performance losses caused by the increase in panel temperatures in the summer months were reduced with the cooling application, and the solar energy utilization rate of the system was increased.

TABLE II. COMPARISON OF SIMULATION RESULTS

| | ***Uncooled PV*** | ***Cooled PV*** |
|---|---|---|
| Panel capacity (kW) | 500 | 500 |
| Annual PV Production (kWh/year) | 703.513 | 919.883 |
| Renewable Energy Rate (%) | 60.4 | 67.1 |
| Total Energy Production (kWh/year) | 1.141.106 | 1.348.345 |
| Grid Sales (kWh/year) | 375.931 | 572.351 |

Table 2 shows that panel cooling positively affects PV system performance. In the cooled scenario, annual PV energy production increased from 703.513 kWh/year to 919.883 kWh/year, representing an increase of approximately 30.8%. Similarly, the renewable energy ratio increased from 60.4% to 67.1%, and the amount of energy sold to the grid increased from 375.931 kWh/year to 572.351 kWh/year. The results indicate that panel cooling using hydroelectric power plant discharge water increases system efficiency and positively contributes to energy production.

## IV. CONCLUSION

This study investigated the effect of using hydroelectric power plant discharge water for cooling PV panels on system performance using HOMER Pro software. Cooled and uncooled PV systems were compared in scenarios created for the Ilısu Dam region. Simulation results showed that reducing panel temperature increased annual PV energy production from 703.513 kWh/year to 919.883 kWh/year, representing an increase of approximately 30.8%. Furthermore, an increase in the renewable energy ratio and the amount of energy sold to the grid was also achieved. The findings demonstrate that using hydroelectric power plant discharge water for cooling PV panels is technically feasible and can improve system efficiency. Future studies could provide a more comprehensive analysis of the system's economic and environmental performance, also considering water pumping energy and cooling infrastructure costs.

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