

# Determining the Condition of Photovoltaic Modules and The Causes of Their Degradation

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**Abstract:** In recent years, the world has placed great emphasis on developing energy-saving technologies and using renewable energy sources. According to International Energy Agency (IEA) estimates, due to social and economic development, the demand for electricity is expected to increase by more than 50 percent by 2030 compared to the beginning of this century, total demand is expected to reach 23.27 billion tons of oil equivalent<sup>1</sup>. To mitigate a potential future energy crisis and reduce negative environmental impacts, the required energy replacement can only be achieved through renewable energy sources.

In this scientific article, the operating status of photovoltaic (PV) modules, the factors affecting their efficiency, and the main causes of degradation processes are analyzed. Photovoltaic systems occupy an important position among renewable energy sources, and their long-term reliability is of great importance. The article presents types of degradation, diagnostic methods, and proposals for improving efficiency. Photovoltaic modules operate on semiconductor materials. When sunlight strikes them, electrons are set in motion, generating an electric current. This process is called the photovoltaic effect.

**Keywords:** Photoelectric module, degradation, efficiency, solar panels, diagnostics, energy loss.

**Introduction:** The growing global demand for renewable energy sources is driving the need to improve photovoltaic module manufacturing technologies. Solar energy, as an environmentally friendly and inexhaustible resource, plays a significant role in the energy system. In recent years, production volume growth and technological innovations have significantly reduced the cost of solar panels.

The main goal in the production of photovoltaic modules is to increase the coefficient of performance (COP), reduce production costs, and ensure long-term operational stability. As decarbonization processes accelerate in the global energy system, solar energy is becoming strategically important. The development of photovoltaic module manufacturing technologies is helping to reduce the cost of electricity and increase

efficiency. Although silicon-based modules have dominated the market for the past decade, new-generation materials are achieving higher efficiency ratings.

Only 10.2% of all energy produced worldwide comes from renewable energy sources. Over the past five years, the share of renewable energy sources in meeting global energy demand has exceeded 20 percent, and the global production share stood at 12.4 percent. Solar photovoltaic power plants, in particular, have risen to leading positions in utilization, through which the efficiency of solar panels is increased, conducting scientific research to improve the efficiency of solar panels, study external factors that affect them, and prevent degradation processes during operation are considered pressing tasks today.

## METHOD

Visual study. Visual inspection is the first stage of analysis, allowing certain defects to be identified by eye. During visual observation, yellowing, delamination, bubbles, cracks in the coating, and scorched coated elements can be detected [3-4]. To ensure the illumination required for a quality analysis, tests can be conducted outdoors under natural sunlight. According to the test conditions for clause 10.1 of the IEC 61215 international standard (International Electrotechnical Commission, 1987), an illumination of more than 1000 lux must be provided. Indoor and outdoor measurements. To determine power reduction, power measurement must be performed under Standard Test Conditions (STC). The Standard Test Conditions must meet the following requirements:

- a) radiation intensity: 1000 W/m<sup>2</sup>;
- b) Solar cell temperature: 25 °C;
- c) spectral irradiance distribution: AM1.5;
- d) Normal incidence on the solar cell surface.

These tests can be performed using a solar simulator (indoor measurement) or outdoors under natural sunlight (outdoor measurement). However, it is not easy to simultaneously measure the uniformity of temperature and light. In indoor measurements, temperature and light uniformity are better controlled. However, even so, it is difficult to accurately replicate the spectral distribution of sunlight when using artificial light. To accurately measure the radiation received by the solar panel under test, a reference standard panel must be used. If the uniformity and spectrum of the light received are very close to that of sunlight, then it can be classified as a solar simulator class. The international standard conditions are not considered real-world climate conditions for PV modules. In real-world climate conditions, the temperature can be much higher or lower than , and the irradiance may not have a uniform spectrum or level. However, even so, conducting tests under standardized conditions is considered a good method for comparing different solar panels under uniform conditions. To determine the rate of degradation processes in PV modules, the requirements of the International Standard IEC 61724 and the following expressions were used. Considering all the losses in PV modules, including crystalline silicon cracking and other changes, the PV system's production capacity is expressed by the following formula.

Photoelectric effect and operating principle: The photoelectric effect is the process in which, under the action of sunlight on semiconductor materials,

electrons are set in motion, generating an electric current.

Types of degradation

1. Optical degradation – surface contamination.
2. Thermal degradation – exposure to high temperatures.
3. Electrical degradation – increase in contact resistance.
4. Mechanical degradation – microcracks.

Causes of degradation: atmospheric exposure, ultraviolet radiation, temperature changes, dust, and low-quality materials.

Diagnostic methods: thermography, I–V characteristic analysis, visual inspection, electroluminescence.

## RESULTS AND DISCUSSIONS

Photoelectric elements are manufactured based on semiconductor materials. Their operating principle is based on the photoelectric effect. Observations and studies of the PV modules in the research object, as well as solar panels in other installations, identified the following defects and conditions:

Yellowing and blackening. These conditions are typically present in the adhesive materials between the EVA or glass and the cells. In these materials, the color changes from white to yellow and sometimes later from yellow to brownish

a color change appears. This defect leads to a reduction in the light rays reaching the PV cells and, consequently, a decrease in the power generated by the solar panel. It was determined that the primary cause of such defects in ethylene copolymer films is a change in the polymer's chemical structure under the influence of ultraviolet (UV) radiation when the temperature exceeds +50°C.

It is known that under real climatic conditions, the operational efficiency of the QFES decreases year after year. This reduction in the operational efficiency of these PV systems is due to the effects of external and internal factors acting on them. External factors mainly include seasonal climatic conditions (rain, snow, fog, hail, dust storms), mechanical impacts (trees

breaking off of branches, impact from stones and other hard objects, and so on). Internal factors (disconnection of connected contacts, corrosion, yellowing of the EVA layers, blister formation, corrosion on the edges and bottom of the protective frame due to rain and snow, cracks appearing in the PV cells, contact burning, and others). Additionally, degradation processes arise from overheating of the PV modules during dry and hot weather, which leads to a decrease in the overall efficiency of the PV power system and

causes changes in the internal layers of some PV modules. We used the requirements of the International Standard IEC-61724 and the following expressions to develop a mathematical algorithm block for determining the rate of degradation processes in PV modules, taking into account external and internal factors.

## CONCLUSIONS

Timely detection and mitigation of degradation are crucial for maintaining the efficiency of photovoltaic systems. The development of recycling technologies is a key factor in establishing a sustainable energy system.

Analyses show that crystalline silicon technology will retain its leadership in the coming years. However, perovskite and tandem cells, with their high efficiency ratings, are expected to be widely adopted on an industrial scale in the future. Automating production processes and ensuring environmental safety remain key priorities.

The following measures can be used to increase the operational efficiency of the modules:

- Regular cleaning and maintenance
- Use of high-quality materials
- Implement cooling systems
- Application of modern monitoring systems

The efficiency of photovoltaic modules depends on their operating conditions and external influences. By detecting and addressing degradation processes in a timely manner, the long-term reliability of solar energy systems can be ensured.

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