An analysis of the prospects and efficiency of floating and overland photovoltaic systems

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ABSTRACT

The world's increasing demand for energy coupled with dwindling natural resources has spurred the need for alternative and renewable energy sources. However, one of the biggest drawbacks of renewable energy is its intermittency. Currently, most of the world's electrical energy comes from thermal power and nuclear energy combined. Despite being heavily reliant on energy imports, Morocco has made progress in developing its solar energy capacity with an installed capacity of 760 MW, 200 MW of which comes from photovoltaics. One way for Morocco to further increase its renewable energy production is through floating solar power, which utilizes the water surface of dams and reservoirs. The challenge with this approach is to secure the floating solar panels to prevent them from being blown about by wind and other elements. Like onshore solar power, offshore solar power also utilizes maximum power point tracking (MPPT) technology to maximize energy production. To compare the efficiency of terrestrial and marine solar power systems, the design and simulation of a solar PV system with MPPT through a boost converter was carried out using MATLAB/Simulink models. The study also examined the impact of water flow characteristics on the output of solar energy from floating panels.

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1. INTRODUCTION

A recently developed method of producing electricity, floating photovoltaic technology (FPVT), has garnered significant interest due to its numerous benefits. The United States is responsible for the development of this strategy (FPVT). The amount of water lost to evaporation is reduced, and energy production is increased, by using the FPVT system. With the hope that it would make my study easier, a huge volume of research has been done on FPVT systems, with researchers exploring them from many different angles. This study provides a systematic overview and a current evaluation of various irrigation and agricultural systems, illuminating their many facets and their many applications [1].

Photovoltaic energy is a renewable energy that converts sunlight into electricity using cells made of crystalline silicon. It is the most technologically and industrially advanced industry, and its name comes from the Greek word for light and the Italian physicist Alessandro Volta, who made significant contributions to the discovery of electricity [2]. PV system performance can be negatively impacted by degradation, which occurs when a PV system component wears out and reaches a critical threshold, making it inefficient [3]. By 2020, it is expected that renewable energy will supply 28.3% of the world's total energy consumption [4]. Solar power plants that generate electricity via photovoltaic cells on the surfaces and reservoirs of hydraulic basins are called “floating photovoltaic” as they allow for the expansion of surface waters beyond their boundaries while also conserving land [5]. Morocco plans to implement this strategy to boost electricity production from hydropower plants while decreasing water loss to evaporation [6].

Despite its potential, floating solar now only makes up around 0.5% of all solar photovoltaic installations worldwide. Floating structures, anchoring and mooring systems, and, to a lesser extent, development expenses contribute to a 20–25% increase in system costs that must be evaluated against its benefits [7]. Solar photovoltaic production atop floating platforms may be the solution to global warming and power outages, but it must be part of the toolset [8], [9].

The government is exploring buoyancy and structural materials to find an economical solution to economic growth [6], [10]. The proportional integral derivative (PID) controller uses the sensor output signal to generate a compensating signal that tracks the peak solar intensity. The receiver must be oriented perpendicular to the sun's rays for maximum power extraction, and batteries are essential for self-sufficient photovoltaic systems [11].

Photovoltaic solar panels may transform sunlight into power without any additional components. However, maximum of the sunlight that hits the modules goes to waste as heat rather than being converted into usable electricity [12]. Temperatures should be maintained low to maximize efficiency of PV modules, and the cell's temperature has an adverse effect on longevity. Different semiconductor materials have different responses and thermal sensitivities, resulting in a wide range of module outputs. Temperature coefficients provide an accounting of how the different electrical outputs respond to temperature variations [13]. FPVT systems have drawn attention due to their higher power output than land-based systems, and their capacity has increased by 27% to reach 512 GW. Further investigation of barriers to widespread adoption of PV technologies is the primary goal of this work.

Solar field data show how solar radiation has changed throughout time. To better meet the demands of solar energy systems, it may calculate the entire amount of energy received by a system and contribute to the most precise sizing that is possible. Direct irradiation at normal incidence, basic irradiations, diffuse component, and global component measured on a horizontal plane, and global irradiation received on a plane inclined at the location's latitude and pointed south, are all used by solar system designers. The vast majority of models are based on empirical data from the field of meteorology [7], [14].

2. CASE DESCRIPTION

2.1. Morocco’s solar deposit and capacity worldwide installed

Morocco is an ideal site for the research and development of a wide variety of solar-powered energy generating systems because to its enormous annual solar deposit Figure 1 and favorable climatic circumstances [15]. 149 hydraulic power systems, eight seawater desalination stations, and hundreds of wells ensure that agricultural and industrial uses get the water they need [7]. Morocco is facing a water crisis due to climate change, erosion, and dams blocked with silt. To address this, 20 desalination facilities must be built by 2030 [16].

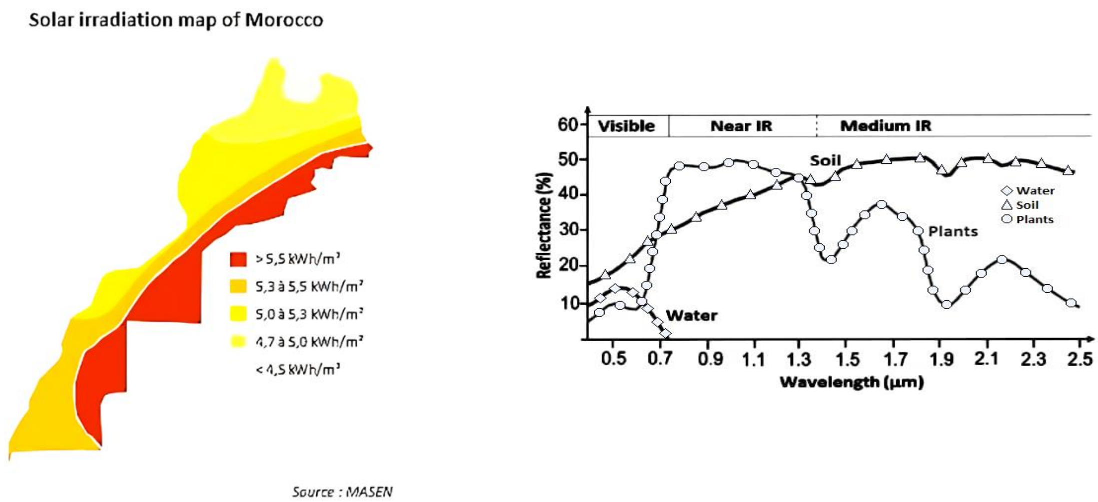

Figure 1. Solar irradiation map of Morocco and reflectance of water curve

2.2. Principle of floating photovoltaic panels for pumping system

In its most basic form, solar-powered water pumps convert the energy contained within the photons emitted by the sun into the mechanical energy required to pump water. To collect the photons, or rays of light, that the sun emits, solar panels are used. To drive the motor that drains the water from the source, these photons are transformed into DC electricity [9]. Solar pumping systems (SPSs) use a solar controller to direct energy from the sun to an electric pump's motor, resulting in low initial investment, low operating costs, extended lifespan, and versatility [17]. In Figure 2 the autonomous solar installation has been illustrated.

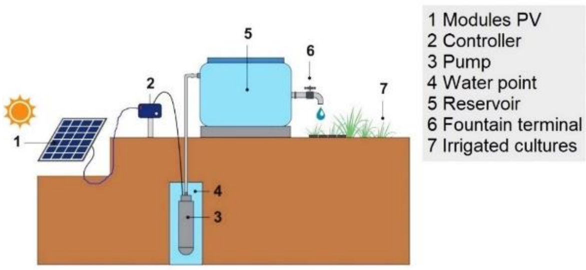

Figure 2. Autonomous solar installation

3. BACKGROUND

3.1. Characteristics of a module

PV systems must have the same system requirements and installation circumstances to compare power production [18]. Floating photovoltaic systems are more efficient than rooftop and ground-mounted PV modules due to the water's environmental surface, quantity of solar radiation, and temperature of panels [19]. The efficiency of the module is determined by comparing the module's maximum electrical output to the intensity of the incident radiation. The “form ratio” is the proportion of the cell's maximum power to its optimum power [20].

3.2. Advantages and disadvantages

Cells have advantages such as lower module temperatures, higher energy efficiency, and improved access to purified water, but drawbacks such as costs and drowning risk [21]. A conventional floating solar module consists of a photovoltaic module, a floating structure, and a supporting device. With this configuration, severe winds and a surface texture pose the greatest danger to stiff solar modules. As an example: Permanent and continuous floating devices need mooring to maintain proper platform placements [19].

3.3. Difference between floating photovoltaic systems (FPVs) and overland photovoltaic systems (OPVs)

FPV systems have superior energy efficiency when compared to terrestrial OPV systems due to their modelling of water and evaporative cooling. Infrared radiation has a negative thermal and thermally effect on photovoltaic panels Figure 3, so installing them in water would result in more energy output [22]. The tilt angle of solar panels should be optimized before usage with FPV to maximize energy production. Tests showed that tilting at the optimal angle yields the most energy, with 20-30% more energy when tilted at 0 degrees [23].

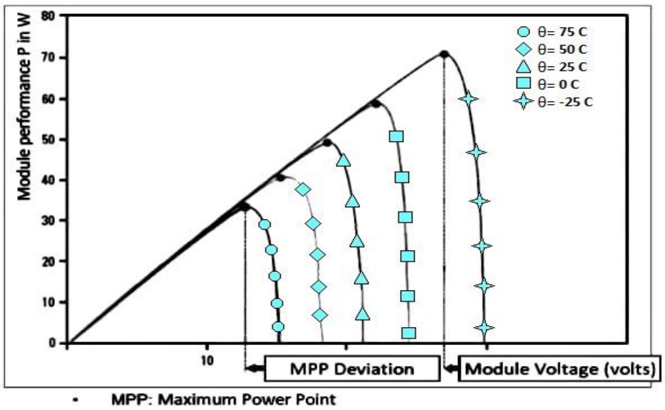

Figure 3. PV module voltage (T)

3.4. Recent technical advances, economic impacts, and environmental implications of floating PV solar energy conversion systems

Compared to CAPEX for power plants on the land, the initial expenditure for floating PV systems is generally 25% more. This occurs when elements like floats, mooring lines, and anchors are included. If the capacity of FPV power plants is expanded from 52 kilowatts to two megawatts, the usual cost of energy (LCOE) might be cut by as much as 85%. More investigation, development, and technological and material breakthroughs are expected to make FPV technology more widely available to customers [8]. Solar panels could generate enough electricity to meet sixteen percent of Europe's needs, and reduce water loss from Lake Nasser. A test bed based on a small-scale solar installation is needed to evaluate the potential [14].

4. METHOD

Solar power plants that float on water may potentially provide additional energy in a variety of lakes. To combat evaporation and generate renewable energy, Moroccan authorities are building water storage reservoirs around the country [24]. PVsyst was created to aid academics, professionals, and architects in the solar project design process. The simulation tools have an annual error margin of 33.09% (PVsyst), 18.34% (SAM), and 38.55% (Helioscope) (compared to the actual energy production of the FPV plant) [7], [25].

4.1. Proposed maximum power point tracking (MPPT) algorithm

The perturbation and observation (P&O) method is often used in MPPT implementations due to its simplicity and ease of use. The MPPT monitors both the input PV current (IPV) and output PV voltage (VPV) to determine the PV power (PPV). This is due to the fact that the MPPT determines the optimal PV panel voltage under varying irradiation conditions [24]. Algorithms that altered the MPPT used PO perturb and observe. In Figure 4 (see Appendix), we see a schematic of the photovoltaic system module used by the suggested maximum power point tracking method. The suggested architecture has been constructed using an improved perturbation and observation MPPT to guarantee proper operation. The simulated outcomes. Simulations of the PV system running under two different illuminations, as well as the proposed system and the PV balancer, are run in Power Sim to analyses the efficiency of the solar power system proposal. In Figure 4 we can see the solar panels' and the converter's individual specs [26].

5. DISCUSSION AND EVALUATION

5.1. Components of radiation

Direct radiation, abbreviated Rd, is solar energy that enters a planet's surface without being scattered by the atmosphere. It casts shadows and may be concentrated using mirrors since its rays travel in opposite directions [27]. Rd is the illumination produced when sunlight is refracted by the air (air, cloud cover, aerosols). Scattering causes the spread of a parallel beam and several other beam configurations in all directions across the sky. Dust, water drops, and air molecules all have a role in the scattering. Therefore, the result will be determined primarily by the climate [24].

Rr stands for reflected radiation, which is the amount of solar energy that is absorbed by the Earth's atmosphere rather than entering space. All these contributions are added together to form the global radiation (RG) in the following equation.

$$RG = RD + Rd + Rr$$

Calculating the typical daily and monthly demand for hydraulic energy based on this [28]:

$$Eh = g\, ḓa\, Va\, h/3600$$

where:

Eh : Hydraulic energy (Wh/day)
g : Acceleration due to gravity (9,81m/s^2)
ḓa : Density of water (1000 kg/m^3)
Va : Volume of water (m^3/day)
h : Total height (m)

The following formula may be used to determine the power output of a solar generator while operating under normal measurement circumstances [28]:

$$Pp = Ş g\, A\, Gce$$

where:

Pp : Output power under the standard conditions of measuring (W)

Şg : Performance of the generator to the reference temperature (25 °C)
A : Active surface of the generator (m^2) Gce: light in the CSM (1000 W/m^2)
The daily electric energy, Ee, is given by [28]:

$$Ee = \eta PV * A * Gdm(\beta)$$

where:
ηPV : Average daily output of the generator under operating conditions
Gdm (β) : Average daily irradiation incident on the plane of the modules at inclination β ($kWh/m^2/day$)
The efficiency ηPV can be calculated using the expression:

$$\eta PV = Fm * [1 - \lambda(Tc - Tcref)] * \eta g$$

Fm : Coupling factor, defined as the ratio of the electrical energy generated under the conditions of exploitation, and electrical energy which generates if the system is working at maximum power.
λ : Temperature coefficient of cell
Tc : Daily average temperature of cells during the hours of sunshine
ηg : Performance of the generator to the reference temperature

5.2. Composition of the photovoltaic system

Load, photovoltaic generator, static DC/DC and DC/AC converters, and a control system make up a photovoltaic system. The energy is generated using photovoltaic cells. The static converter's primary function is to achieve impedance matching, which allows the generator to provide its full output [29].

5.2.1. The GPV photovoltaic generator

The photovoltaic generator is a system designed to meet electrical load requirements through solar energy generation. It is composed of individual main solar cells connected in series or parallel to generate the desired electrical characteristics, such as power, current, and voltage. One or more PV modules can be combined in series or parallel to form a generator [30].

5.2.2. The photovoltaic cell

The photovoltaic cell (or solar cell) is the smallest and most essential component of any solar energy system. It is made of semiconducting components and converts optical energy into electrical power [31]. Solar cells are shaped like a grid and use conductive metal contacts to collect this current. This current can be used to provide electricity to homes and the rest of the grid. The performance of a PV cell can be determined by measuring how much electricity it generates in relation to how much energy the sun provides when light shines on the cell. The amount of electricity that can be produced by PV cells is dependent on a number of factors, including the technical performances of the cell and the qualities of the available light [32].

5.3. Principle of operation of a photovoltaic cell

Silicon, a semiconducting semiconductor, is often used to create the one- or two-layer PV cell. The application of light to a cell generates an electric field that permeates its several layers, triggering the flow of electrons. It is the photovoltaic effect that causes a solar cell to generate electricity when exposed to light. Lighting intensity is proportional to current across the circuit. Consequently, an electromotive force is created inside the cell, which may be utilized to power electrical devices [33]. PV cells have three types: monocrystalline, polycrystalline, and amorphous. Monocrystalline cells have the highest cost and best performance, but also the lowest yield. Polycrystalline cells have a simpler architecture, while amorphous cells are inexpensive to produce and need just thin layers of silicon. They are often used in solar-powered calculators and wristwatches due to their inexpensive production cost [34].

5.4. Actual module performance

Cell temperature and well-ventilated solar roof are important factors in ensuring a successful installation. Devices that aim the panels squarely towards the sun can maximize the amount of energy harvested from the sun. Single- or dual-axis tracking mechanisms can be used to concentrate solar energy in a direction perpendicular to the PV panels, increasing both power density and efficiency. The majority of FPV systems use a single-axis tracking mechanism, with a diameter of 30 meters [35].

5.5. Discussion and illustration

Floating solar PV plants have the potential to increase the quantity of grid-interactive solar power without requiring land. Morocco presents a prime location for floating PV plants, and the government has stated it will do so by 2025 [36]. A graphical illustration of the MPPT system being examined for the proposed improved PV system with MPPT is shown in Figure 5 [37]. The proposed circuit's use of MPPT algorithms with intelligent prediction allows it to maximize the total amount of energy harvested in scenarios with changing irradiance, including those with partial shadow [38]. Measured waveforms of PV module voltage (VPV), current (IPV), and power (PPV) using the basic P&O algorithm at small, fixed step sizes or large, fixed step size, using the P&O algorithm at two irradiances low I1 (=600 W/m^2) or high I2 (=1000 W/m^2), and PV module power (PPV) waveforms measured using the proposed MPPT algorithm under situations with a sudden shift in the amount of available irradiance [38].

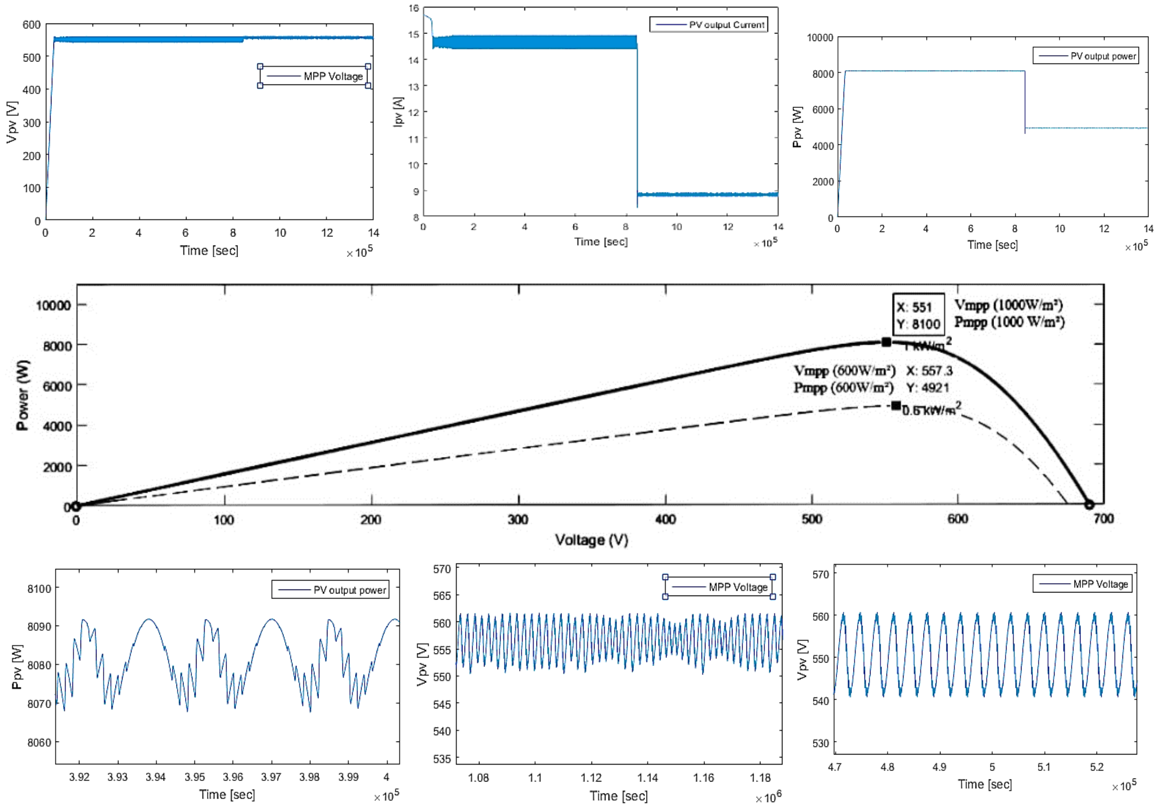

Figure 5. Curve, behavior, and waveforms

6. CONCLUSION

The study provides a comparison between solar power plants that are installed on land and those that are designed to float. Compared to an on-the-ground solar array, a PV system installed on water has several benefits, including increased energy efficiency, reduced temperatures, reduced land use, and reduced water use. The availability of potable water and the amount of demand placed on the electrical grid (known as “required output”) are two of the most important issues of our day as a direct effect of global warming. Floating solar power plants have many advantages, such as higher efficiency, less water loss through evaporation, and fewer greenhouse gas emissions. Scientists have been asked to devise novel solutions that are uniquely suited to floating solar to address these problems. Life cycle assessment data from other programs like SimaPro, GaBi, OpenLCA, and others may be imported into Excel via the use of external plugins. By 2025, the worldwide installed capacity of solar energy systems like the FPVT is projected to increase by 485.4 GW. Several factors, such as ambient temperature, water temperature, wind speed, and algorithmic calculations, go into the determination of the optimal size for the floating PV system. Lower temperatures and higher wind speeds at hydropower stations have a cumulative effect of decreasing the temperature of the solar cells, which in turn leads in a higher energy output. Information utilized by the P&O methodology to evaluate the panel's efficacy is provided and discussed. This article proposes an enhanced maximum power point tracking (MPPT) approach for use in decentralized PV systems. Distributed PV systems that need high MPPT efficiency and fast dynamic response should strongly consider going with floating solar.

APPENDIX

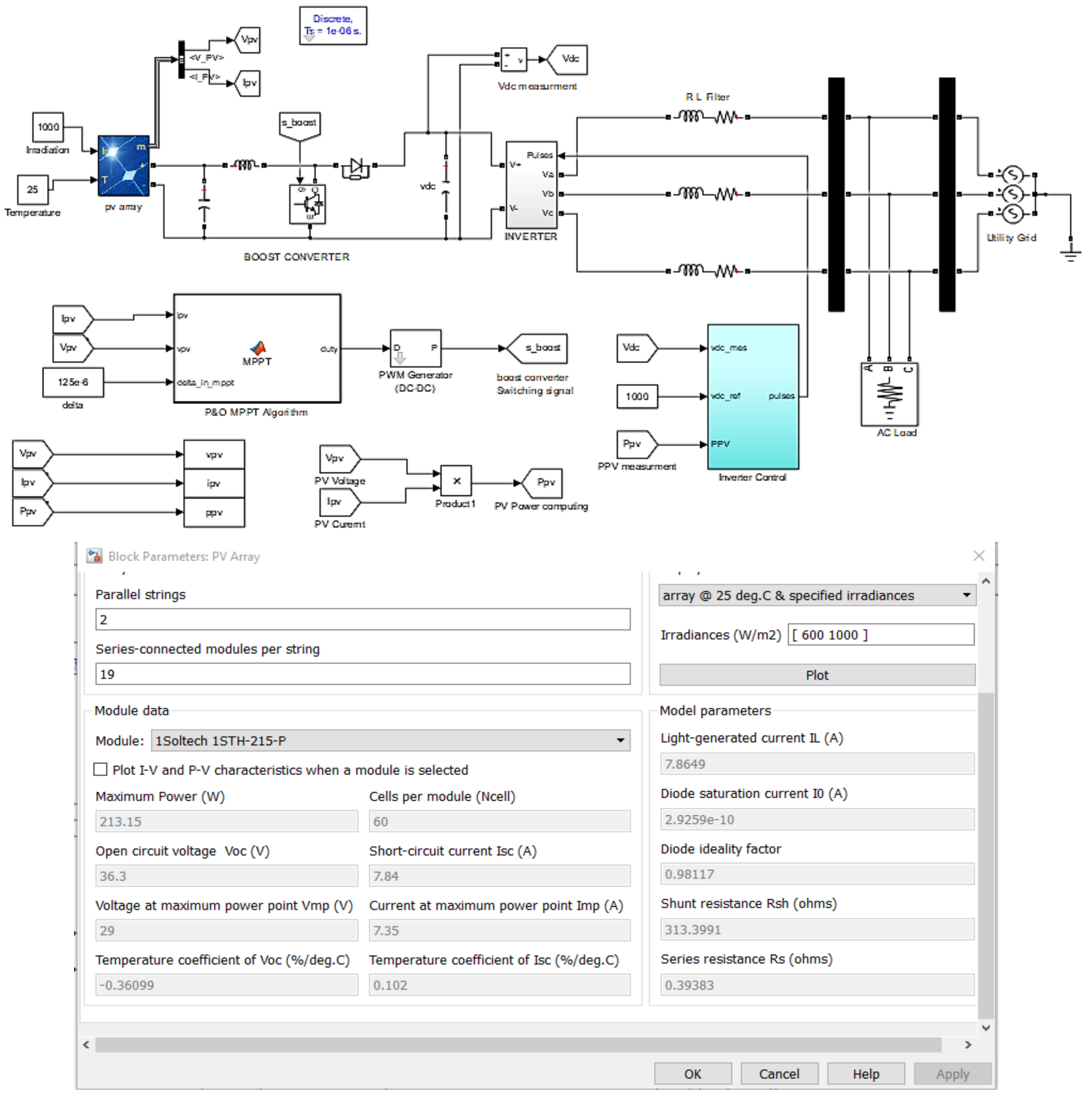

Figure 4. Module, P&O algorithm, and parameters

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