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CENTRAL AND MICRO INVERTERS USING FUZZY LOGIC CONTROL FOR SOLAR PHOTOVOLTAIC INTEGRATED TO GRID

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Abstract

This article extensively models both central and micro inverters to facilitate the integration of solar photovoltaic (PV) technology into the AC grid. The validation of these models is conducted using data obtained from a 100 kW solar PV plant. The performance of the models is then compared under several weather conditions, including bright, overcast, and partly shaded days. Models of a 250 W micro inverter and a 5 kW grid tie central inverter were developed using polycrystalline solar PV and MATLAB/Simulink. The SCADA system of the actual solar PV plant supplies information regarding the temperature of the PV modules and the solar irradiation. This data is subsequently inputted into the simulation models. The solar photovoltaic (PV) system equipped with micro inverters has consistently demonstrated greater performance in various operational scenarios when compared to systems using central inverters. The comparative results are shown in relation to the power output of the inverter AC under different operating situations.

Key words: Photovoltaic, micro inverters, SCADA system, solar, MATLAB

I Introduction

The photovoltaic technology relies on the solar cell as its fundamental component. Materials that are used as semiconductors, like silicon, are what make up solar cells. Impurities introduced into the crystal lattice of a semiconductor may readily alter its conductivity, which is one of its most valuable features. To illustrate the point, photovoltaic solar cells are made by treating silicon, a material with four valence electrons, to make it more conductive. Impurities, which are n-donor phosphorus atoms with five valence electrons, contribute to the silicon material by donating weakly bound valence electrons, leading to an excess of negative charge carriers on one side of the cell. In contrast, boron atoms with three valence electrons (p-donor) provide a stronger electron attraction than silicon atoms. Electrons diffuse from the n-type side, where the concentration of electrons is high, into the p-type side, where the concentration of electrons is low, due to the establishment of a p-n junction caused by the close proximity of the p-type and n-type silicon. It is the p-type sides of the p-n junction that the electrons recombine with when they diffuse across it.

The electric field that results from the charge imbalance at the junction causes carrier diffusion to stop at a certain point, however. A diode, created by this electric field, can only allow current to flow in one way. An external load may be attached to the electrodes after ohmic metal-semiconductor connections were formed to the n-type and p-type sides of the solar cell. The charge carriers in the cell get energy from photons when light hits them. Positive charge carriers (holes) and negative charge carriers (electrons) are separated at the junction by an electric field. By connecting the circuit to an external load, an electrical current may be extracted.

1.1 Photovoltaic system

Among the many potential applications for solar-generated energy is the feeding of electricity into the main distribution grid, the pumping of water from a well, the operation of a tiny calculator, and many more besides. These tasks may be achieved by use of a PV system's numerous linked components. The system's design is dictated by the work it has to do, as well as the site's location and other operational requirements. Here we'll take a look at what goes into a PV system, how its design changes depending on its use, how big a system has to be, and how to keep it running well. Energy consumption is increasing at a fast pace in today's globe. Half of the world's energy comes from oil, a third from gas and nuclear (about one sixth each), and a fifth from coal. The contemporary electricity sector, nevertheless, is not without its issues. Two major ones are the imminent danger to the environment and the slow but steady depletion of energy supplies. The importance of exploring and implementing alternative energy sources is growing in this regard. The use of sustainable or "clean" energy sources is the foundation of the alternative power sector. Solar energy is the most important one, and in order to transform it, we need equipment that generate energy, such as solar power plants.

Solar power's popularity has skyrocketed in recent years. There is an estimated 30% yearly growth rate for the "solar" industry, according to experts. Several benefits of solar energy contribute to this share. To begin, unlike traditional power plants, solar arrays do not release harmful "greenhouse" gasses, chemicals, or dust into the air. Second, solar power plants produce almost little noise while they are operating. Thirdly, there is an almost endless supply of solar energy. In the fourth place, solar power plants may be used to augment existing energy sources for the generation of electricity. When Russia sets up its distributed generation system, it will allow solar power facilities to be used as energy sources. However, in order to make solar power plants more economically feasible, their efficiency has to be raised. The quality is mostly associated with the solar modules' surface temperature and amount of light. In the summer, panels may reach temperatures of 700C or even higher, according to both theoretical and empirical investigations. Earlier research looked at how different operation temperatures affected the energy properties of solar panels. Additional study into the effects of temperature and light on the efficiency of solar power plants is required, according to the authors' studies. The impact of solar radiation on the functioning of solar modules has also been assessed.

3. Existing system

An integrated solar power generating system including a power smoothing function is the primary focus of this project. Environmental conditions have a substantial impact on the output power of solar power generating systems (SPGS), which in turn impacts the dependability and stability of power distribution systems. A power smoothing function-based SPGS is suggested in this work. Parts of the proposed SPGS include an array of solar cells, batteries, a DIBBDAI, or boost power converter, and an AC inverter with two inputs. Voltage bucking, voltage boost, and DC-AC power conversion are all done by one device with the DIBBDAI. The BPC charges the batteries in between the array of solar cells and the battery set. The suggested SPGS uses a single power stage to convert direct current (DC) from the solar cell array or battery set into alternating current (AC).

The sunlight based cell exhibit utilizes a solitary power stage to charge the battery set. The utility, battery set, and solar cell array all have their power conversion efficiency improved. By charging or discharging the battery pack in response to significant fluctuations in the output power of the solar cell array, the Stabilized Power Generation System (SPGS) is specifically designed to maintain a consistent output power. Additionally, the DIBBDAI can control the electric current flow caused by the solar cell array's undesirable capacitance. A Solar Photovoltaic Generation System (SPGS)'s proposed power conversion interface improves power efficiency, reduces leakage current, and mitigates power fluctuations.

4. Proposed System

The majority of commercially available 250 W standard micro inverters are manufactured by Repulse, Enphase, and other businesses. These little inverters can be used for small residential projects. The central inverter meets the typical 5 kW projected load requirement for a single Indian house. Solar micro inverters also solve problems like DC cable loss and partial shading of incoming PV strings, both of which can lower the output of solar central inverters. We take into consideration a group of 250 W solar micro inverters and a 5 kW solar central inverter with the intention of comparing the performance of three distinct types of inverters. The results of a comprehensive modeling effort for a 250 W micro inverter and a 5 kW central inverter are presented in this study. Investigations are performed independently on PV module and exhibit displaying utilizing MPPT rationale. The displaying of sunlight based, focal, and miniature inverters is led utilizing genuine information on irradiance and module temperature during brilliant, cloudy, and somewhat concealed days. We then evaluate the performance of each system by quantifying its output in AC power units.

4.1 Fuzzy Logic Controller

Fuzzy set theory can be applied to FLC with great success. Utilizing linguistic variables rather than numerical variables is the primary focus. The FL control method is based on quality control principles and the human capacity to comprehend system behavior. With input data that is unclear, ambiguous, imprecise, noisy, or incomplete, FL provides a straightforward method for arriving at a clear and certain conclusion. The diagram that follows provides an illustration of the fundamental configuration of a fuzzy logic controller (FLC).

A Fuzzification interface converts input data into linguistic values that are appropriate. An Information Base is a store that incorporates a data set along with the important language definitions and control rule set. A Dynamic Rationale is a framework that assembles the fluffy control activity in view of the data given by the control rules and the language variable depictions. An instrument that transforms an inferred fuzzy control action into a non-fuzzy control action is known as a defuzzification interface.

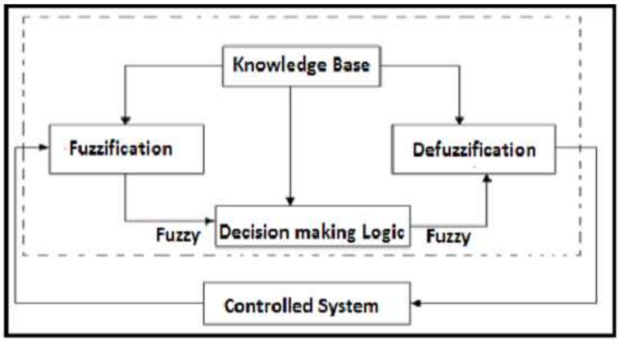


Fig.6. Basic structure of Fuzzy Logic controller

4.2 Modeling of Photovoltaic Module and Array

Rooftop solar panels generate 100 kW of electricity using polycrystalline solar PV technology. To simulate the ELDORA 250 polycrystalline solar PV panels installed on rooftops, MATLAB/Simulink was used to model a 250 W module and a 5 kW PV array. Here are the equations that show the I-V characteristics of the solar PV module. For micro inverter functioning, a 250 W solar panel is modeled using equations (1-4). A single module's I-V curve slope is used to determine the Rs and Rp resistors. Changing (2) into (5) makes it possible to transform a single module into a 5 kW array. Ns is the number of modules in a string, whereas Np is the total number of strings linked in parallel, as shown in equation (5). We assume Ns = 20 and Np = 1 for a 5 kW PV array. The array current (Ia) and voltage (Va) are defined in equation (5), respectively. For the central inverter, PV array modeling incorporates a 4-ohm DC wire equivalent resistor as a string resistor. When modeling solar micro inverters, this DC resistance is ignored. The incremental conductance (IC) approach is used to obtain maximum power from 250 W and 5 kW solar systems, respectively.

4.3 Modeling of central inverter

The schematic design of the 5 kW central inverter is presented in Fig. 1, which is based on a two-stage, two-level PWM inverter. Boost converters with k factor III controls are used within the inverter [10]. Calculations for the input inductor L and capacitor Cin of a boost converter are based on ripple factors of 1% for current and 10% for voltage, respectively [11]. With a voltage ripple of 1% in mind, the boost converter's DC link capacitor, Cdclink, is computed [11]. We provide the settings for the boost converter.

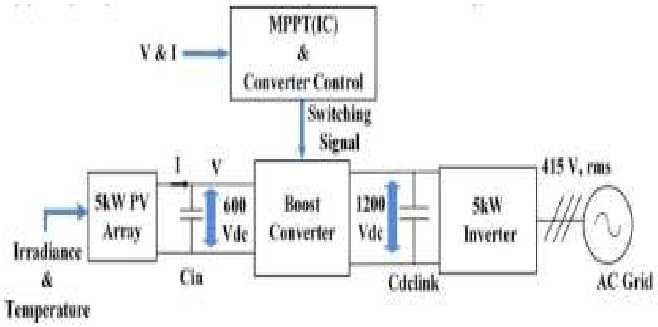


Fig 1. Schematic diagram of 5 kW grid tie central inverter

4.4 Modeling of PWM Inverter

Power is supplied to the three phase PWM inverter using the boost converter type. The KACO TL 5.0 data sheet is used to simulate the grid side inverter, which is a 5 kW central inverter. Three phase central inverter modeling makes use of the synchronous dq frame approach, as seen schematically in Fig. 4. A αβ frame is created from the measured grid voltage, and a dq frame is created from the current. The phase lock loop (PLL) is used to determine the grid voltage angle θ, and the grid voltage vector is orientated along the d axis. By using cascaded control loops for voltage and current, this synchronous frame approach allows for separate control of the inverter's active and reactive power. The transfer function for the present control loop is provided in (16), and the inner loop includes a L filter. When calculating the AC side resistor and filter inductor L values, 10% and 5% of the base impedance, respectively, are taken into account. You may regulate the present control loop using a PI controller and a pole zero cancellation approach [5]. In order to simulate the external voltage control loop, a DC link capacitor is used. When evaluating the PI controller, it is important to take into account the second-order closed-loop system and use the formula (17) for the outer voltage control loop transfer function [12]. We provide the inverter's parameters.

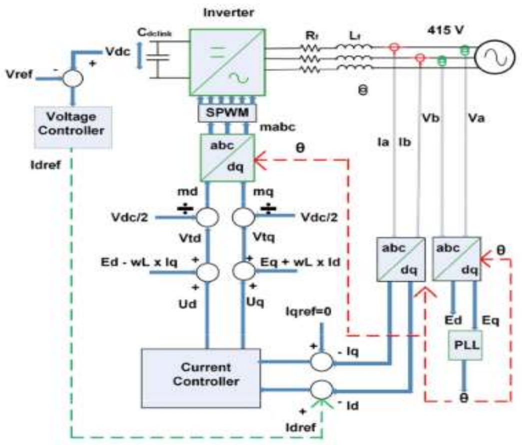


Fig 2. Cascaded voltage and current control loops for PWM inverter

4.5 Modeling of micro inverter

The solar micro inverter is designed according to the Repulse250 data sheet. One phase full bridge inverter with a fly-back converter make up a micro inverter. The schematic design of a micro inverter may be shown in Figure 5. A high frequency isolator transformer is used to decrease the inverter's size while simultaneously introducing high voltage gain. Figure 5 shows that the magnetizing inductor of the transformer stores energy from the photovoltaic cells when switch Q1 (MOSFET) is turned on. The energy stored in the inductor is transmitted to the full bridge inverter when diode D1 conducts. Using the high frequency isolator transformer's 1:n turns ratio as a basis, the fly-back converter scales the inductor voltage and current [6]. The flyback converter's input and output voltages determine the turns ratio n. The magnetizing reactor is determined using a switching frequency of 150 kHz and a current ripple of 1%. To test the Cin* input capacitor, we measure its voltage ripple at 5% and its current ripple at 1%. Consideration of power transmission to a single-phase inverter is made while calculating the DC link capacitor Cdclink*. The duty ratio for the fly-back converter is generated by the change in the input voltage using a PI controller. You may find the fly-back converter's parameters in Table V.

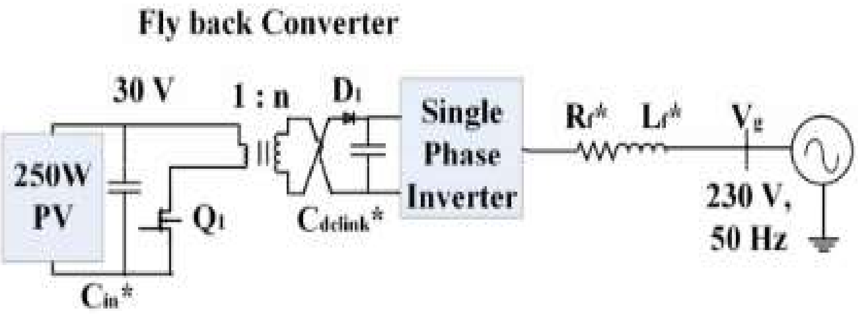


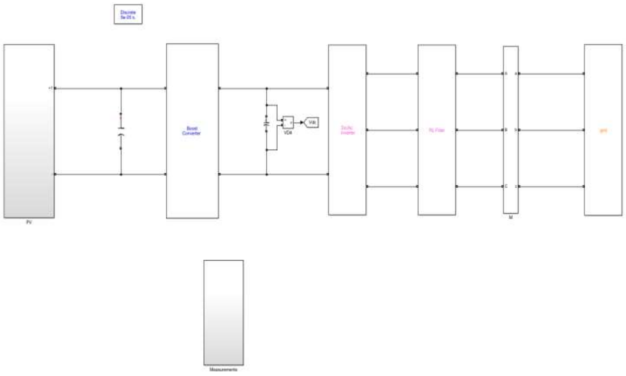
Fig. 5 Single phase 250 W micro inverter with fly-back converter

4.6 Single Phase Full Bridge Inverter and Orthogonal PLL

Four field-effect transistors (MOSFETs) are used to represent a single-phase full-bridge inverter. To bring a micro inverter into sync with a single-phase AC grid, an orthogonal PLL [13] is used. The design process for the micro inverter's L filter and current and voltage control loops is identical to that of the central inverter, as mentioned above. Table provides the micro inverter's parameters.

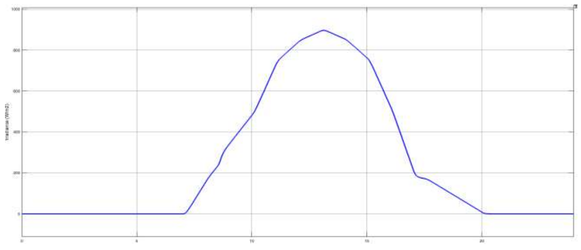
5. MATLAB RESULTS

5.1 Simulation model existing system

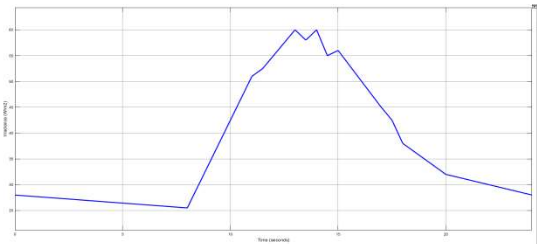


MATLAB model of existing system

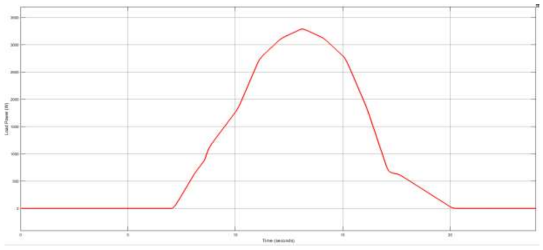
1. Sunny day



Irradiations

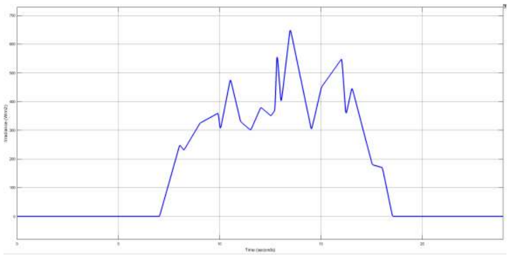


Temperature



Power (V and I grid)

2. Cloudy day



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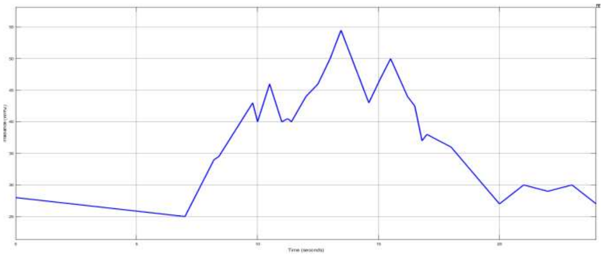

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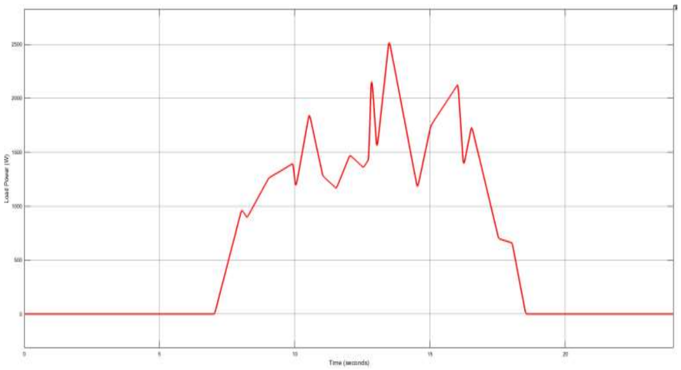
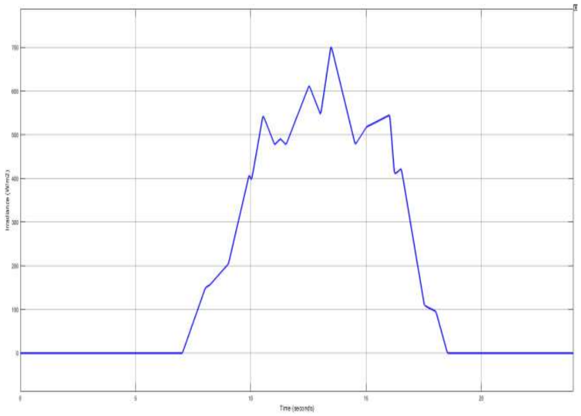


Output power (v and I grid)

3. Partial shaded day



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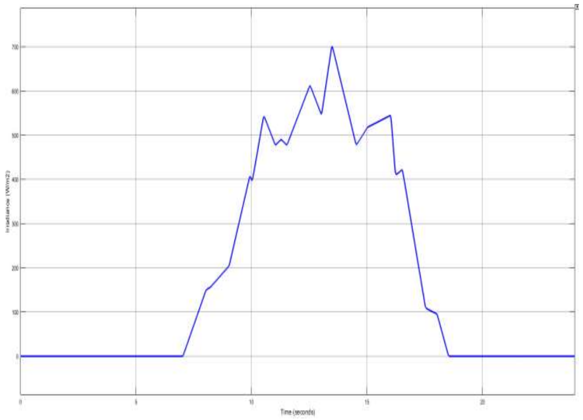

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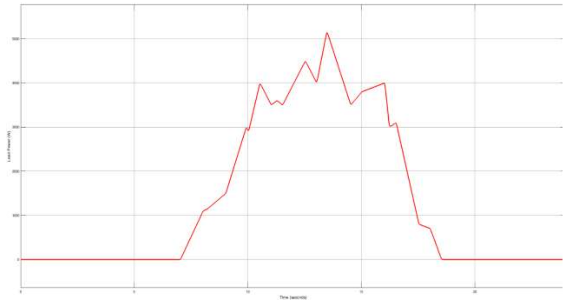
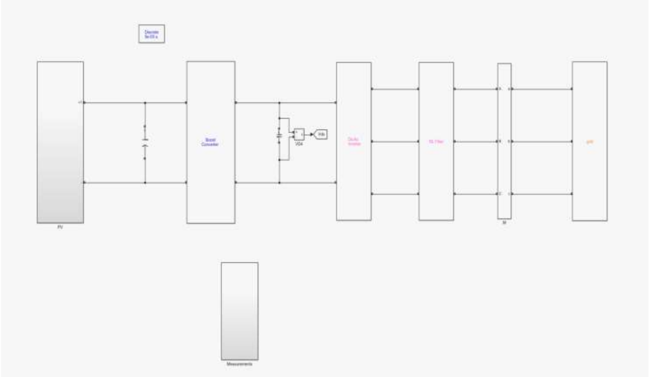


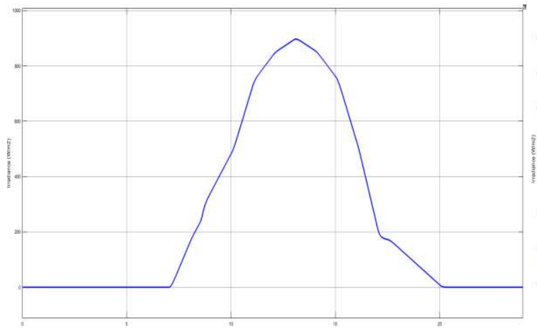
Output power

5.2 Proposed system (Fuzzy results)



MATLAB model of proposed system

1. Sunny day



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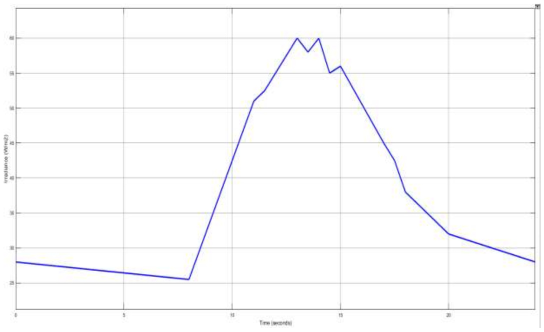

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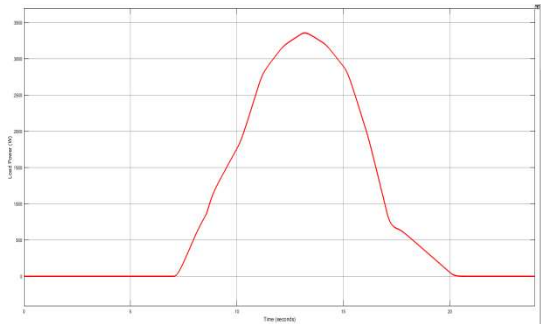
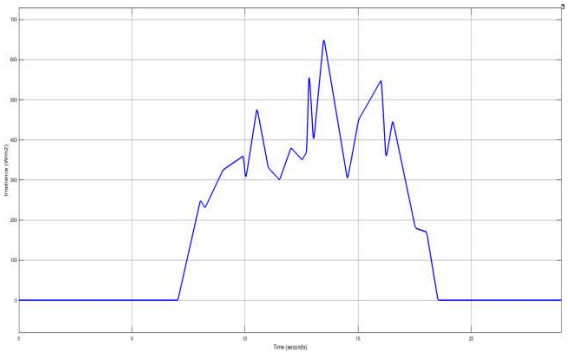


Output power (v and I grid)

2 .cloudy day



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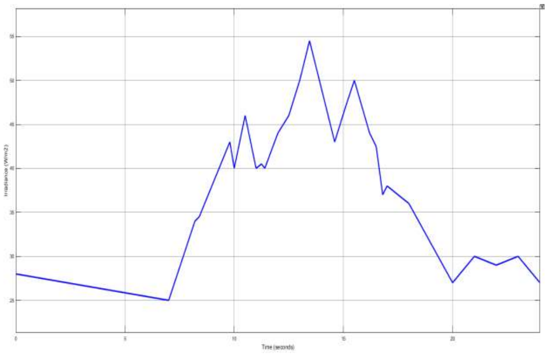

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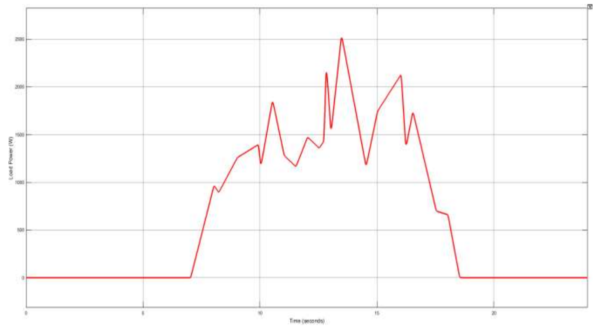
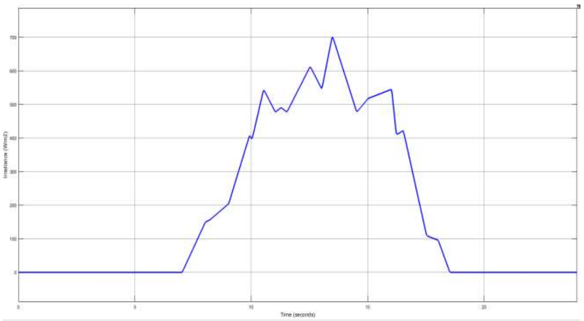


Output power (v and I grid)

3. Partial shaded day



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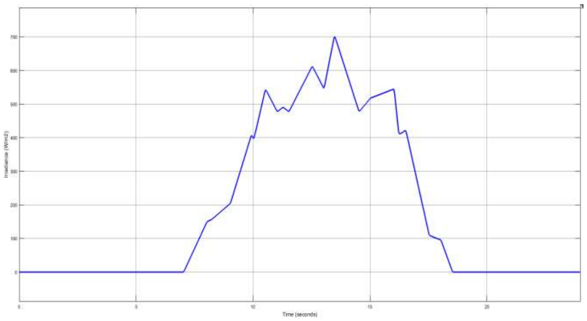

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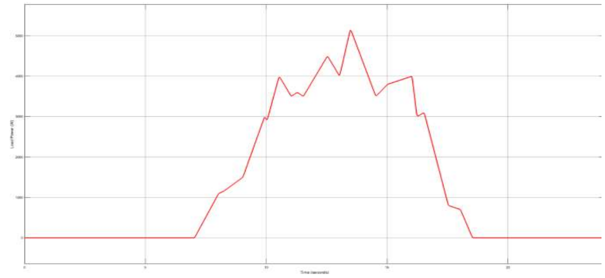

Output power (v and I grid)

6. Conclusion

The majority of solar PV systems on a large scale use central inverter technology. These plants have a wide geological dissemination, and thus, they are adversely impacted by both cloud shadowing and halfway shade, which prompts a reduction in their presentation past the expected level. In this scenario, each PV panel is transformed into an AC PV panel by placing a micro inverter next to each PV panel, which operates as an independent system. In situations where there is shadowing, photovoltaic (PV) plants perform better when micro inverters are used. Micro and central inverter models are both developed and simulated in this study. Real solar irradiance and module temperature data are used in the simulations, which take into account various weather conditions like sunny, overcast, and partially shaded days. The actual output of the solar PV plant is compared to the AC power output of both types of solar inverters. The simulation results have confirmed that PV plants' solar central inverters perform less well under shadowing conditions. A collection of solar micro inverters surpasses the central inverter-based PV plant in terms of maximum AC power output, and the micro inverter exhibits modular performance. This demonstrates that solar micro inverters outperform central inverters in a photovoltaic (PV) system when it comes to power output.

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