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Standalone Photovoltaic Power Stabilizer Using Double Series Connected Converter in Sudden Cloud Condition

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Abstract: Renewable energy is clean energy that cannot harm the environment in its way, especially on standalone photovoltaic electricity generation. The only problem with renewable energy electricity generation is the intermittency and its instability in power quality and power efficiency. Power system stability in renewable energy is essential during the real environmental case problem such as the sudden cloud. The sudden cloud, known for its ability to decrease solar irradiance input, depends on how thick and big the cloud is. Several attempts had been tried to increase renewable energy power system stability, including modifying its maximum power point tracker with a new algorithm such as perturb and observe. This paper discussed an improved way of maintaining renewable energy power system stability using perturb and observe Algorithm in double series-connected Converter as the current and power stabilizer. The findings indicate that the abrupt cloud simulation reveals an undershoot current of 6,781 A at 500 W/m2, along with a steady-state current of 7,606 A. In a single converter scenario under sudden cloud conditions, there is a significant decrease of 3,416% in the steady-state current. Subsequently, in a dual converter setup, the reduction in steady-state current is demonstrated by an undershoot current of 6,781 A and a steady-state current of 7,606 A at 500 W/m2, corresponding to a decrease of 3,266%.

Keywords: Double converter, perturb and observer, power stability, sudden cloud, standalone photovoltaic

1. Introduction

Energy plays a crucial role in sustaining life, with the rise in population leading to a higher need for energy. The heavy dependence of the world economy on fossil fuels is facing growing jeopardy due to the combined issues of supply vulnerability and climate shifts. [1]. Global oil and gas reserves are estimated to be exhausted by the middle of the 21st century, with coal reserves expected to deplete sixty years thereafter [2]. Modern political discussions and policy formulation have been driven by scientific and public worries surrounding the relentless use of fossil fuels and its strong connection to accelerated global climate change [3]. Globally, the shift from fossil fuels to renewable energy sources is acknowledged as a crucial step in addressing the mentioned twin difficulties [4]. As an illustration, the European Union has embraced a fresh climate and energy framework that encompasses achieving a minimum of 27% of renewable energy consumption by 2030 (European Commission, 2018). According to [5], [6], [7], The diminishing accessibility of fossil fuels and the elevated emissions have highlighted the significance of transitioning to renewable energy sources.

Renewable energy refers to energy sourced from an unlimited reservoir, and the effective utilization of energy assets is a prominent subject of contemporary discourse [8]. Selecting the appropriate energy source and the reasons behind that choice are of utmost importance. Numerous factors including cleanliness, cost, reliability, efficiency, and environmental

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impacts should all be considered [9]. Regrettably, the reality remains that numerous industries across the globe continue to rely on fossil fuels for generating electricity [10]. While fossil fuels are currently efficient for power generation, their long-term viability is questionable due to depletion and environmental concerns. Industries must swiftly transition to renewable sources to address these issues and prevent ecological risks posed by fossil fuels [11].

Utilizing renewable energy for independent power generation offers an appealing choice for isolated communities unable to rely on the main power grid. To ensure consistent operation of standalone microgrids, effective management of power fluctuations resulting from renewable energy interruptions is essential [12], [11]. The persistent fluctuations in voltage present significant challenges in standalone systems. If not addressed, these fluctuations can lead to system instability, and the efficiency of solar energy optimization is not at its best [13]. Additional strategies can result in excessive voltage overshoots and insufficient undershoots.

As stated in [14] a variety of Maximum Power Point Tracker (MPPT) algorithms have been suggested so far. These algorithms can be categorized into two groups. The initial set of algorithms relies on voltage feedback. In this approach, a predetermined reference voltage is contrasted with the photovoltaic (PV) array voltage. The resulting error signal is then processed through a feedback loop to generate a control command. However, under changing environmental conditions, this algorithm struggles to adapt the reference voltage, leading to notable power losses.

One of the provided algorithms is the perturb and observe (P&O) method [15], [16], hill-climbing [17], [18], and incremental conductance (INC) methods [19], [20]. A review of perturb and observe (P&O) methods has been provided, revealing that current approaches encounter issues like oscillations, intricacy, reliance on the designer's choices, and increased computational demands. Within the P&O technique, the operational point fluctuates around the Maximum Power Point (MPP), resulting in the loss of a portion of available energy. These fluctuations can be lessened by decreasing the fixed perturbation magnitude, although this approach prolongs the time required to reach the MPP.

The study proposes solving the problem by employing a DC-DC Converter and MPPT. Using a DC-DC Converter without MPPT can decrease Converter lifespan and potentially lead to operational issues due to improper input voltage. The research suggests improving the performance of a single Converter by adding another converter in a double converter simulation using the same MPPT algorithm. Performance enhancement, particularly in overshoot and undershoot, will be evaluated by comparing the output of each Converter in the single and double Converter configurations.

Presently, it is common to incorporate a light-based transducer with a sensor into power electronic components like Converters, inverters, and rectifiers, as these components are frequently influenced by power electronics. Although omitting the use of MPPT is often preferred for its higher efficiency but reduced stability, MPPT usage contributes to increased stability. The primary objective of this paper is to compare the performance of a double Converter setup with a single converter scheme in a standalone photovoltaic plant that employs renewable energy. This comparison will focus on overshoot and undershoot effects at the load. The simulation will be conducted using MATLAB Simulink. The analysis will encompass changes in voltage, current, and power responses resulting from sudden cloud or partial shading impacts on the standalone photovoltaic system.

2. Literature

2.1 Standalone Photovoltaic

Standalone photovoltaic (PV) systems are employed in regions where convenient access to an electric grid is limited or unavailable. In such systems, energy generated is self-contained and stored within batteries. A standalone PV system consists of PV modules, batteries, and a charge controller. Additionally, an inverter might be integrated into the system to convert DC current into AC current [12].

A stand-alone PLTS system is designed to operate independently to supply DC or AC loads. This type of system can be powered by the photovoltaic array alone, or it can use additional sources of energy, such as water, wind, and diesel engines. Batteries are used in most stand-alone PV mini-grid systems for energy storage.

Due to the challenges in accessing the utility grid, standalone photovoltaic systems are specifically engineered to operate autonomously [21]. A self-contained PV system includes both a storage unit and a controller to cater to the energy demand. The combination of storage units and controllers is essential for supplying power when the energy generated by the PV panels falls short of the load's requirements. Conversely, when the PV panel generates surplus power beyond the load's demands, it contributes to powering the load while simultaneously replenishing the storage device. In a standalone photovoltaic setup, solar panels are independent of a grid and instead charge an energy storage system. This stored solar power is then utilized to power electrical loads.

2.2 DC - DC Converter

A DC to DC converter captures the voltage from a direct current (DC) source and transforms the input voltage into a different level of direct current (DC) voltage [22]. They are used to adjust voltage levels, a common practice in vehicles, portable chargers, and DVD players. Some devices require specific voltage to function, as excessive power can harm them, and inadequate power can render them nonfunctional. The converter harnesses energy from the battery to modify voltage levels.

Likewise, a converter enhances the voltage level. The Converter draws energy from the battery and reduces the voltage level. Similarly, a converter increases the voltage level. DC to DC converters in electronic circuits utilize switching technology [23]. A switched-mode DC-DC converter alters the DC voltage level through a process of temporarily storing input energy and subsequently discharging it at varying output voltages. This energy storage occurs in components such as inductors, transformers, or capacitors, either utilizing magnetic or electric fields. This technique of conversion enables voltage levels to be raised or lowered.

Switching conversion surpasses linear voltage regulation in terms of power efficiency, as linear regulation results in heat dissipation [24]. The enhanced efficiency of switched-mode converters decreases the demand for heat sinking and extends the battery life of portable devices. The use of power FETs has contributed to increased efficiency by enabling more efficient switching with lower losses at higher frequencies compared to power bipolar transistors. Additionally, the replacement of the flywheel diode with synchronous rectification using a power FET, which features significantly lower 'on resistance,' further minimizes switching losses in DC-DC converters.

Efficiency gains in Converters are attributed to the adoption of power FETs, which exhibit superior switching efficiency at higher frequencies compared to power bipolar transistors and involve simpler drive circuitry. Furthermore, DC-DC converters have been enhanced by substituting the flywheel diode with synchronous rectification using power FETs that have substantially lower 'on resistance,' leading to decreased switching losses.

2.3 Perturb and Observe Algorithm

MPPT methods address the challenge of autonomously determining the voltage VMPP or current IMPP at which a photovoltaic (PV) array yields the highest power output, considering specific temperature and irradiance conditions [25].

Within the perturb and observe (P&O) approach, the MPPT algorithm relies on computing the photovoltaic (PV) output power and power variation. This computation involves taking samples of both the current and voltage of the PV array [26]. The tracker functions by periodically increasing or decreasing the voltage of the solar array [27]. If a particular perturbation results in a rise (fall) in the photovoltaic (PV) output power, the subsequent perturbation is produced in the same (opposite) direction.

The duty cycle of the DC chopper is adjusted, and this cycle is reiterated until the maximum power point is achieved. The system fluctuates around the MPP. Decreasing the size of the perturbation step can mitigate the oscillation. However, using a smaller step size slows down the MPPT process. The photovoltaic (PV) array displays distinct characteristic curves for varying levels of irradiance and cell temperatures [28]. Every curve possesses its own maximum power point, which is the juncture where the converter receives the highest corresponding voltage [29].

The perturb and observe (P&O) technique follows the maximum power point (MPP) [30] by iteratively adjusting the photovoltaic output voltage towards the MPP. The method's application is relatively straightforward, yet it struggles to track the MPP effectively when irradiance changes rapidly. The method's strength lies in its sole emphasis on the input voltage. The perturb and observe approach requires power output to fluctuate around the maximum power point, even when irradiance remains constant. Conversely, the incremental conductance method holds an edge over the perturb and observe (P&O) method by detecting the maximum power point without experiencing fluctuations around this point.

The method relies on alterations in power (Δρ) and voltage (Δv) [14]. The direction of changes in power and voltage, whether positive or negative, determines whether the step size increases or decreases. This step size can represent a voltage reference or duty cycle for a DC-DC Converter. The pseudo-code for the perturb and observe (P&O) technique is presented below,

$$\Delta\rho = \rho^{i} - \rho^{i} \quad (1)$$

$$\Delta v = v^{i} - v^{i-1} \quad (2)$$

If both $\Delta\rho$ and $\Delta v > 0$. ΔD will be modified to determine whether it increases or decreases.

2.4 Incremental Conductance Method

The Incremental Conductance Method is a strategy employed to track the maximum power point (MPPT) in photovoltaic (PV) systems. PV systems produce electric power using sunlight, and the power generated varies based on the PV module or array's operating state. The maximum power point (MPP) denotes the operational state where the PV system generates the utmost power [31]. The Incremental Conductance Method is among several algorithms for tracking the maximum power point (MPP) of a PV system. It relies on the insight that the MPP is reached when the power's derivative with respect to voltage (dP/dV) is zero. This implies that, at the MPP, a slight voltage change doesn't affect power output [32].

Here is how the Incremental Conductance Method works: Measure the instantaneous values of voltage (V) and current (I) from the PV module or array, Calculate the instantaneous power $P = V \times I$, Calculate the incremental conductance (ΔI/ΔV), which represents the rate of change of current with respect to voltage, and If ΔI/ΔV is zero, then the system is at the MPP. If it is positive, the operating point needs to be shifted to a higher voltage, and if it is negative, the operating point needs to be shifted to a lower voltage [33]. The technique steadily modifies the operational voltage through minor increments, guided by the computed incremental conductance, until the MPP is attained. It's important to highlight that the Incremental Conductance Method performs optimally under relatively stable solar irradiance and temperature conditions, as alterations in these factors can impact the method's precision [34].

2.5 Fractional Open Circuit Voltage

The suggested Fractional Open Circuit Voltage (FOCV) method using Genetic Algorithm (GA) is straightforward, economical, and straightforward to put into practice. Unlike alternative hybrid approaches, this proposed technique does not introduce intricacy to the MPPT algorithm and relies on a solitary decision parameter. The restricted search range introduced streamlines the search for optimal solutions, reducing computational intensity and diminishing the number of iterations required to attain the overall best outcome [35].

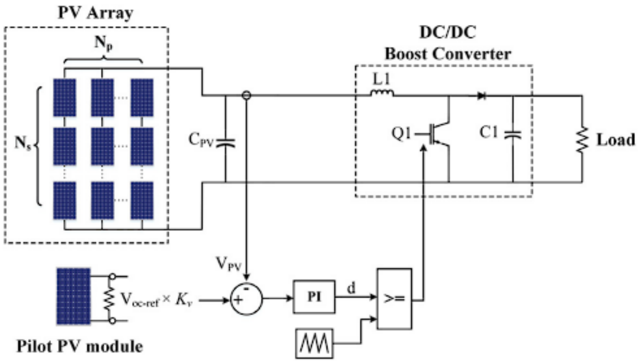

Fig. 1 - Diagram illustrating the traditional FOCV MPPT method

The newly suggested method for MPPT does not necessitate extra sensors or measurement setups, nor does it rely on beforehand knowledge about the PV modules' traits. It functions akin to the standard FOCV technique and can be executed with an inexpensive microcontroller. Unlike conventional MPPT methods, this proposed approach precisely monitors the genuine MPP even in swiftly changing environmental scenarios, retaining tracking consistency and eliminating steady-state oscillations. Furthermore, the proposed method adeptly tracks the overall MPP when faced with multiple power peaks due to partial shading [36].

2.6 Fuzzy Logic

Fuzzy logic techniques belong to the realm of artificial intelligence and computational logic, addressing the handling of uncertain and imprecise data and decision-making. Unlike conventional binary logic, which presents a binary true or false state, fuzzy logic accommodates intermediate values between true and false, providing a more nuanced depiction of reality [37]. Fuzzy logic techniques have been employed in the realm of photovoltaics (PV) to improve the performance and regulation of PV systems. These methods have showcased their effectiveness in boosting the efficiency, performance, and dependability of photovoltaic systems. Their capability to navigate uncertain and dynamic situations positions them as an asset in tackling issues related to the incorporation of renewable energy. As ongoing research and development unfold, the complete potential of fuzzy logic techniques within photovoltaic systems stands ready to be harnessed, thereby advancing sustainable energy technologies [34].

3. Method

3.1 Standalone Photovoltaic

In this research, the photovoltaic (PV) system is connected to a Ramp input, incorporating two crucial signals: irradiance and temperature. The irradiance signal is derived from actual data, specifically at 500 W/m² and 1000 W/m². This choice aligns with the accessible data, reflecting the highest recorded irradiance assumed to reach up to 1000 W/m² in Surabaya. The simulation also considers the influence of abrupt cloud cover, leading to an instantaneous drop in radiation to 500 W/m².

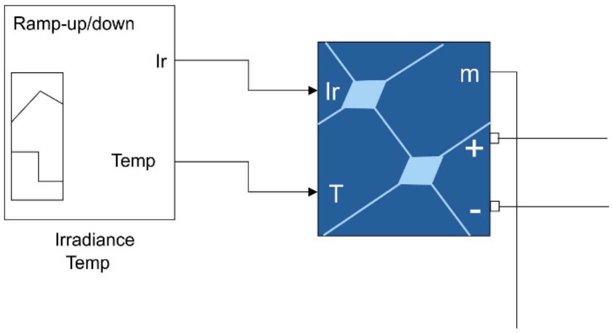

Fig. 2 - Photovoltaic plant

MPPT Plant is connected without feedback from the voltage output. The input is only obtained from the current, voltage, and power response from photovoltaic.

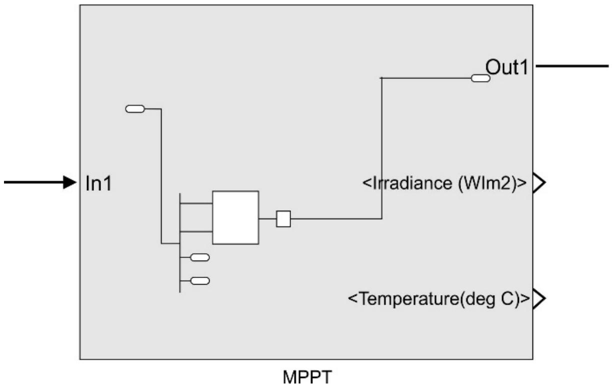

Fig. 3 - MPPT plant

Title There is a single converter simulation plant in the same DC bus with the load simulated for the whole converter scheme.

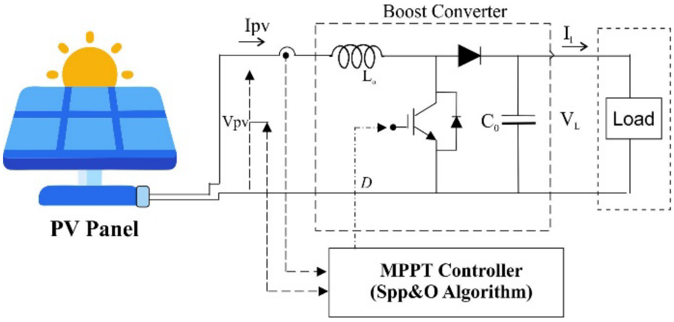

Fig. 4 - Single converter total plant

For the double converter scheme, the Converter is connected in series order. At the same time, the duty cycle input from MPPT is used twice.

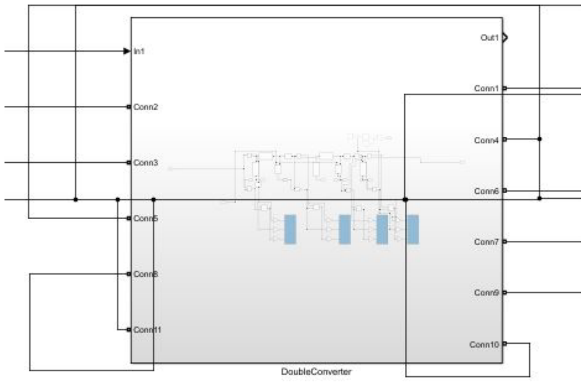

Fig. 5 - Double converter plant

For the load, the resistive load plant is used due to the DC bus system load. The load is set at 300 W.

3.2 Input Modelling

The input is simulated using data from Surabaya, Indonesia, rounded to 1000 W/m² and decreased to 500 W/m² during sudden cloud cover. The temperature remains constant across all simulations, as only the irradiance input is varied in this study. The simulation runs for 2 seconds to stay within computational capacity. The initial 0-1 second segment represents normal irradiance at 1000 W/m², while the subsequent 1-2 seconds depict the sudden cloud-induced irradiance drop to 500 W/m².

4. Results

The simulation is carried out by simulating and observing the Algorithm's maximum power point tracker in the single converter scheme and double converter scheme.

4.1 Single P&O Converter Simulation Results

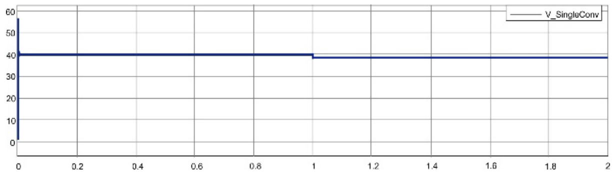

Fig. 6 - Single converter voltage output

The simulation results reveal that the voltage overshoot at 1000 W/m² is measured as 55,351 V, while the voltage in steady-state conditions at 1000 W/m² stands at 39,725 V.

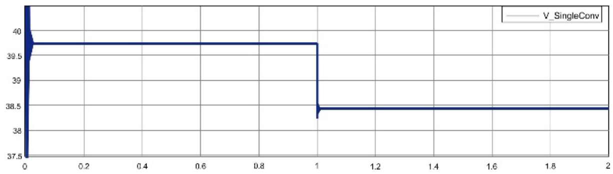

Fig. 7 - Single converter voltage output zoomed in

The abrupt cloud simulation indicates an undershoot voltage of 37,934 V at 500 W/m² and a steady-state voltage of 38,429 V at the same irradiance. The decline in steady-state voltage under sudden cloud conditions in a single converter setup amount to 3,262%.

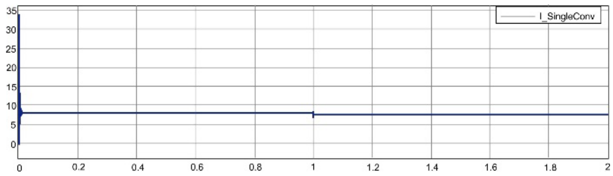

Fig. 8 - Single converter current output

The simulation results indicate that the current overshoot at 1000 W/m² is recorded as 32,068 A, while the steady-state current at the same irradiance is 7,875 A.

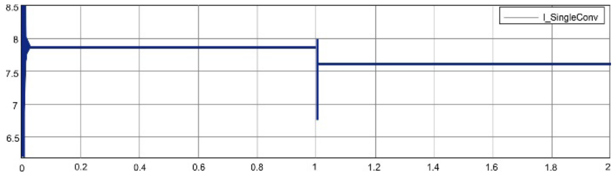

Fig. 9 - Single converter current output zoomed in

The abrupt cloud simulation reveals that the current undershoot at 500 W/m² is 6,781 A, with a corresponding steady-state current of 7,606 A. The reduction in steady-state current during a sudden cloud condition in a single converter setup is measured at 3,416%.

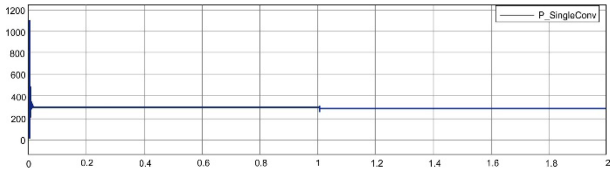

Fig. 10 - Single converter power output zoomed in

The abrupt cloud simulation reveals that the power undershoot at 500 W/m² is 262,089 W, while the steady-state power at the same irradiance level is 292,626 W. The decline in steady-state power during a sudden cloud condition in a single converter setup is measured at 6,475%.

4.2 Double P&O Converter Simulation Results

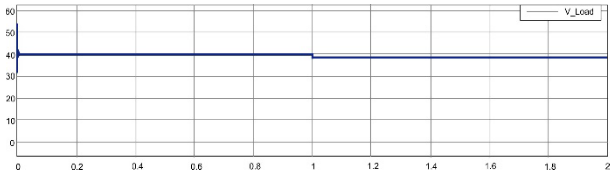

Fig. 11 - Double converter voltage output

The simulation results show that the voltage overshoot at 1000 W/m² amounts to 55,608 V, while the steady-state voltage at the same irradiance is 39,337 V.

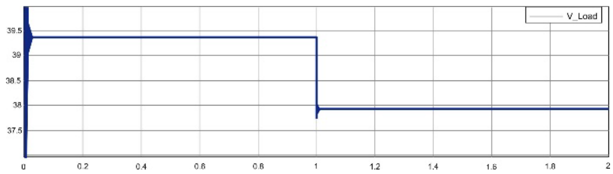

Fig. 12 - Double converter voltage output zoomed in

The abrupt cloud simulation reveals that the voltage undershoot at 500 W/m² is measured at 37,485 V, with a corresponding steady-state voltage of 38,048 V. The reduction in steady-state voltage during a sudden cloud condition in a double converter setup amount to 3,276%.

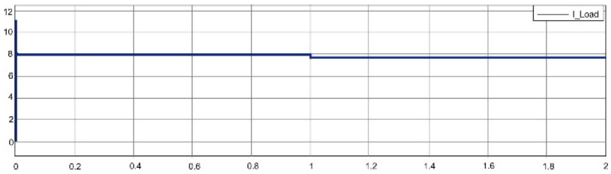

Fig. 13 - Double converter current output

The simulation results indicate that the current overshoot at 1000 W/m² is recorded as 11,116 A, while the steady-state current at the same irradiance is 7,867 A.

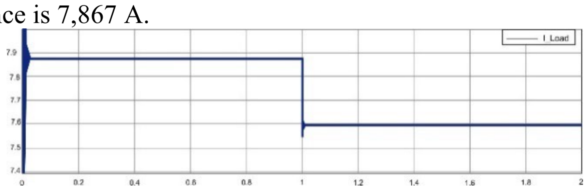

Fig. 14 - Double converter current output zoomed in

The abrupt cloud simulation reveals that the deficient current at 500 W/m2 is 7,495 A, while the constant current at the same irradiance is 7,610 A. The reduction in stable-state current during a sudden cloud scenario for a single converter is 3,266%.

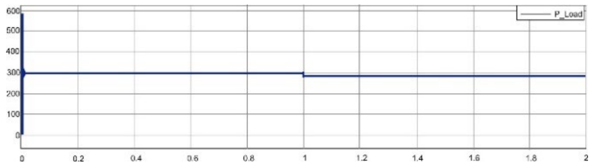

Fig. 15 - Double converter power output

The simulation results indicate that the excessive power at an irradiance of 1000 W/m2 is 619,352 W, and the power in a stable state at the same irradiance is 309,529 W.

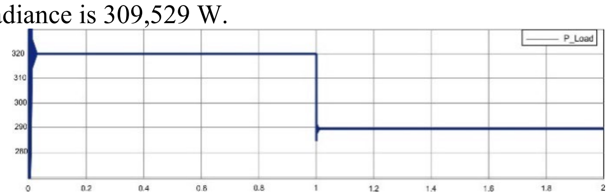

Fig. 16 - Double converter power output zoomed in

The abrupt cloud simulation reveals that the diminished power at 500 W/m2 is 280,786 W, while the power in a consistent state at the same irradiance is 289,374 W. The decline in stable-state power during a sudden cloud scenario for a single converter is 6,511%.

5. Conclusion

The simulation results unequivocally demonstrate that the dual converter with the Perturb and Observe algorithm exhibits superior current and power stability compared to the single converter scheme. The reduction in current overshoot stands at an impressive 65.336%, with sudden cloud-induced undershoot decreasing by 10.529%. Furthermore, power overshoot diminishes by 43.685%, and abrupt power undershoot caused by cloud cover drops by 7.133%. This study aims to elevate the stability and efficiency of standalone solar photovoltaic power generation systems through the utilization of the double series-connected converter approach. By doing so, the research has the potential to yield a more effective solution in maintaining power stability from solar panels, reducing power fluctuations triggered by sudden weather changes like unexpected cloud cover, and enhancing the efficiency of converting solar energy into electrical power. This solution bears significant implications in addressing operational challenges and amplifying the productivity of solar photovoltaic power generation systems.

In summary, despite the absence of specific renewable energy standards governing nominal voltage and current during overshoot, the renewable energy industry adheres to various guidelines and best practices to proficiently manage these parameters. Essential references in this context include the IEEE 1547 standard, which delineates technical requirements for integrating distributed energy resources and offers general guidance on the interconnection of renewable energy sources to the grid. Similarly, the international standard IEC 61727 delves into the characteristics of grid-connected photovoltaic systems, furnishing insights into safe limits for voltage and current through testing and characterization requirements. These standards collectively contribute to ensuring the robust and reliable integration of renewable energy sources into modern energy systems.

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