Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 5, May : 2024

Battery Current-Sharing Power Decoupling Method for Realizing a Single-Stage Hybrid PV System

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Abstract –

Conventionally, the single-stage grid-connected PV inverter needs a large PV-side electrolytic capacitor to suppress the double-line frequency current ripple to keep the PV operating at maximum power point (MPP). However, the short lifetime electrolytic capacitor will reduce the PV inverter's reliability dramatically. In order to overcome the above problem, a novel battery current-sharing power decoupling (BCSPD) method for hybrid photovoltaic (PV) power systems is proposed in this project.

The proposed BCSPD circuit is parallel connected with the string PV module to achieve as a single- stage topology. Thus, high power conversation efficiency can be obtained. The current-injection method is adapted to solve the current ripple problem. Therefore, the required capacitance in PV side can be greatly reduced, so long-life film capacitors can be used instead of electrolytic capacitors. In addition, the battery storage system with the droop control is also used to realize the power regulation function to meet the requirements of actual applications. Proposed method was designed and implemented to assess the system performance. MALTAB/SIMULINK Simulation results show that the proposed system can track MPP, regulate the load power condition, and reduce current ripple.

Keywords – PV system, MPPT, BCSPD circuit, PI controller, Fuzzy Logic Controller.

I. INTRODUCTION

Among the clean energy technologies, PV has significantly grown in recent years. Not only are the efficiencies of the most domestic solar panels low, i.e., around 10-20%, but the performance of other components such as inverters and batteries are limited as well. Battery, which can provide fast response for balancing the power between the generation and consumption, is becoming a good candidate for the electrical energy storage system (ESS). However, the initial installation costs are still high. Power electronic converters, which regulate voltages from one form to another are compatible with end-use electricity supply, are key elements for renewable energy power generation. Inverters that convert DC to AC voltages are broadly used in solar power conversion. In some applications such as the residence area, a single-phase PV inverter is usually used.

Conventionally, string of PV modules is serially connected to a high enough voltage and connected to a PV inverter (i.e., a grid-connected PV inverter). The traditional PV inverter is divided into single-stage and two-stage. The single-stage PV inverter has high power conversion efficiency. Unfortunately, the single-stage PV inverter has a double-line-frequency current ripple in the PV side. This means that there is a significant and huge double-line- frequency ripple current in the PV panel. Therefore, the operating point cannot be maintained at the maximum power point (MPP). This results in a significant reduction in PV panel output power. A usual solution to reduce the double-line-frequency current ripple is to use a large electrolytic capacitor (i.e., decoupling capacitor *Cpv*) at the DC link to buffer the ripple power. However, the short lifetime electrolytic capacitor will reduce the PV inverter's reliability dramatically, and weight and volume are obviously increased. Thus, the two-stage topology was used to avoid the current ripple problem at the PV side. However, the cost, weight, volume and efficiency of a two-stage topology are worse than that of a single stage topology. Furthermore, the typical two-stage topology cannot comply with the European standards EN50160, which stipulate that the low frequency voltage pulsation of the DC bus voltage should be kept within the range of 2%. In the other method, active decoupling circuits connected at the PV side or AC side was proposed to sink the ripple current. This kind of active power decoupling techniques utilize auxiliary power electronic circuits to pump/sink the ripple power into small film capacitors which can be used to replace the large electrolytic capacitor. Although active power decoupling techniques can effectively suppress the ripple current, they increase circuit complexity and cost. In reality, sunlight is not constant, and the loads and PV power are often mismatched. When much more energy being is produced in the PVs than is being consumed by the loads, the grid will be fluctuated. The droop control PV inverter was used to overcome this problem. However, generated energy of the PV modules is wasted. Therefore, a hybrid PV power system (i.e., grid-connected PV inverter with battery storage system) was suggested to store the extra power in the battery and then smoothly inject power to the grid to solve this problem. Battery storage systems assist in performing one or more important tasks such as (i) smoothing power fluctuation (ii) shift peak generation period, and (iii) protection during outages when installed along with large PV generation.

In this project, an active decoupling function tries to be realized by using a battery storage system, and then the DC/DC converter in a conventional hybrid PV power system can be eliminated. Thus, a hybrid PV power system with single-stage topology can be realized to reduce the power conversion loss. In addition, the battery storage system with the droop control is used to realize the power regulation functions. MATLAB/Simulink results show that the proposed method can really track the MPP of the PV modules, regulate the load power, reduce the current ripple, and reduce the circuit components and cost as we wanted.

II. POWER DECOUPLING METHODS

For those applications power rating is lower than 10 kW, e.g., residential PV system, the single-phase conversion is commonly used. During the integration of these distributed PV arrays to the power system, single-phase inverters play an important role in the energy conversion as well as voltage regulation. However, due to the double-line-frequency issue of the single-phase inverter, i.e., there is voltage/current ripple generated at the dc-link. Such voltage ripple degrades system performance such as the maximum power point tracking

(MPPT) efficiency of the PV system. However, the input solar power is desired to be constant. Figure 1 shows the output power of the inverter and the input solar power. The pulsating power is transferred to the dc side, which generates a second-order ripple on the dc voltage/current. The undesirable ripple results from power mismatch. Therefore, extra energy storage system (ESS) is required to be placed between the PV and output of the inverter to eliminate the pulsating power, which is also called power decoupling. For example, when *po* > *ppv*, EES provides the deficient power; otherwise, ESS stores the surplus power. Then the solar power can be harvested as much as possible.

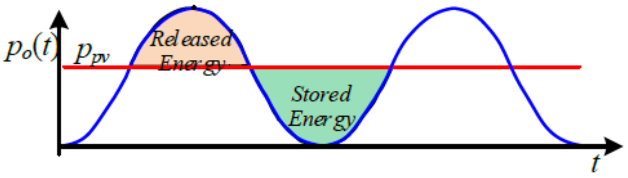

Fig: 1. Power decoupling of the PV system with the ESS.

The power decoupling technology can be generally divided into control and topology parts, which means that modification of the control strategy or the topology with additional components can eliminate (or suppress) the double frequency ripple. Then the power decoupling method can be classified as passive power decoupling method, active decoupling method and hybrid power decoupling method.

A. Passive Power Decoupling Method

The conventional passive solutions are usually using a capacitor or LC filter on the PV side or inverter dc-link to absorb the ripple power. This solution is simple and easy to be implemented because it does not need extra control and hardware.

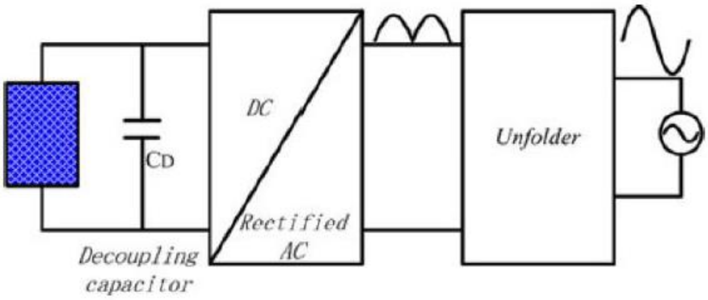

Fig: 2. Passive power decoupling for single stage inverter.

As shown in Figure 2, only the decoupling capacitor *CD* is installed at the PV side. *CD* with large capacitance is needed if power is decoupled on the PV side only to keep *Δvdc* to very low value for achieving high MPP efficiency. For example, regarding a 200-W microinverter to realize a 98% PV utilization factor, the required minimum decoupling capacitance is 13.9 mF. This represents a very large value. Due to the requirement of high capacitance, usually an aluminum electrolytic capacitor is used. Electrolytic capacitors typically have a limited lifetime, namely 1000~7000 hours at 105°C operating temperature.

Additionally, the electrolytic capacitors are usually oversized. Therefore, the bulky electrolytic capacitor not only increases the size of the microinverter but also reduce the lifetime of the inverter. In short, using electrolytic capacitor alone is far from being a satisfying solution to power decoupling. Figure 3 shows LC power decoupling for a single-phase ac-dc converter. The LC resonance filter can suppress the DC-side ripple for sharing certain current with the DC side. However, the resonance frequency is very low (e.g., 120 Hz for a 60-Hz grid), the weight and size of the passive components are comparatively large, so we need to consider them. Additionally, the voltage across the capacitor of the LC filter can be much higher than the maximum dc-link voltage.

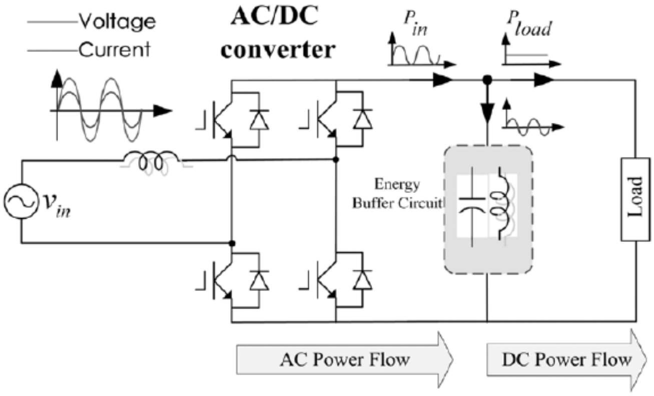

Fig: 3 Single-phase ac–dc converter with conventional power decoupling.

B. Active Power Decoupling Method

To resolve the drawback of the passive power decoupling solutions, active decoupling methods are created.

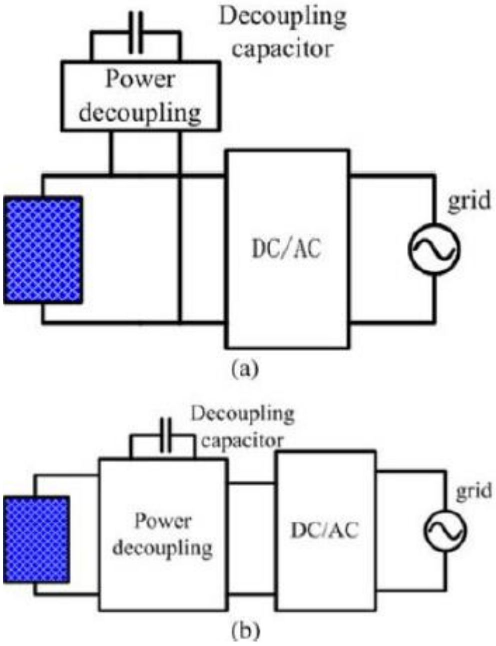

Fig: 4 Different ways of connection for power decoupling. (a) Parallel mode; (b) Series mode.

Therefore, the basic idea of active decoupling method is the use of a new specific energy storage device with relatively small size and long lifetime to instead the original passive components. It is realized through the addition of active switching devices (such as diodes, transistors), and filters. This kind of decoupling method usually involves a lot of additional power semiconductor devices, which increases cost significantly. According to the connection way of the active decoupling circuit with DC side, they are divided into series compensation (decoupling circuit in series with PV), parallel compensation (decoupling circuit in parallel with PV). Figure 4 shows the schematic of parallel mode and series mode.

III. PROPOSED SYSTEM

The presented battery current-sharing power decoupling (BCSPD) circuit is mainly constructed by a bidirectional dc/dc converter and parallel-connected with the PV modules and the PV inverter, as shown in Figure 5. Compared with the traditional hybrid PV power system, we can see that the DC/DC converter can be eliminated and there is only a single power stage between PV modules and load in the proposed system. So, the single-stage hybrid PV power system is achieved by using the proposed methods. The presented BCSPD circuit is composed of an input capacitor *Ci*, two power MOSFETs *S*1 and *S*2, an inductor *L* and an output capacitor *Co*. Diodes *D*1 and *D*2 are the body diodes of power MOSFETs *S*1 and *S*2.

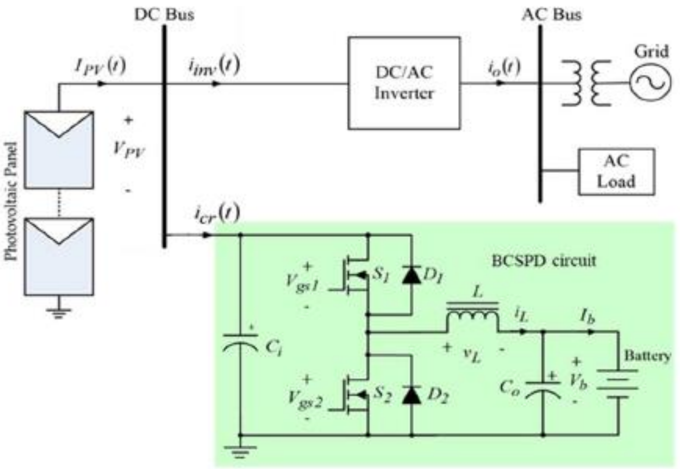

Fig: 5. The block diagram of the proposed BCSPD circuit for PV power applications.

Thus, the simplified model can be plotted as Figure 6. In which, the model of PV module equals a PN junction semiconductor when sunlight can produce a current source *IPV*.

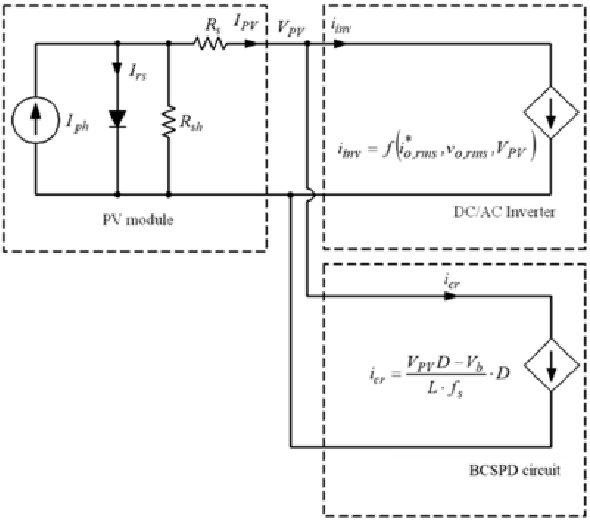

Fig: 6 The simplified model of the proposed BCSPD circuit for PV power applications.

Figure 7 shows the flowchart of the proposed system. First, the root-mean-square (rms) of the grid voltage $vo;rms$ is measured. Then the rms value of the injecting current $io;rms$ can be decided by the droop control method to realize the power regulation.

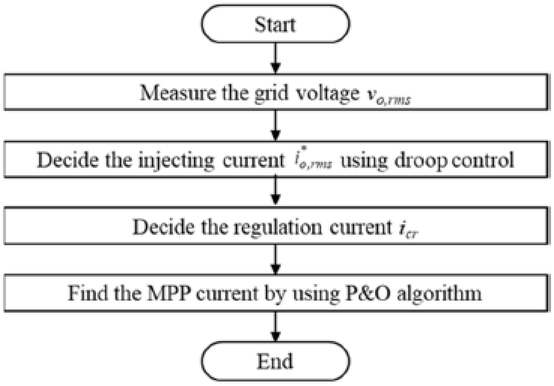

Fig: 7 The flowchart of the proposed system.

There are two kinds of current ripple influence the MPPT. One is the PWM switching current ripple (i.e., high frequency current ripple) from the BCSPD circuit, the other is the twice utility frequency current ripple (i.e., low frequency current ripple). In order to ensure that the proposed BCSPD circuit can provide the required compensation current of the low frequency current ripple, the small signal analysis is used to check the system control loop stability and frequency response. Figure 8 is the control loop of the proposed system. In which, the $Tp(s)$, $Tc(s)$, and kf are the transfer functions of the bidirectional converter, the compensation circuit and the feedback gain.

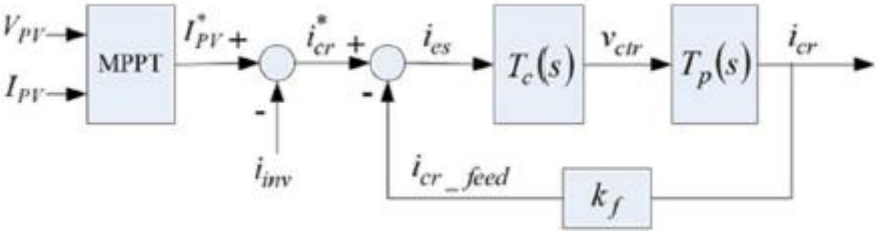

Fig: 8 The control loop.

IV. SIMULATION RESULTS

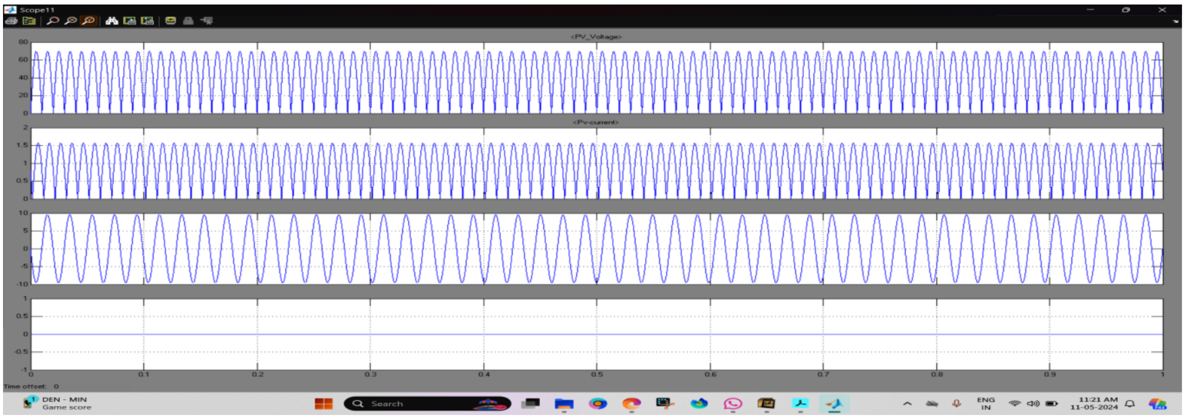

Fig: 9 simulation waveforms of the PV power system without the proposed BCSPD circuit.

Figure 9 shows simulation waveforms of the PV power system without the current ripple reducing function. Clearly, the PV modules have a current ripple that is caused by the DC/AC inverter. The output ripple current of the PV modules 1*IPV* is 10A and the output ripple voltage of the PV modules 1*VPV* is 70 V. Therefore, the output power of PV modules is the time-variable value. The operation point of the PV modules does not operate at MPP.

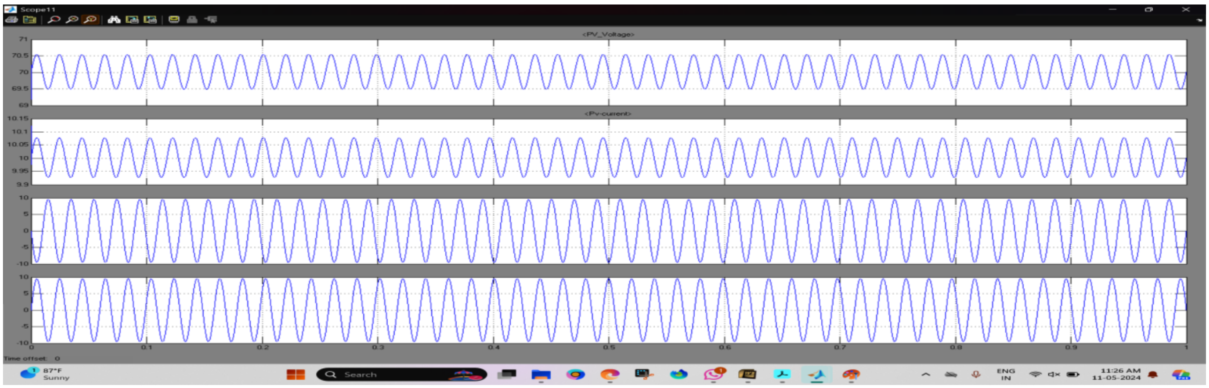

Fig: 10 waveforms of the proposed BCSPD circuit.

Figure 10 shows simulation waveforms of the proposed BCSPD circuit. We can see that the proposed BCSPD circuit can generate a completely complementary current ripple to reduce the PV modules current ripple from 10 A to 700 mA and the PV modules voltage ripple from 70 V to 5 V, obviously. The ripple current of the PV modules reduces to 3% and then the output power of the PV modules is increased.

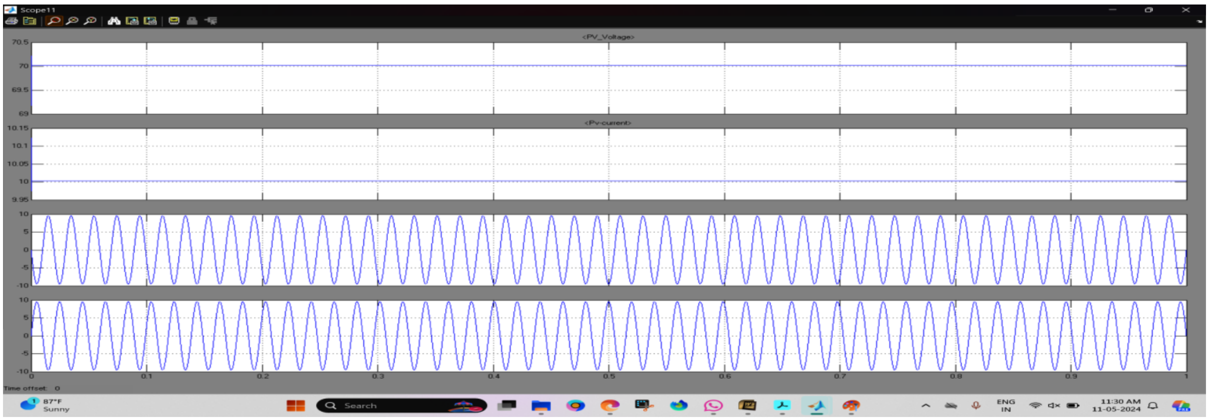

Fig: 11 measured waveforms when the proposed BCSPD circuit works in daytime.

Figure 11 shows the measured waveforms when the prototype works in daytime. Clearly, the average current of the DC/AC inverter *iinv* (i.e., 1 A) is smaller than the current of the MPP *IPV* (i.e., 5 A). We can see that the proposed BCSPD circuit works as charger with 4 A. to make the PV modules work at MPP and the current ripple reducing is also maintained.

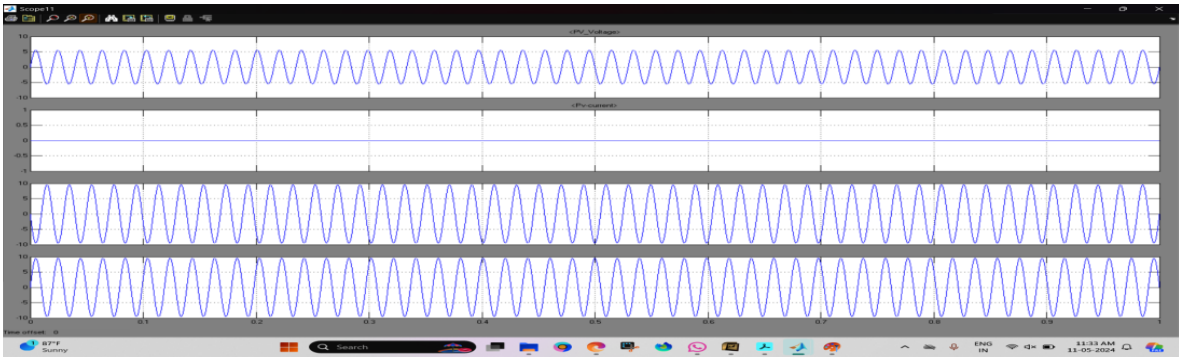

Fig: 12 measured waveforms when the proposed BCSPD circuit works at night.

Figure 12 shows the measured waveforms when the prototype works at night. The current of the MPP *IPV* is 0A and the BCSPD circuit works as discharger with -3.5 A to make sure the utility power stability and the current ripple reducing is also maintained.

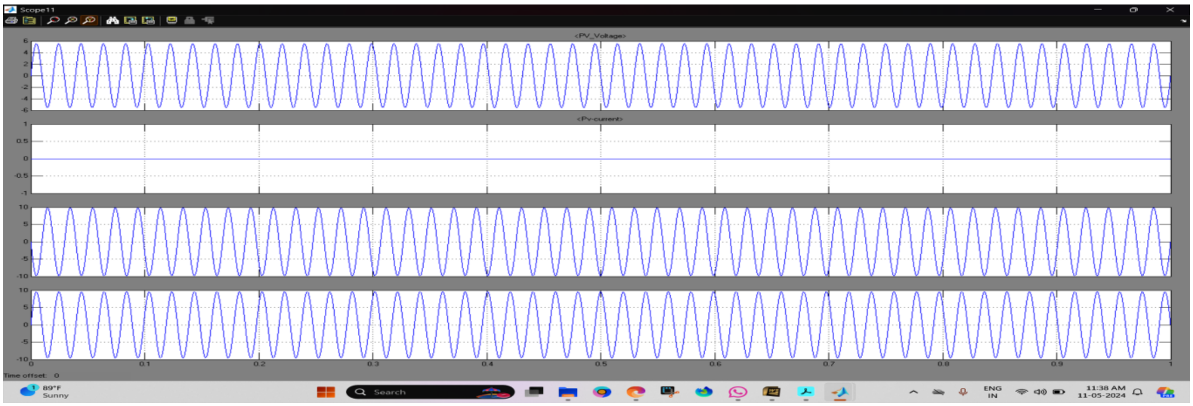

Fig: 13 measured waveforms when the proposed BCSPD circuit works at night.(Fuzzy)

V. CONCLUSION

A traditional PV inverter is divided into single-stage and two- stage. Although the single-stage PV inverter has high power conversion efficiency, it has the problem of low-frequency ripple in PV. This causes a decrease in the efficiency of PV power generation. A novel BCSPD technology for PV power applications was successfully proposed in this paper. The proposed system is a parallel-connected structure, so its power conversion efficiency is as high as that of a single-stage PV inverter. In addition, the proposed CS-MPPT can track the MPP, regulate the load power condition and reduce current ripple at the same time. Therefore, a high output power of PV power generation is also obtained.

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