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Research Paper

ENHANCED EFFICIENCY AND RIPPLE REDUCTION IN HYBRID PV SYSTEMS USING BATTERY CURRENT-SHARING POWER DECOUPLING

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Abstract *Conventional single-stage grid-connected photovoltaic (PV) inverters require large electrolytic capacitors to suppress double-line frequency current ripple, ensuring operation at the maximum power point (MPP). However, the limited lifespan and reliability issues of electrolytic capacitors hinder the system's performance. To address this, a novel Battery Current-Sharing Power Decoupling (BCSPD) method is proposed, which connects a decoupling circuit in parallel with the string PV module, forming a single-stage topology. This reduces the required capacitance and allows the use of long-life film capacitors, significantly improving reliability and efficiency. The proposed BCSPD system is modelled and validated using MATLAB/Simulink, enabling detailed simulation and analysis of its components and behaviour. The PV system is designed with MPP tracking algorithms and integrates the BCSPD circuit, including bidirectional DC/DC converters, MOSFETs, and control algorithms. The battery storage system with droop control is also simulated to manage power regulation, stabilize grid voltage, and store excess energy. Simulations demonstrate the system's ability to minimize current ripple, reduce conversion losses, and enhance PV energy output. The use of MATLAB/Simulinkfacilitatessystemdesign,optimization,andvalidation, providing a scalable and reliable solution for hybrid PV systems. This approach ensures the system meets real-world application requirements and accelerates advancements in sustainable energy technologies*

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1. Introduction

In recent years, the grid-connected photovoltaic (PV) power system has been developed dramatically and gradually to form a considerable part of the main grid because the environmental concern and continuous depletion of fossil fuel reserves. 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 a high power conversion efficiency as shown in Figure 1. Unfortunately, the single-stage PV inverter has a double-line-frequency current ripple in the PV side. In order to briefly describe the double-line-frequency current ripple phenomenon, assume that the grid voltage vO(t) and the injected current iO (t)

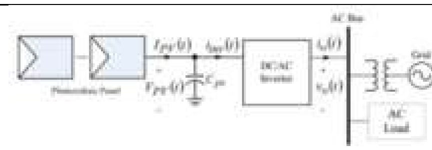

Fig1: Thesingle-statePVinverter

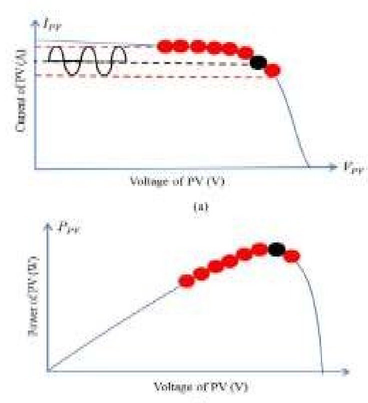

Fig2: Theeffectofripplecurrenton(a)VIcurve and (b) VP curve

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This means that there is a significant and hugedouble-line

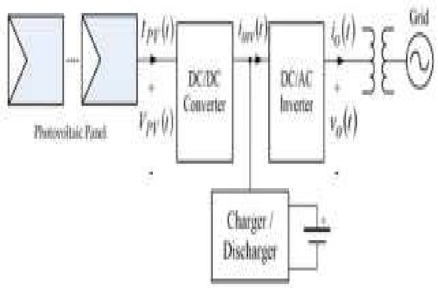

Fig3: The hybrid PV power system

In this paper, an active decoupling function tries to be realized by using a battery storage system, 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. Experimental 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.

2. System description

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. Compared with the traditional hybrid PV power system as shown in Figure 4, 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 S1 and S2, an inductor L and an output capacitor Co. Diodes D1 and D2 are the body diodes of power MOSFETs S1 and S2.

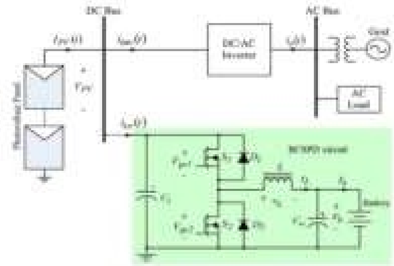

Fig4: The block diagram of the proposed BCSPD circuit for PV power applications

Figure 6 shows the waveforms of the proposed BCSPD circuit. Note that the gate-source voltages Vgs1 and Vgs2 are complementary and circuit works like a synchronous switching buck/boost converter. The duty cycle of the inductor voltage is controlled by the gate-source voltages Vgs1 and Vgs2. The inductor current of the bidirectional dc/dc converter iL can be written as (4) according to Volt-Second balance law. Thus, the simplified model can be plotted as Figure . In which, the model of PV module equals a PN junction semiconductor when sunlight can produce a current source IPV .

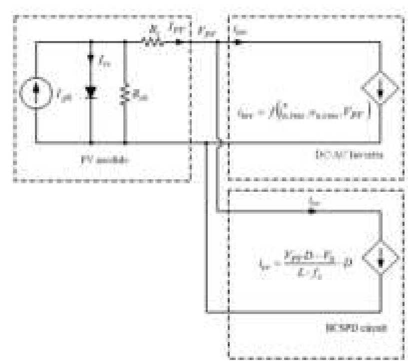

Fig5: ThesimplifiedmodeloftheproposedBCSPD circuit for PV power applications

In order to simplify the mathematical formulas and circuit diagrams, resistors and capacitors with the same resistance value or the same capacitance value are represented by the same component numbers. The transfer function of the lead. The gain margin and the phase margin should be large than 20dB and 45◦ to ensure the proposed system being stable. 2. The bandwidth should be larger than 10fr to ensure the proposed system tracking the input current of the PV inverter. 3. The gain at switching frequency fpwm should be smaller than−20dBtoensure the switching noise being small enough. 4. The phase shift Pr of the ripple current frequency should be close to zero to reduce the phase shift error at frequency fig 5. To meet these compensation criteria, the frequencies of the zero and poles in the lead compensation circuit

3. Sliding Mode Controller

Sliding Mode Control (SMC) is a robust nonlinear control technique designed to manage systems with uncertainties and disturbances. It operates by forcing system trajectories onto a predefined sliding surface, ensuring desired behavior despite model inaccuracies. SMC emerged from the concept of Variable Structure Control (VSC), introduced by Soviet researchers in the 1950s. Vadim Utkin significantly advanced SMC, providing a systematic frame work for its application. The core idea involves designing a control law that switches system dynamics based on the current state, guiding trajectories toward and maintaining them on a sliding surface. This approach ensures robustness against matched uncertainties—those entering through the same channel as the control input.

4. Simulation results

Existing system

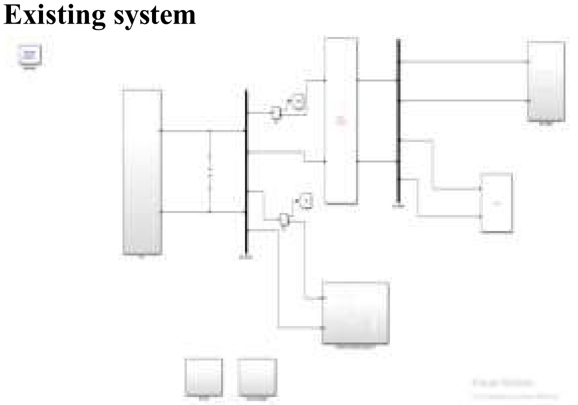

Fig6: Model diagram

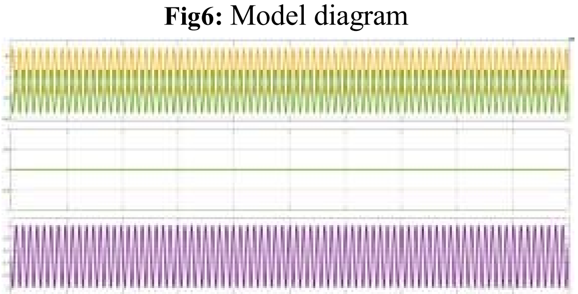

Fig7: PV power system without the proposed BCSPD circuit

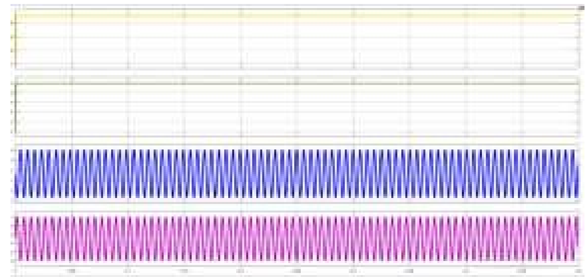

Fig8: Wave forms of the proposed BCSPD circuit

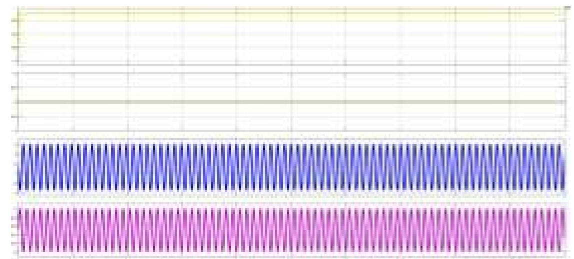

Fig 9: The measured waveforms when the proposed BCSPD circuit works in day time

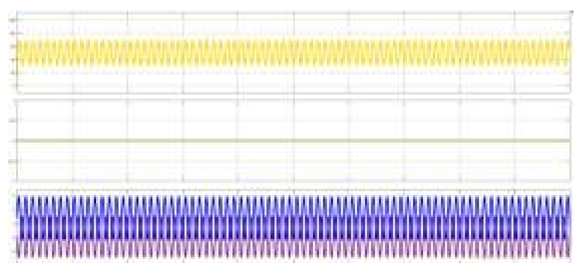

Fig10: The measured wave forms when the proposed BCSPD circuit work at night

SMC Controller Simulation results

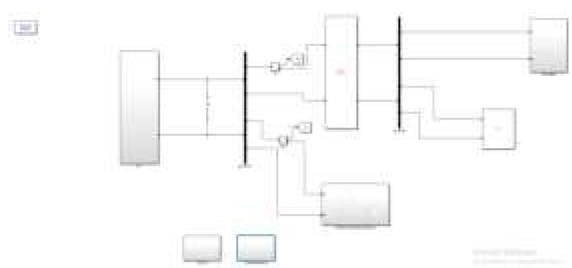

Fig11: Simulation model with Sliding Mode Controller

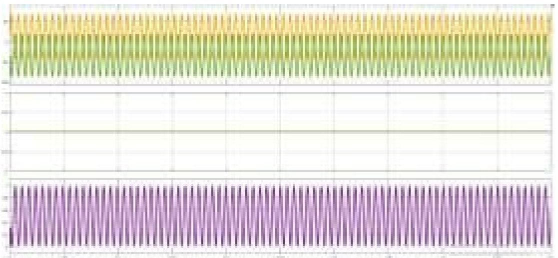

Fig12:PV power system without the proposed BCSPD circuit

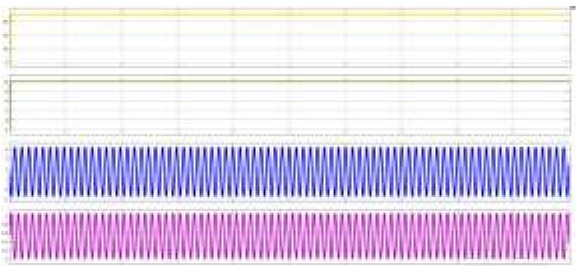

Fig13: Wave forms of the proposed BCSPD circuit

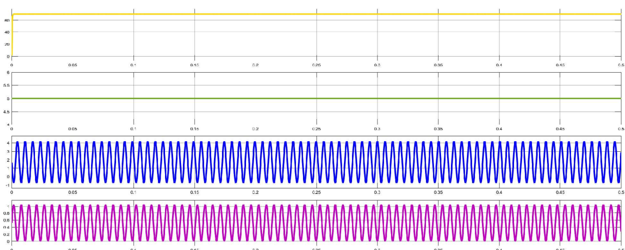

Fig14: The measured wave forms when the proposed BCSPD circuit works in day time

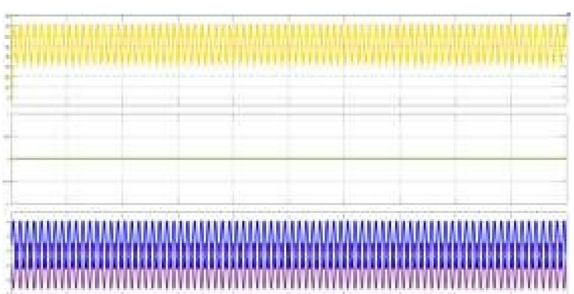

Fig 15: Proposed BCSPD circuit work at night

5. Conclusions

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. The two-stage PV inverter can be buffered by a DC bus without the problem of low-frequency ripple. Therefore, the efficiency of PV power generation is high. However, the two-stage PV inverter has one more series-connected DC/DC converter than the single-stage PV inverter, so the power conversion efficiency is low. In order to overcome the above problem, a novel CS-MPPT with ripple-reducing 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 efficiency of PV power generation is also obtained. In order to assess the proposed system performance, a 1200 W prototype was designed and implemented. Experiment results show that the proposed CS-MPPT with ripple reducing system can generate a completely complementary current ripple to reduce the PV modules current ripple from10 A to 700 mA and the PV modules voltage ripple from 70 V to 5 V, obviously. Thus, the power efficiency of the PV modules is increased as theatrical prediction.

The feasibility and excellent performance of the proposed CS-MPPT with ripple reducing system are verified by experiment results. 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. In order to assess the proposed system performance, a 1200 W prototype was designed and implemented. Experiment results show 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. Thus, the output power of the PV modules is increased as theoretical prediction. The feasibility and excellent performance of the proposed BCSPD circuit are verified by experiment results.

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