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Implementation of a Fuzzy Logic Controller for Power Conversion Through a PV-Battery Based Multi-Bus Power Router System

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Abstract:

As a result of the recent surge of interest in renewable energy, scientists have made great strides in developing effective technologies for converting renewable energy. This includes traditional power grids, alternative energy sources, and battery packs. This research proposes partial power conversion (PPC) between two DC buses as a novel AC/DC hybrid multi-port power routing(MPPR) system. Power from one source, such as a photovoltaic array, is converted into another, such as a series-connected DC bus, only when needed. This is known as Partial Power Conversion. Two DC voltage buses and a PV port are included in this setup. Grid-connected inverters have a high-voltage ride-through (HVRT) feature that allows them to function normally even during a grid voltage surge. PV ports can utilise maximum power point tracking (MPPT) technology. Because just a small amount of power from the PV panel is allowed to flow to the series-connected DC bus, and because constant DC voltage is maintained with Fuzzy logic control (FLC), the PPC-based PV conversion feature achieves lower loss than full power conversion (FPC) for PV. MATLAB/Simulink simulations are used to produce the results.

Index: HVRT, MPPT, PPC, FPC, MPPR

I.INTRODUCTION:

As a result, the usage of fossil fuels and carbon emissions have decreased, while renewable energy sources like the Photovoltaic system have swiftly advanced. There has been a lot of research into how to make PV conversion more effective and cheaper. While the low flow cost, compact structure, and high efficiency of a single-stage PV power-generating system are all advantages, grid-connected inversion cannot be accomplished under typical PV power conditions. Two-stage PV conversion is widely employed because of the pliability it provides in terms of Maximum power point, energy, and control. Partial power conversion, which can be employed in non-isolated conversion applications, is highly efficient and cost-effective because it only evaluates a considerable proportion of the system's total energy. Inspired by the work in [1], a new method of partial power conversion was proposed. A standard push-pull forward converter typically achieves power flow control and voltage adjustment in a three-phase power distribution system. In reference, a high-efficiency DC/DC converter was proposed to be used in distributed PV systems of varying sizes. High efficiency is achieving partial power processing and coordinating the operation of the interleaved channels of the converter. The ability to remove energy or smooth PV output with quick response The problem of voltage over limit and fluctuation caused by PV grid-connected can be effectively alleviated through the rational configuration of BES [3], [4]. Now, the tradition-centralised power generation is gradually changing to the coexistence of centralised and distributed power generation. The unidirectional flow mode of power is gradually transforming into multidirectional modes. To improve the energy utilisation of the PV-battery grid-connected system, the electrical power router has communication and intelligent choice capabilities, which are supported by the mature application experience of microgrid and information technology integration-making capabilities and can realise active management of power network energy flow based on network operation state and user and control centre instructions, while also improving system power utilisation effectively [5]. [6] proposed a quad-port power routing circuit that integrated storage and distributed generation, such as Photovoltaic, and enabled the implementation of power quality features. The authors of reference [7] suggested a multi-port power routing (MPPR) converter that integrates PV and battery power for high step-up applications, as well as a control strategy that made use of energy storage to keep the Maximum power point of PV constant across a wide range of illumination and load conditions, to realise the multi-mode and efficient operation of the PV power generation system. Research on low-voltage ride-through solutions for PV systems has progressed tremendously as HVRT is still developing. Scholars have conducted early research into HVRT technology for grid-connected devices. An HVRT control method with adaptive DC bus voltage adjustment in response to grid voltage variations was presented to remedy the situation where power was being sucked back into the grid from the grid-side converter. Protecting the grid against instability when using significant amounts of wind power requires a solution based on the combination of a series impedance divider and parallel high impedance grounding at the wind turbine terminal. To accomplish the MPPT of PV and HVRT of the grid-connected converter by volume compression, an extra port is created for the MPPR system in Figure 1 based on PPC. A power router comprises a PV port, a battery port, an AC port, and two DC voltage buses. The auxiliary port aids in implementing the PVMPPT with a PC that only transmits power determined by the electric potential difference between the DC bus and the PV panel. The Photovoltaic panels connected to the DC bus must be handled within the loop, which significantly reduces the loss compared to the FPC for PV. In the scenario where the photovoltaic conversion is unaltered, the HVRT of grid-connected converters is likewise achieved through voltage modulation.

II. System Description of the Power Router:

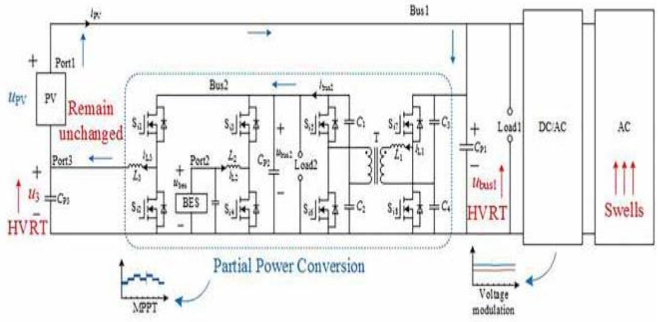


Fig 1 The MPPR topology of PV-battery grid-connected system.

As shown in fig 1. A total of three ports and two DC buses make up the system. A power router comprises a PV port, a battery port, an AC port, and two DC voltage buses. The primary power source of the system is accessible through Port 1. Accessing the BES via Port 2 allows for modulation and augmentation of the PV output. To manage the power produced by the MPPT and HVRT implemented by the voltage differential between the DC bus and the PV module, port 3 is a PPC port. HVRT stands for High Voltage Ride Through, a technique used to ensure that the PV system can continue to operate even when the grid voltage is higher than the rated voltage. Bus 2 is controlled by a bidirectional dual half-bridge (DHB) DC/DC converter, whereas bus 1 is controlled by a three-phase converter connected to the grid. The coordination of Bus 1 and Port 3 is also essential for the MPPT deployment of PV arrays. The BES controls the charging and discharging processes to improve the system's overall energy efficiency. Two separate direct currents (DC) buses, Bus 1 and Bus 2, are employed to supply power to their respective loads and transfer energy between them. The DC bus of a three-phase converter is constructed by connecting a PV port and a PPC port in sequence to create Bus 1. The BES's power is transmitted via Bus 2, and the stability of u3 is regulated using buck/boost converters. To realise the transfer control of BES and partial PV power, a non-isolated dual half-bridge (DHB) links Bus 1 and Bus 2. Battery energy storage, or BES, is a technology used to store power generated by renewable resources like solar and wind. To adapt the voltage from the BES to the system's needs, buck/boost converters are used. Power converters known as Dual Half-Bridges (DHBs) are commonly employed to transfer energy across two DC buses. Partial Power Conversion, also known as PPC, is a method for transforming the energy created by the disparity between the DC bus and the PV module.

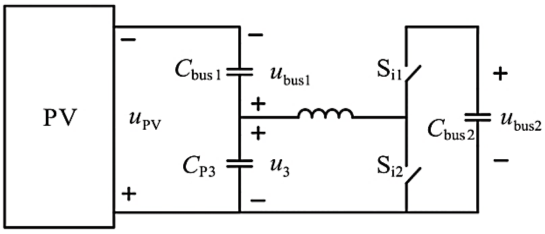


Fig 2: The equivalent model of PPC and HVRT.

From fig 2: For a PV array's maximum power point tracking to be effective, the voltage at Port 3 (u3) must be dynamically adjusted to maintain a constant maximum power point at the array's output. This kind of partial power conversion uses a non-isolated converter to actualise the PPC, which boosts energy transfer efficiency. When only a fraction of the power is converted, this process is called partial power conversion (PPC). Compared to Full power conversion (FPC), which transfers 100% of the power, this method only assigns a portion of the energy. Realising the PPC with non-isolated converters can increase energy transfer efficiency while decreasing the system's size, weight, and price. The proposed PPC scheme in this paper can also assist in carrying out the HVRT under the grid voltage surge condition. After all the loads are connected to the DC bus via a power electronic converter, the voltage on Bus 1 u_{Bus} 1 may fluctuate within a certain range. As AC side voltage spikes are detected, the DC bus voltage uBus1 can be increased via Port 3 to compensate. The MPPT control determines the PV output voltage u_{PV}, and the DC bus voltage uBus1 is found by adding the voltage at Port 3 (u3) to the voltage at the PVs (u_{PV}). As the DC side of the three-phase converter experiences a voltage spike from the grid, the voltage at Port 3 (u3) should be increased to keep the PV system working at the MPPT. If there is a high-voltage failure, the voltage on Bus 1 will need to be raised to accommodate the higher demand for power at Port 3, which $u_3=u_{Bus} - u_{PV}$..

The control scheme of Bus1 voltage u_{Bus1} is shown in Figure 3. Voltage and current double closed-loop control are used in the grid-connected condition. Since reference values id,iq and feedback values id,iq are DC signals in steady state, current tracking control without steady-state error can be realised through the FUZZY controller. According to the control scheme of the converter, the control objective is that the voltage and power can be matched in real-time to maintain the stability of both the Dc link voltage and perform the MPPT. The voltage at Bus 1 is regulated as shown in Figure 3. This control approach is utilised in the grid-connected mode, which uses voltage and current double closed-loop control. A Fuzzy controller is utilised to achieve current tracking with zero steady-state error, and both the reference and feedback values (id, iq) are DC signals at rest.

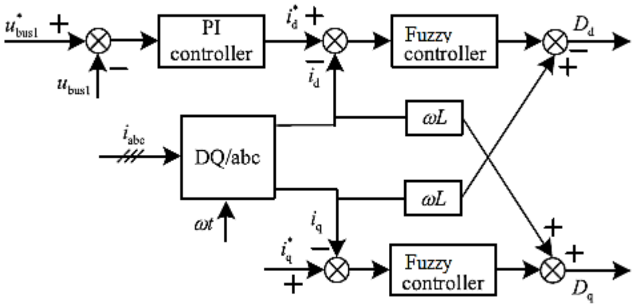


Fig 3: The control strategy of u_{Bus1}

Maintaining a constant DC bus voltage and completing Maximum Power Point Tracking (MPPT) of the Photovoltaics (PV) in a grid-connected state are two goals of the converter's control approach that require real-time matching of voltage and power. The control strategy of the system is based on the concept of voltage modulation. This means that the voltage of the auxiliary port is modulated to control the PV maximum power point tracking (MPPT) and high-voltage ride-through (HVRT) of the grid-tied inverter. Depending on the system's energy requirements, the converter can work in inverter or rectifier mode.

III. Description of energy flow diagram:

Two DC voltage buses, one for connecting batteries and one for connecting solar panels, make up Fig. 4. How the solar photovoltaic (PV) array, the bus load, and the battery energy storage (BES) interacts determines the system's energy flow direction.

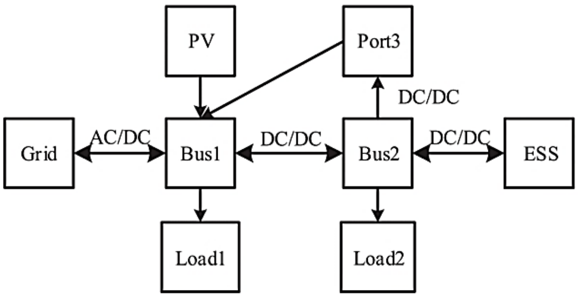


Fig 4 Energy flow diagram

If the equation $Q_{Grid} + Q_{PV} - Q_{Load1} > 0$ holds, energy from the three-phase converter is sent to Bus 2 via the DHB bi-directional DC/DC converter when the converter is in rectifier mode. This equation mathematically represents the direction of energy flow, with Q_{Grid} representing the grid's reactive power, QPV representing the PV's reactive power, and Q_{Load1} representing the load connected to Bus 1. If the equation $Q_{Grid} + Q_{PV} - Q_{Load1} < 0$, then the energy is transferred to Bus 1 through the DHB bi-direction DC/DC converter. When the three-phase converter is in inverter mode, the energy is transferred to Bus 2 through the DHB bi-direction DC/DC converter if the equation QPV − QGrid − QLoad1 > 0. Where QPV is the reactive power of the PV, QGrid is the reactive power of the grid, and QLoad1 is the reactive power of the load linked to Bus 1, this equation represents the direction of energy flow mathematically. If the equation $Q_{PV} - Q_{Grid} - Q_{Load1} < 0$.

The DHB bidirectional DC/DC converter sends the power to Bus 1. When the BES discharges, the energy is transferred to Bus 1 through the DHB converter if the following equation is true: QBES − Qu3 − QLoad2 > 0. Here, QBES is the power output of the BES, Qu_3 is the power output of the PV port, and QLoad2 is the power output of the load connected to Bus 2. On the other hand, if the equation $Q_{BES} - Qu_3 - Q_{Load2} < 0$ is true, then the energy is transferred to Bus 2 through the DHB converter. The energy is transferred to Bus 2 through the DHB converter when the BES charges.

IV. Fuzzy Logic Controller:

In part, fuzzy Logic Controllers' success can be attributed to their intuitive similarity to a human controller. Like a human operator, it uses a knowledge base and the associated if-then rules to perform its functions. Compared to alternative methods of control, this one requires less effort and study of complex mathematics.

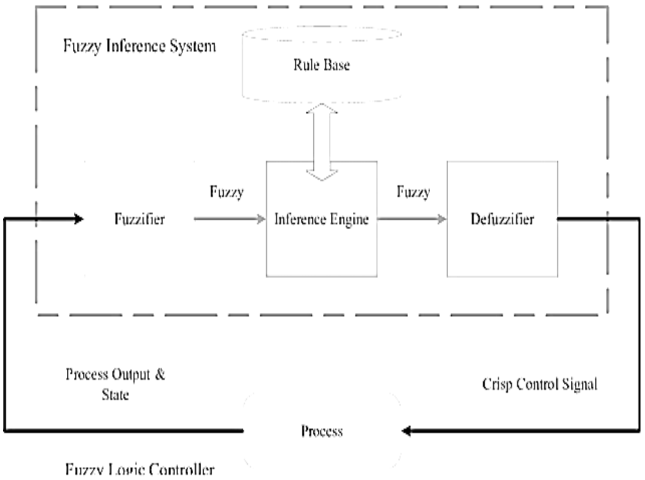


Fig 5: fuzzy diagram

The FLC is simple to operate and develop because it requires only a qualitative understanding of the system. Linguistic variables, specified by membership functions, are then used to process the inputs to a Fuzzy Logic Controller. It is intentional that the membership functions selected encompass the entire linguistic space. Adjacent fuzzy sets must overlap to prevent a behaviour gap in response to subtle input shifts. Fuzzy Logic Controllers have a concise time constant. Hence this requirement is crucial to their development.

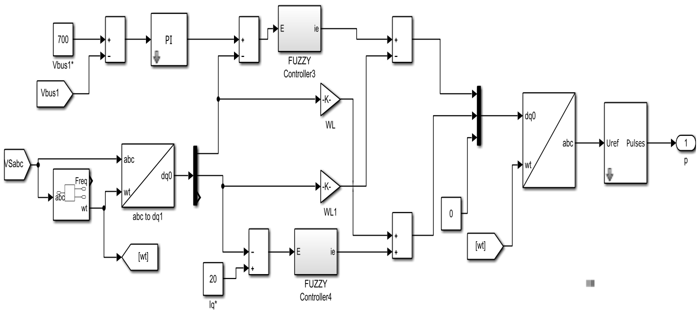


Fig 6: simulation diagram of the control system

IV. Simulation results:

USING FUZZY:

The simulation will involve changing the working conditions to verify the system's functioning principle under various settings.

Case I: Figure 7 depicts the pre- and post-switch voltage u_{Bus1} conditions for Bus 1. Bus 2 operates at a voltage of 400V. The current u3 at Port 3 is 100V. Constant 30A current is used to power the BES. Indefinitely maintaining a 47A current at its output, the PV module is reliable. The inductive current iL1 shows that energy is always being sent via the buck/boost circuit to the capacitor C_{P3} to increase the voltage at the Ports 3 terminals. After doing the math, we find that a value of 2000 W, or roughly 1/6 of PV capacity, is the partial power conversion value. During 0-1s, the grid's current and voltage are in phase and at the same frequency. The three-phase converter has entered rectifier mode to transfer energy from the power grid to Bus1. Waveforms of the voltage and current at a steady state in the inductance used for phase shifting, L3, are shown along with the output curves from the controller in the phase-shifting control module.

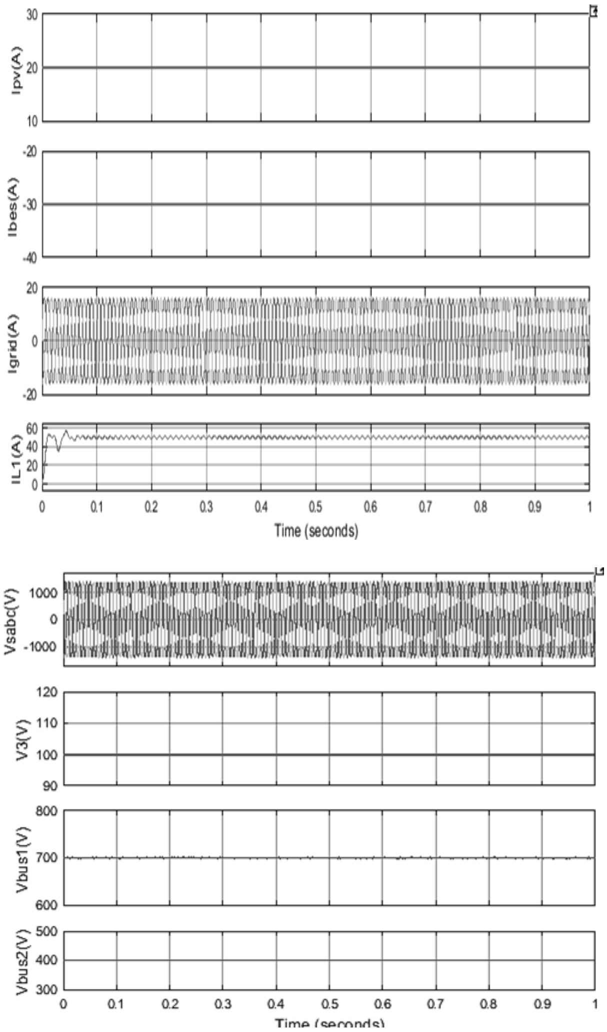


Fig 7 Simulation result of case I

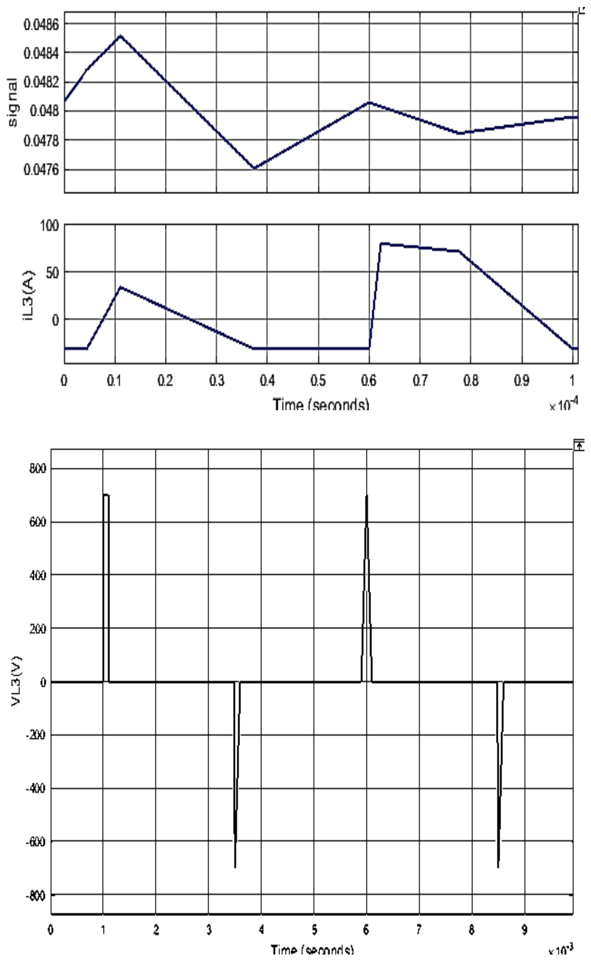


Fig 8: Steady state waveform in 0-1 s

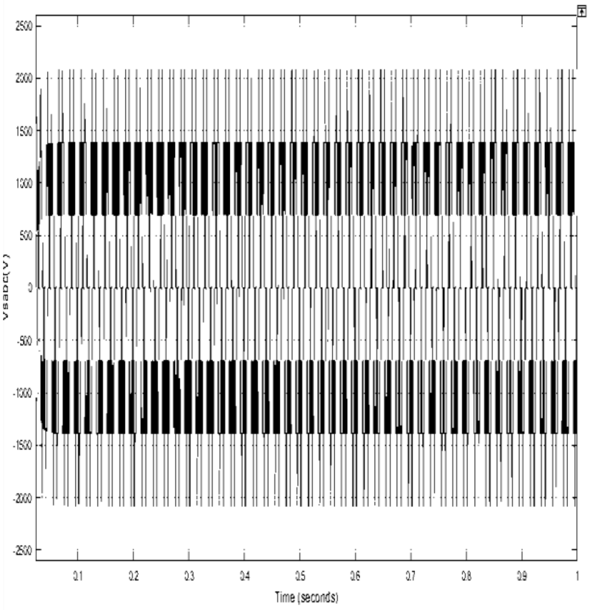
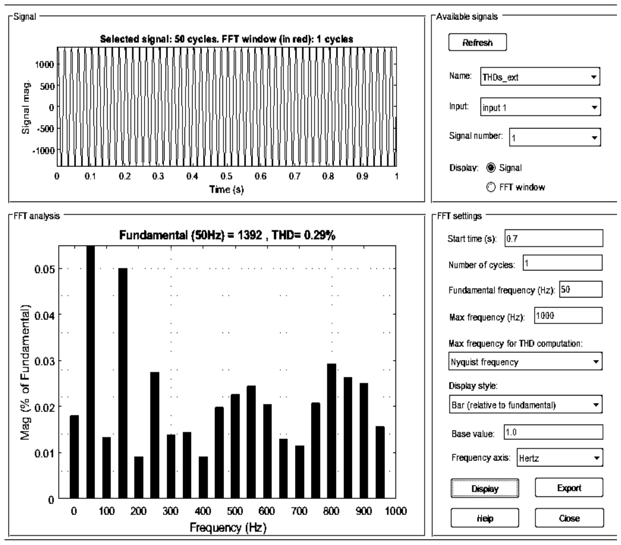


Fig 9: Inverter voltage



Signal

Selected signal: 50 cycles. FFT window (in red): 1 cycles

FFT analysis

Fundamental (50Hz) = 1392 , THD= 0.29%

Available signals

Name: THDs_ext

Input: input 1

Signal number: 1

Display: ● Signal ○ FFT window

FFT settings

Start time (s): 0.7

Number of cycles: 1

Fundamental frequency (Hz): 50

Max frequency (Hz): 1000

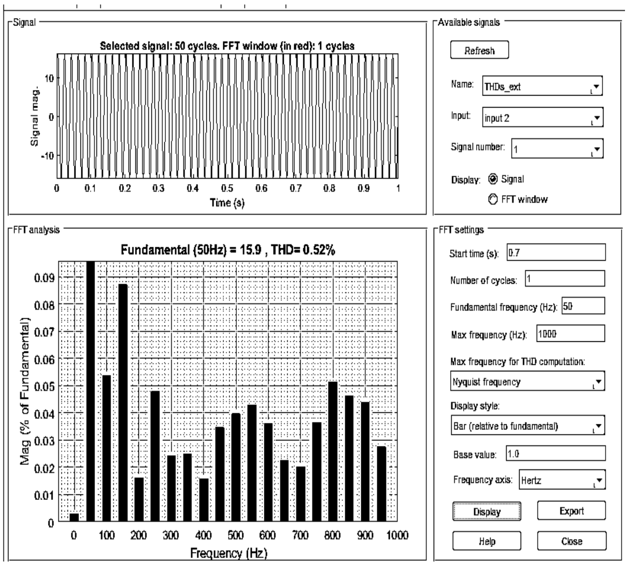
Max frequency for THD computation: Nyquist frequency

Display style: Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Fig 10. Voltage THD



Signal

Selected signal: 50 cycles. FFT window (in red): 1 cycles

FFT analysis

Fundamental (50Hz) = 15.9 , THD= 0.52%

Available signals

Name: THDs_ext

Input: input 2

Signal number: 1

Display: ● Signal ○ FFT window

FFT settings

Start time (s): 0.7

Number of cycles: 1

Fundamental frequency (Hz): 50

Max frequency (Hz): 1000

Max frequency for THD computation: Nyquist frequency

Display style: Bar (relative to fundamental)

Base value: 1.0

Frequency axis: Hertz

Fig 11: Current THD

The output curves of the controller of the phase-shifting control module and the steady-state waveforms of the voltage and current of the phase-shifting inductance L3 are shown in Figure 10. The controller's output is positive, and the DHB bi-direction DC/DC converter is in the forward operating mode. The energy is transferred to Bus 2 through the DHB bi-direction DC/DC converter. During 1-2s, the three-phase converter works in inverter mode. Power is transferred to the grid side through Bus 1. The output of the controller of the phase shift control module is negative, and the DHB bi-direction DC/DC converter is in reverse operating mode. The energy is transferred to Bus 1 through the DHB bi-direction DC/DC converter. The current and voltage waveforms of inductance both reach a steady state.

CASE II

The simulation time is 2.5s; the system works in HVRT conditions for 1-2s. The simulation results are shown in Figure 12. The current direction in the system structure diagram is the positive direction.

Case II: As shown in Figure 12, during 0-1s, the BES is charged with a constant current of 30A, and all loads in the system are switched into 10□ during 1-1.5s and 2-2.5s, the BES discharges at a continuous current of 30A, and the DC bus is not connected to the load. The output current of the PV is increased to 30A. During 1.5 2s, based on the operation in the last working condition, the grid voltage rises. Under the normal operation state of grid voltage, DC bus voltage uBus1 is 700V; DC bus uBus2 is 400V. The Port 3 voltage u3 is 100V. During 1.5-2s, the grid voltage rises, and the DC bus voltage u_{Bus1} is stable at 860V, while the Port 3 voltage u3 is stable at 260V as shown in fig 13.

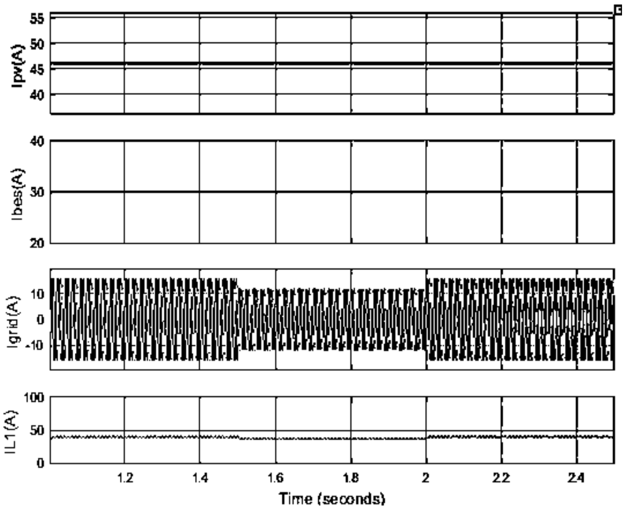


Fig 12: currents of PV, BES, and inductor

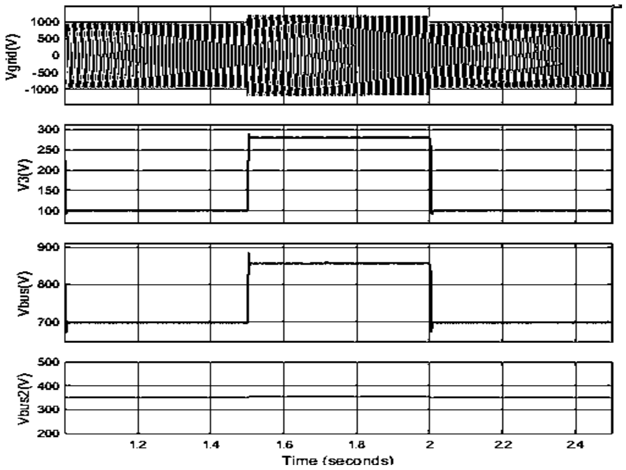


Fig 13: Grid voltage

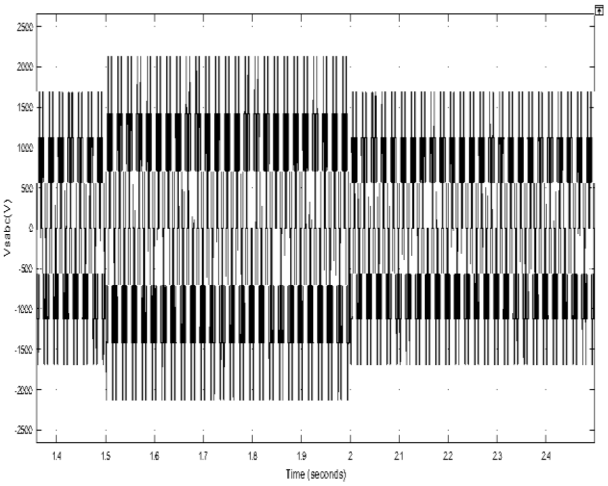
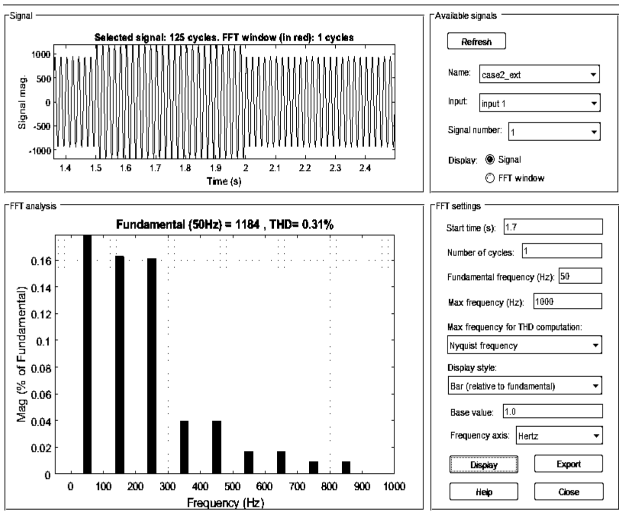


Fig 14: Inverter Voltage



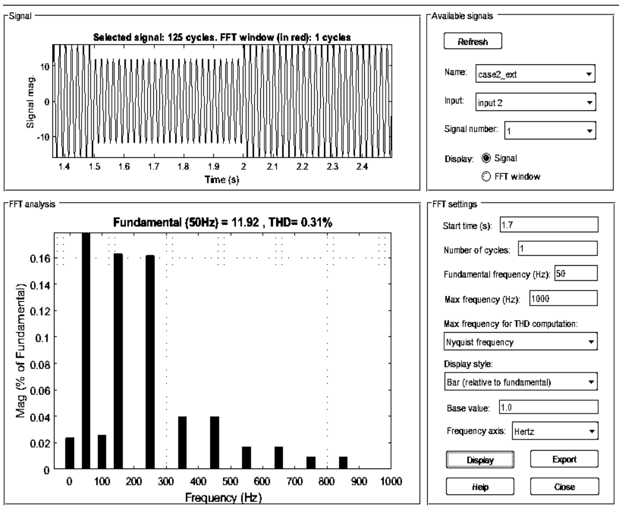
Selected signal: 125 cycles. FFT window (in red): 1 cycles

Name: case2_ext
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window

Fundamental (50Hz) = 1184 , THD= 0.31%

Start time (s): 1.7
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Fig 15: Voltage THD



Selected signal: 125 cycles. FFT window (in red): 1 cycles

Name: case2_ext
Input: input 2
Signal number: 1
Display: ● Signal ○ FFT window

Fundamental (50Hz) = 11.92 , THD= 0.31%

Start time (s): 1.7
Number of cycles: 1
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Fig 16: Current THD

Under normal operating conditions, the buck/boost converter transfers some energy from the inductor current iL1 to the capacitor CP3 to raise the voltage at Port 3. The cost per kilowatt-hour of PPC is roughly 1/6 of that of PV power. Still, HVRT only makes use of around half of the PV capacity. The voltage and current on the grid are in phase and at the same frequency during the 0-1 s. Bus 1 receives power from the power grid via the three-phase converter operating in rectifier mode. The DHB bi-directional DC/DC converter is in forward working mode to transfer energy from Bus 2 to Bus 2 when the energy supplied by the BES is insufficient to match the load power consumption and partial power conversion on the Bus 2 side. Voltage and current are out of frequency and phase during 1-1.5s and 2-2.5s. The three-phase converter is now operating in inverter mode. To the side of the grid, energy is sent via Bus 1. The energy storage device's charging requirements and the energy utilised for partial power transformation are both met by the PV system because the power of the PV panels has been raised, and there is no load connected to the bus. Also, the surplus power can be fed back into the grid. DHB's bidirectional DC/DC converter, working in forward mode, transfers control to Bus 2.

Comparison Table of conventional method (PI) and the proposed method (FUZZY):

	VOLTAGE THD	CURRENT THD
PI Regulator	2.48%	2.45%
FUZZY	0.29%	0.52%

Conclusion:

This paper will review a method of using solar batteries as part of a multi-port power routing(MPPR) scheme. One key aspect of the MPPR proposed in this study that sets it apart from the standard PV-battery grid-connected system is that it achieves partial power conversion of the DC/DC stage through a single auxiliary port. Under the presumption of constant PV output, MPPR uses HVRT as a backup system. Altering the DC bus voltage of the three-phase converter to raise the grid-side voltage is taken care of by the auxiliary port. The system's three ports, two DC buses, and the grid allow various power exchange combinations; by incorporating fuzzy logic, both the PV current and the THD might be enhanced.

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