IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Design And Analysis Of A Novel Hybrid Multiport Converter For Stand-Alone Pv Systems

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Abstract:This paper introduces an innovative Multi-port Converter (MPC) with a reduced number of switching devices for hybrid sources and loads. It is integrating solar energy with energy storage system. The increasing demand for renewable energy solution has to the development of efficient power converters for standalone Photovoltaic (PV) systems. The hybrid topology of the converter enables seamless bidirectional power flow ensuring optimal energy utilization while improving the reliability of standalone PV systems. The system dynamically prioritizes PV energy, directs excess power to battery storage and supports loads in case of insufficient PV generation. The proposed converter is equipped with Maximum Power Point Tracking (MPPT) to optimize the harvesting of solar energy and to maintain consistent voltage regulation, even when environmental conditions fluctuate. Simulation and experimental results demonstrate that the proposed hybrid multi-port converter achieves high efficiency. Reduced power losses and improved energy management compared to conventional multi-stage conversion systems. At long last a performance comparison is carried out featuring the upsides and downsides of the various topologies leading to solution for the directions of future research.

Key words *- Multi-port Converter (MPC), Photovoltaic (PV) systems, Maximum Power Point Tracking (MPPT).*

I. Introduction

At present, the use of renewable sources like Photovoltaic (PV) systems, wind energy, and fuel cells has attracted due to global warming and the increasing cost of fossil fuels [1]. Conventional energy systems, which depend on several independent converters, often struggle with issues like system failures, elevated costs, and increased operational complexity[2]. Multi-Port Converters (MPCs) offer a solution by integrating multiple functions in a single converter, thereby reducing the system's complexity and improving overall efficiency [3]. The development of multi-port single-stage bi-directional converters has significantly advanced the integration of photovoltaic (PV) systems with energy storage, offering a more efficient solution for managing energy flows. [4]. These break through are essential for improving the efficiency and reliability of renewable energy systems. MPCs are available in each standalone and interconnected configurations, each offering distinct advantages depending on the applications. Standalone converters typically provide galvanic isolation through transformers, while inter-connected converters are valued for their portable design and cost-effective [5, 6]. MPCs are developing gradually important in hybrid renewable energy system like those used in electric vehicle charging station. Their ability to manage complicated power flows establishing the reliable energy conversion makes them ideal for such applications [7]. Efficient power utilization strategies are essential for managing the multiple inputs and outputs of MPCs efficiently. These strategies ensure that power is scattered optimally across. Different sources like PV systems fuel cells, and super capacitors, thereby enhancing the overall reliability and efficiency of the energy systems [8, 9]. Hybrid

Multiport Systems, which combine multiple energy management functions into a single converter, have been shown to reduce the size and cost of renewable energy systems [10, 11]. The capacity to manage bidirectional power flows is a key feature of modern MPCs, specifically in applications involving energy storage systems. This proficiency is essential for balancing energy generation and consumption, primarily in systems that rely heavily on variable renewable energy sources [12]. These converters can effectively manage high-power applications while maintain the stable voltage levels across different systems component [13]. In electric vehicle (EV) systems, the implementation of Multiple Input Multiple Output (MIMO) DC-DC Converter has shown significant promise. These converters approve the simultaneous management of energy from different sources, like abroad batteries and external chargers, optimizing the charging process and increasing overall system efficiency [14]. The combination of hybrid modulation strategies in MPCs has lead to significant improvements in power balance control. These strategies establish that power is distributed evenly across different system components, enhancing the stability and operation of multiport converters in high-demand applications [15]. Many existing topologies face demanding in integrating various energy sources, particularly when each AC and DC outputs are required. Effectively handling bidirectional power flow between renewable energy sources, loads, and storage systems is crucial for dependable energy management. Tackling this issue requires the development of innovative control techniques and converter designs that incorporate advanced modulation strategies and cutting-edge converter technologies. It is reducing the switch count and component cost remains an ongoing challenge in MPC design [16, 20].

This paper proposes the growing demand for renewable energy solution has driven the development of efficient and cost-effective power conversion systems for standalone Photovoltaic (PV) applications. Traditional PV standalone systems rely on multiple power converters to manage energy flow between the solar panel, battery storage, and load, leading to increased system complexity, higher power losses, and reduced efficiency. To overcome these challenges, a novel Hybrid Multi-port Converter (HMPC) is introduced to integrate multiple energy sources and loads into a single, unified power conversion system.

The proposed HMPC topology allows seamless integration of PV panels, battery storage, and auxiliary power sources, such as fuels cells or wind energy systems, within a compact and efficient framework Unlike conventional converters, which require separate power stage for energy transfer, the HMPC consolidates these stages, reducing component count, power losses, and cost. Moreover, the systems supports bidirectional power flow, enabling effective energy management by prioritizing solar energy utilization, directing surplus power to the battery, and ensuring continuous power supply even during periods of low solar irradiation.

II. LITERATURE SURVEY

Techno-economic analysis and size optimization of an off-grid hybrid photovoltaic, fuel cell and diesel generator system in this paper introduces a hybrid renewable energy systems have attention for standalone applications, especially in remote and off-grid areas and this study by Jamshidi and Askarzadeh(2019).

Boost-integrated phase-shift full-bridge converter for three-port interface, in this paper introduces increasing the use of hybrid power systems combining multiple energy sources like photovoltaics ,batteries, and fuel cells and this study by H.Al-Atrash and I.Batarseh(2007).

III. PROPOSED TOPOLOGY AND CONTROL SCHEME

(A) Proposed Topology

Multiport Converters (MPCs) are relatively recent power converter structures, which bestow the merits such as the omission of redundant power stages, centralized control, compact packaging, enhanced efficiency, improved reliability, and so on and have larger potential in domestic applications. They have the ability to amalgamate energy sources such as photovoltaic (PV) sources and battery storage's, and can accommodate hybrid (ac and dc) domestic loads (bulbs, fans, induction stoves, and electric bike chargers). Hence, they can replace the conventional off-line uninterruptible power supplies, which are habitually used in domestic applications.

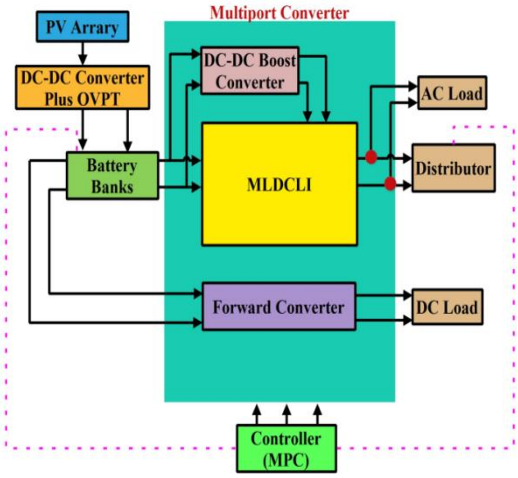


Fig. 1 Block diagram of proposed hybrid load MPC

The unique feature of MPCs is the ability to transfer the power between multiple sources and loads concurrently independently. This article proposes Cascaded Sources Switched Tapping Multilevel DC-Link Inverter (CSSTMLDCLI) involved hybrid loads MPC, which can integrate PV sources and feed above mentioned hybrid domestic loads. The involved novel Nine level multilevel inverter structure, the CSSTMLDCLI has reduced component count to offer a high quality ac output, while the dc output is synthesized by a forward converter structure.

A block diagram representing an off-grid solar power system tailored for a Nigerian household. The system utilizes solar energy to power both AC and DC loads. Here is a breakdown of the components and their functions: Solar Panel which converts sunlight into DC electricity. Proposed Nine-Level Inverter which transforms the DC power from the solar panel into AC power suitable for AC loads. Multi-level inverters are used to improve the quality of the AC output.AC Load represents devices or appliances that run on AC power. The flow of power and operation of the system was managed by control unit. Fly-back Converter which converts the DC power from the control unit to a different DC voltage level required by the DC load. DC Load represents devices or appliances that run on DC power.

The solar panel captures sunlight during operation and generates DC electricity. This DC power is then fed to a proposed nine-level inverter, which converts it into AC power for the AC load. Simultaneously, the control unit regulates the power flow and directs a portion of the DC power to a fly-back converter, which adjusts the voltage level for the DC load. This setup allows the system to power both AC and DC appliances independently, making it suitable for households with diverse energy needs. The design and implementation of such a system are crucial for providing electricity in areas with limited access to the main grid.

1.1 Nine-Level Inverter

A nine level inverter is a type of multilevel inverter that produces a stepped-wave output with a higher number of levels compared to a standard two-level inverter, resulting in a smoother AC waveform and reduced harmonic distortion.

1.2 Flyback Converter

Fly-back converters are DC-DC converters that provide voltage conversion and galvanic isolation, making them suitable for interfacing PV modules and batteries with different voltage levels.

IV. HARDWARE DETAILS

4.1.PIC Controller*:*

- Only 35 single-word instructions to learn
- All single-cycle instructions except for program branches, which are two-cycle
- Operating speed: DC – 20 MHz clock input DC – 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory, Up to 368 x 8 bytes of Data Memory (RAM), Up to 256 x 8 bytes of EEPROM Data Memory
- Pin out compatible to other 28-pin or 40/44-pin
- PIC16CXXX and PIC16FXXX microcontrollers

4.2. Crystal Oscillator

A Crystal Oscillator is an electronic circuit that generates an electrical signal with an exact frequency by harnessing the mechanical resonance of a vibrating piezoelectric crystal. It features automatic amplitude control and exhibits minimal frequency drift due to temperature variations. Crystal Oscillators are exclusively suitable for high-frequency applications.

Every microcontroller requires a crystal oscillator. When selecting one, consider purchasing a silicon oscillator if its accuracy is sufficient and the cost is reasonable; otherwise, opt for a quartz crystal.
Commonly used crystal oscillators include:
8MHz,11.0592MHz,12MHz,16MHz,20MHz, 32MHz
Additionally, a variety of crystal oscillators with different frequencies are available in the market for various applications.

4.3.REGULATOR

A regulated power supply is essential for every electronic device, as these devices rely on semiconductor materials that require a fixed voltage and current. Any deviation from these fixed values can lead to damage. Although batteries serve as primary sources of DC power, they are not suitable for prolonged use in sensitive electronic circuits due to their gradual loss of potential and eventual depletion. Batteries offer various voltage levels, such as 1.2V, 3.7V, 9V, and 12V. Since most integrated circuits operate with a 5V supply, a voltage regulator is necessary to ensure a stable 5V output. The 7805 voltage regulator, part of the 78XX series of linear voltage regulators, fulfills this requirement by providing a reliable 5V regulated output.4.3.1.7805

4.3.1. Voltage Regulator Circuit

The circuit diagram for the 7805 voltage regulator illustrates the process of generating a 5V regulated supply from AC mains. This circuit consists of a step-down transformer (230V-12V), a bridge rectifier, a 1A fuse, a 1000µF capacitor, an IC 7805 voltage regulator, capacitors (0.22µF and 0.1µF),and a diode (1N4007).

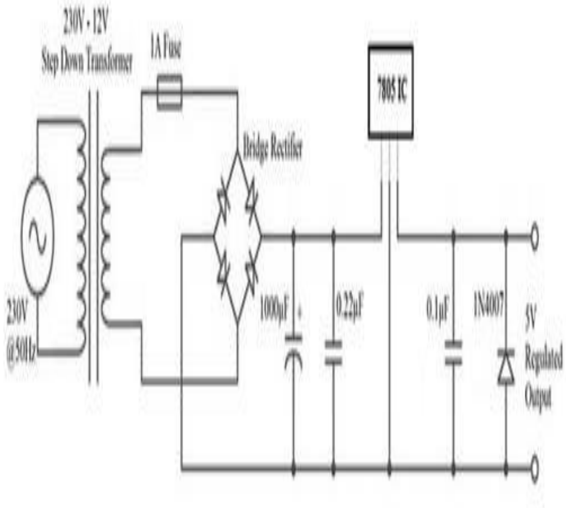


Fig.2. 7805 Voltage Regulator Circuit

4.3.2.IC 7805 Voltage Regulator Working

In the circuit described, AC power is converted into DC. It includes components such as a transformer, a bridge rectifier, an IC 7805 linear voltage regulator, and capacitors. The circuit is divided into two sections: in the first section, the AC mains are converted to DC, and in the second section, this DC is regulated into a 5V DC output.

Initially, a step-down transformer reduces the voltage from 230V to 12V by connecting its primary winding to the mains supply, while its secondary winding connects to the bridge rectifier. A 1A fuse is placed between the bridge rectifier and the transformer to prevent excess current flow in the circuit.

The bridge rectifier produces rectified DC, which is then smoothed by a 1000µF capacitor. The output of this capacitor is a 12V unregulated DC, which serves as input to the IC 7805 voltage regulator. The voltage regulator then converts this unregulated DC into a stable 5V DC output, available at the output terminals.

Ensuring that the input voltage exceeds the output voltage is crucial. The input and output currents remain approximately the same. For instance, when a 7.5V 1A supply is provided at the input, the output will be 5V 1A. The excess power is dissipated as heat through the 7805 IC.

4.4.Capacitors

The term "capacity" signifies the ability to contain something, which aligns perfectly with the purpose of a capacitor—to store electric charge.

A basic capacitor consists of two conductive plates separated by a dielectric medium, an insulating material that can be polarized, forming positive and negative charges on opposite surfaces. When voltage is applied to the plates, current flows through them, causing one plate to accumulate a positive charge (electron deficiency) and the other a negative charge (electron surplus). Since opposite charges attract, the charges on the plates exert a mutual force of attraction.

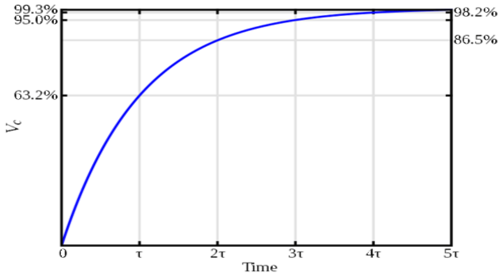
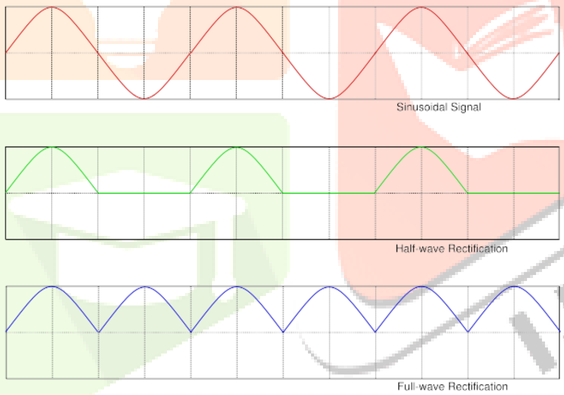


Fig.3. From the graph you can see that the capacitor reaches 63% of the applied voltage in one time constant.

4.5.RECTIFIER:

A rectifier is an electrical device that converts alternating current to direct current or at least to current with only positive value, a process known as rectification. Rectifiers are used as components of power supplies and as detectors of radio signals.



V. RESULT AND DISCUSSION

The figure.2 shows a simulation diagram of nine level inverter.The proposed Multiport Converter (MPC) represents a significant advancement in power conversion technology by integrating both AC and DC outputs with a streamlined, reduced-component architecture. This novel design addresses several key limitations of traditional converters, by employing a more efficient and compact structure, the MPC not only lowers system complexity and cost but also enhances performance with faster response times and reduced harmonic distortion. The simplified control strategy minimizes the need for extensive filtering, addressing common issues found in conventional designs.

The figure.3 shows a output result for nine level inverter which have stepped wave output with nine level.

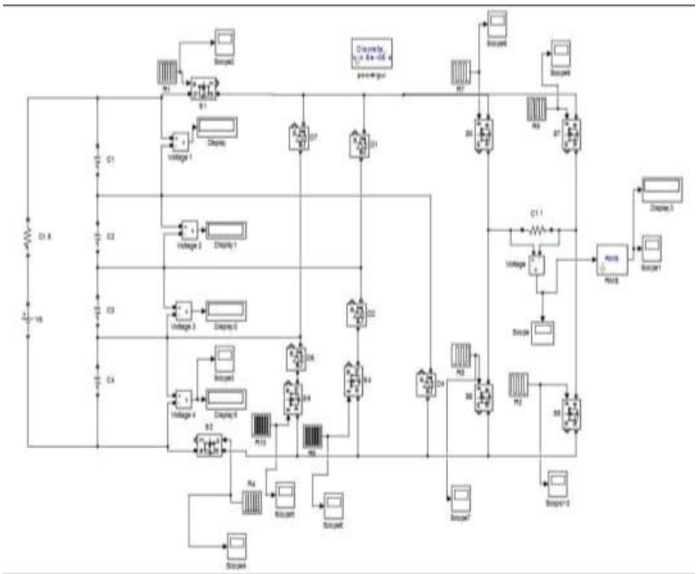


Fig.2 Simulation for a nine level inverter

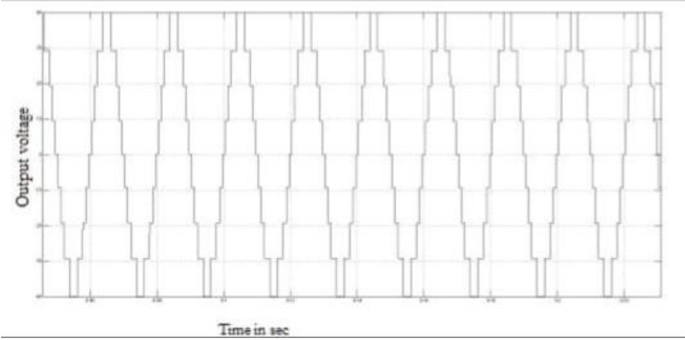


Fig.3 Simulation output for nine level inverter

VI. CONCLUSION

The hybrid output multiport converter (HOMC) for standalone loads and photovoltaic (PV) array integration provides a reliable and efficient power management solution. By integrating multiple input and output ports, the converter optimizes energy utilization, supports seamless renewable energy integration, and ensures consistent power delivery to standalone loads.

The main advantages of this converter include high efficiency, bidirectional power flow, adaptive power management, and compact design. Leveraging advanced control techniques such as MPPT, intelligent energy distribution, and AI-driven optimization, the system adapts dynamically to changing solar input conditions, ensuring stable and dependable power delivery.

Additionally, the HMPC is highly suitable for off-grid and remote applications, where maintaining a steady power supply is essential. Its ability to efficiently manage energy storage and load distribution makes it a scalable and cost-effective option for modern renewable energy systems.

In conclusion, this innovative hybrid converter design enhances standalone PV system performance by improving energy utilization, enabling precise power control, and ensuring long-term sustainability, making it a promising choice for future smart energy solutions.

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