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Multi-Port DC-DC Converter for Grid Integration of Photo Voltaic Systems through Storage Systems with High Step-Up Ratio

CH.Rekha
M.Tech (Energy Systems),
Dept of EEE,
JBIET-Hyderabad.

M.Vinod Kumar
Assistant Professor,
Dept of EEE,
JBIET-Hyderabad.

R.Suresh Babu
Associate Professor& HOD
Department of EEE,
JBIET-Hyderabad.

Abstract:

A multi-port dc–dc converter integrating photovoltaic, wind and battery power for high step-up applications is proposed in this paper. The proposed converter has charge controller which increases the system efficiency by controlling the power management between the PV, wind and grid. The multi-port converter which enables the interconnection multiple number of power sources at-a-time time to grid with storage capability. The voltage gain ratio of the DC-DC converter is high when compared with conventional dc-dc converters. The MMPT control strategy proposed which helps to extract maximum power from renewable sources like wind and PV systems. A dc-link capacitor connected between wind, PV and battery makes the voltage balance in the network to supply constant voltage to power system. The performances of the proposed DC-DC converter are verified by MATLAB/Simulink software and are described in simulation results section.

I. INTRODUCTION:

In recent years the falling cost of solar energy systems has sparked increasing interest in developing renewable methods for rural electrification. Individual solar home systems can be formed in rural areas and can be interconnected to form a DC microgrid or can be in standalone mode. Those who have no solar home systems can access this grid for their basic needs. In standalone photovoltaic systems, to deliver continuous and reliable power to the consumers, storage devices with backup power are required. Usually the source, storage and load are being interconnected via three separate DC-DC converters. They have certain disadvantages like requirement of more number of conversion devices, complex design and requirement of communication capabilities. In order to overcome these shortages, multiport topologies are introduced. Integrated multiport converters, instead of several independent converters have advantages such as less component count and conversion stage because resources like switching devices and storage elements are shared in each switching period. They feature reduced size, compact design, centralized control, single power conversion stage, improved power density and fast and simple power flow management. Multiport converters can be realized using isolated, non-isolated or partially isolated topologies.

There are numerous isolated DC–DC converter topologies proposed in the literature. They are attaining the high voltage gain by adjusting the turn's ratio of the high-frequency transformer [4]. It is also significant to notice that solar home systems are compact in nature. In applications where galvanic isolation is not a must, non-isolated DC–DC converters can be used to achieve voltage step-up or step-down, with consequent reduction of size, weight and volume associated to the increase of efficiency because of the lack of a high-frequency transformer. The conventional non-isolated boost converter is the most popular topology for this purpose, although the conversion efficiency is limited at high duty cycle values. Numerous publications are there in literature, focusing on DCDC converter derived topologies to overcome such limitation and to improve the conversion ratio.

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Considering the main limitations of the classical boost converter, several works have been proposed to improve key issues, such as the static gain, voltage stress across the semiconductors, efficiency, power capacity and many other aspects of the original topology. Coupled inductors are an alternative to increase the static gain in DC–DC converters by properly adjusting the turn's ratio. They are realized by replacing the controlled switch of single switch boost converter with a voltage source inverter network. This type of converters require less number of switches to handle AC and DC loads with more reliability and better power density.

II. Three-Port DC-DC converter:

The proposed converter topology is illustrated in Fig. 1. The main switches S1 and S2 transfer the energy from the PV to the battery or load, and can work in either interleaved or synchronous mode. The switches S3 and S4 are operated in the interleaved mode to transfer energy from source to load. L1 and L2 are two coupled inductors whose primary winding (n1) is employed as a filter and the secondary windings (n2) are connected in series to achieve a high output voltage gain. LLK is the leakage inductance of the two coupled inductors and N is the turns ratio from n2/n1. CS1, CS2, CS3 and CS4 are the parasitic capacitors of the main switches S1, S2, S3 and S4, respectively.

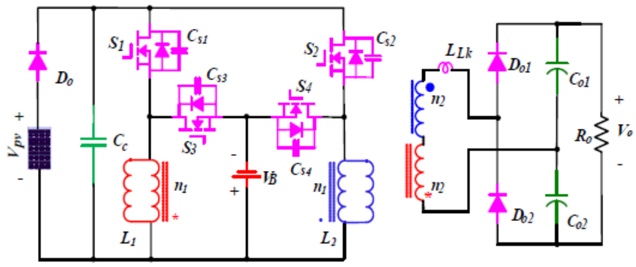


Fig 1:Three-port DC/DC converter

There are three operational modes for the converter, as illustrated in Fig. 2. In mode 1, the PV array supplies power to load and possibly also to the battery, corresponding to the daytime operation of the PV system.

Two 180° out-of-phase gate signals with the same duty ratio (D) are applied to S1 and S2 while S3 and S4 remain in a synchronous rectification state.

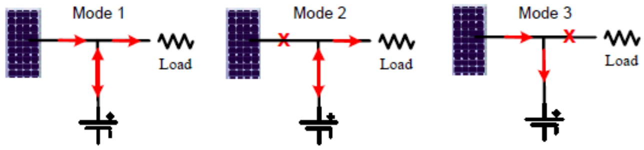


Fig 2: Operating Modes

In mode 2, the battery supplies power to the load, indicating the nighttime operation of the stand-alone system. The circuit works as the Flyback-Forward converter, where S3 and S4 are the main switches, Cc, S1 and S2 form an active clamp circuit. When the load is disconnected, the stand-alone system enters into mode 3. The PV array charges battery without energy transferred to the load due to the opposite series connected structure of the coupled inductor. S1 and S2 work simultaneously and the topology is equivalent to two paralleled Buck-Boost converters.

Control Strategy:

In mode 1, S1 and S3 complementarily conduct, and the on/off operation of S2 and S4 is complementary. When the output power of the PV array is lower than the load power, the battery should supply the difference. The primary side of the proposed converter is equivalent to a bidirectional Buck-Boost converter, while the secondary side is a Buck converter in discontinuous conduction mode. The output voltage can be controlled by PS on the primary side bridge arm, which can be approximated to adjust the duty cycle of Buck converter of secondary side to realize output voltage regulation. The control block diagram of the proposed control scheme is further illustrated in Fig. 3. The maximum power point tracking (MPPT) can be implemented by adjusting the duty cycle of switching devices. In the MPPT loop, the PV voltage is regulated to follow an optimal operating point, which is initially assigned to 80% of the open-circuit voltage of the PV array. This point can be determined by the outer MPP Tracker, as previously reported.

Moreover, the PV voltage regulation loop is used to improve the MPPT performance. In the output voltage control loop shown in Fig. 3, the phase angle of the modulation carrier is the control variable, which regulates the output voltage to follow the expected voltage. Because of the block diode in the PV input, mode 1 can be switched to mode 2 by changing D≥0.5 to D<0.5. Likewise, the modes can be switched from 1 to 3 by controlling the phase shift angle between S1 and S2. These transitions are smoothly achieved by the proposed control method.

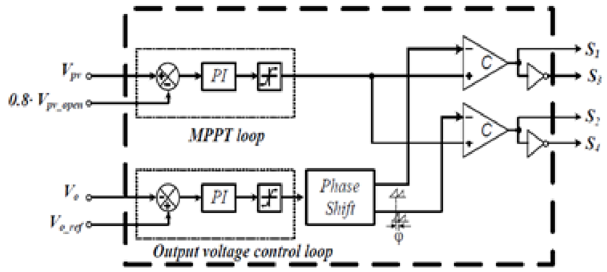
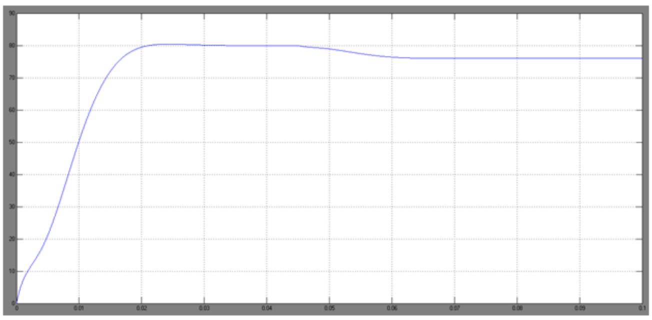


Fig 3: Diagram of the proposed control scheme Simulation Analysis

The PV voltage is regulated to 12.8 V, which represents the MPP. The output voltage is controlled at 80 V as expected. At 45ms, the load resistance is suddenly reduced from 100 Ω to 40 Ω (perturbation); the output voltage drops to 73 V, and recovers to 80 V after 15ms adjustment, as presented. It is also seen in that the PV array voltage recovers to the MPP voltage after 1ms adjustment when subjected to an input power step change from 500 W/m2to 1000 W/m2 (perturbation) at 40ms.



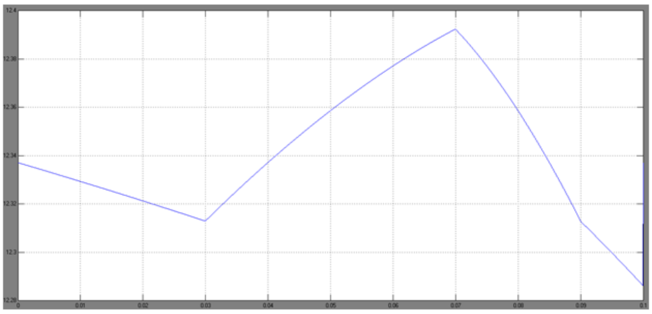


Fig 4: Converter analysis under load variation (Load voltage and PV voltage)

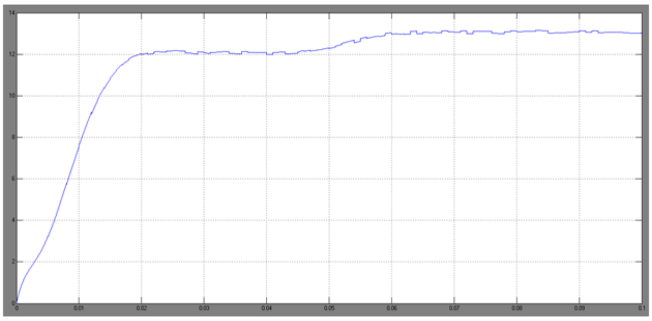


Fig 5: analysis under source power increment

III. Multi-Port DC-DC converter:

The Multiport dc/dc converter for household applications is shown in Fig. 6, which can work either in stand-alone or in grid-connected modes. This system is suitable for household applications, where a low cost, simple and compact topology capable of autonomous operation is desirable. The core of the proposed system is the multi-input transformer-coupled bidirectional dc–dc converter that interconnects various power sources and the storage element. Furthermore, a control scheme for effective power flow management to provide uninterrupted power supply to the loads while injecting excess power into the grid is proposed. Thus, the proposed configuration and control scheme provide an elegant integration of PV and wind energy source. It has the following advantages.

1) The maximum power point (MPP) tracking of both the sources, battery charging control, and bidirectional power flow is accomplished with controllable switches.

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2) The voltage boosting capability is accomplished by connecting PV and battery in series.

3) The improved utilization factor of the power converter, since the use of dedicated converters for ensuring MPP operation of both the sources is eliminated.

4) The proposed controller can operate in different modes of a grid-connected scheme, ensuring proper operating mode selection and smooth transition between different possible operating modes.

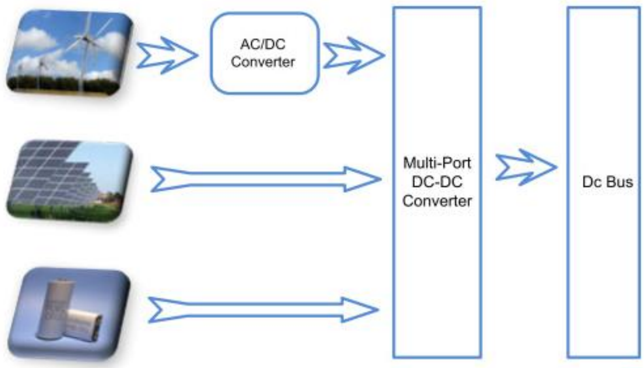

Fig 6: Block diagram of multiport dc/dc converter

Simulation analysis

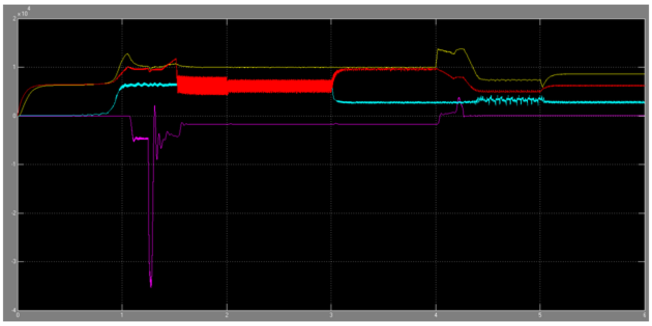

Fig 7: Simulation results for total powers

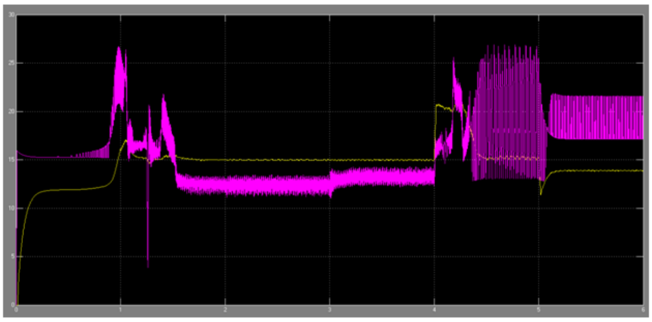

Fig 8: Inverter output and input currents

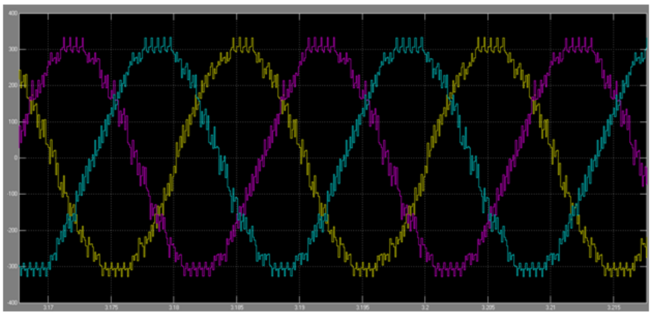

Fig 9: Output voltage of inverter

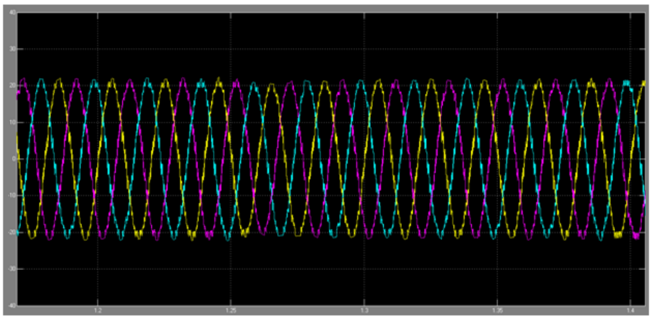

Fig 10: Output current of inverter

IV. CONCLUSION:

This standalone hybrid topology shows excellent performance under varying load power requirement, solar irradiation and wind speeds where solar irradiation and wind speed data are based on real world records. The converter can provide a high step-up capability for power conversion systems including the PV array, the battery storage, and the isolated load consumption. A novel hybrid PV-wind renewable power generation system with appropriate power management algorithm has been designed and modeled in this paper for standalone island uses in the absence of electric power grid. The power available from green energy sources is highly dependent on weather conditions such as solar irradiations and wind speed. In this paper, a PV system integrated with a wind turbine and battery bank using a novel topology to overcome this deficiency. Three operating modes are analyzed and have shown the effective operation of the proposed topology for PV applications.

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