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SOLAR PV BASED HIGH GAIN DC-DC BOOST CONVERTER FOR GRID TIED INVERTER SYSTEM

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ABSTRACT-
Adding photovoltaic (PV) energy sources to a DC Microgrid can be complicated and costly. The PV-module's output does not match the high voltage DC bus to which it is attached so PV-modules must be connected in a series string fashion in order to reach the required level. This means all PV-modules .must be identical in electrical characteristics, must be connected in identical string lengths, be oriented in the same direction and are subject to complete string failure if PV-modules within the series strings fails. A high gain DC-DC Boost Converter that can output a voltage that matches the bus allows each PV-module to be an independent contributor, regardless of its technology or electrical characteristics, and to be connected in parallel so that now each PV-module is an independent power generator. This paper describes the DC-DC converter, the advantages of the parallel connectivity and some of the other benefits attainable with PV-module level electronics as PV is integrated into microgrids.In order to make them to use we have to step up these levels to grid voltage level. The boost converters, first of all stepped up voltage to sufficient level at which inversion of DC to AC can be performed. The PV side HGICB Converter is controlled by P&O MPPT algorithm to extract the maximum power from the variable solar irradiation. if any, at the point of common coupling (PCC), thus enabling the grid to supply only sinusoidal current at unity power factor. The battery energy storage system (BESS) is regulated to balance the power between PV generation and utility grid.

Key words-PV Energy Conversion System, High Gain Integrated Cascaded Boost DC-DC Converter,DC-DC Converter; Renewable Energy; Microgrid; PV; Boost Converter; Battery; Parallel PV; DC Bus; Storage.

I. INTRODUCTION

Global energy consumption tends to grow continuously. To satisfy the demand for electric power against a background of the depletion of conventional, fossil resources the renewable energy sources are becoming more popular. According to the researches despite its fluctuating nature and weather dependency the capacity of renewable resources can satisfy overall global demand for energy. The international investments and R&D efforts are focused on reduction of Renewable energy production cost. The conversion of the distributed energy sources like wind energy, fuel cell and photovoltaic's into the useful energy such as ac or dc power source increasing day by day in order to meet out the global energy requirement[1-3]. Earlier the environmental issues have accelerated the use of more efficient and energy saving technologies in renewable energy systems, here comes the importance of DC-DC converters. In the recent years, the high step up dc-dc converters are playing a vital role in DC-back up energy system for UPS, grid system, high intensity discharge lamp and automobile applications also. In many applications, high-efficiency, high-voltage step-up dc–dc converters are required as an interface between the available low voltage sources and he output loads, which are operated at much higher voltages [4-5]. In order to provide high output voltage, the classical boost converters are used, but these should operate at extreme duty cycle. The conventional boost converter can be advantageous for step-up applications that do not demand very high voltage gain, mainly due to the resulting low conduction loss and design simplicity. Too low to be able to connect to the load in standalone application or to the grid [6-7]. This urges the need for a high step up converter to boost the low voltage to very higher level.Architecture of a solar micro-grid where there is a need of high voltage gain considering the cost, size and efficiency non-isolated transformer less converters is preferred.

Simple boost converters are the conventional and simple topology among non-isolated systems with continuous input current. But to achieve high voltage [8] gain duty cycle approaches unity causing poor dynamic responses to line and load variations. Consequently efficiency decreases drastically. Also the voltage stress across the switch is very high since the output voltage will come directly across the switch [9-10]. Later various boost converters have been cascaded and is found that high voltage gain is obtained but the efficiency becomes the product of each added boost converters. Also it becomes complex and difficult to regulate the output voltage due to multiple switches [11-12].

II. PARALLEL PV

First, Initially, PV was deployed with the PV-modules connected in a parallel mode, operating at 12-20Vdc, and under the control of an MPPT charge controller which transferred the power to the battery pack, typically lead acid. This in turn either directly fed a low voltage load or an off-grid inverter. This system worked well unless the PV was some distance from the battery pack/inverter where I2R losses had a large, negative effect on production. Then, as PV gained popularity and feed-in tariffs or net metering took effect, it became important to connect to the electrical grid for bidirectional power flow, using the grid for power when needed or selling the PV power when it was not utilized by the system owner. This drove the need for higher capacity systems, but which increased the current for a parallel connected installation. However, PV-modules, like batteries, can be series string connected to increase their output voltage and keep the line current to a minimum. The inverter now took over the role of charge controller, but at a higher voltage, since it was connected to the grid. The magnitude of the series string voltage is limited to the National Electrical Code limit of 600Vdc for residential and commercial applications (1,000Vdc for “behind the fence”, or utility type installations) which bookends the amount of power that can be transported over #10AWG wiring.

The advantages of the series string connected PV are offset by the inherent weaknesses of such an arrangement. Series strings are subject to the “Christmas tree lights” effect, whereby if one light, or PV module, faults then the whole string faults. But, it isn’t just catastrophic faults that are of concern. Any effect that reduces current in one PV-module affects the current for that series string and subsequently that string’s total power. Economic returns are calculated over long time frames, typically 20-25 years and PV-module power degradation must be accounted for in the financial analysis. With a series string, the weakest power producing PV-module sets the operation of the entire string. This degradation and mismatch of PV modules has a number of different sources. PV-modules, even those with very tight manufacturing tolerances, will have different rates and modes of degradation when deployed in the field, and this effect increases as the installation ages. Mismatch can also occur because of soiling, temperature gradations, and shading due to obstructions, manufacturing defects, damage and weather. So, a mismatch or defect in a single PV-module can affect the string's other 12-15 PV-modules' power production. In series string configurations, the strings are aggregated in a combiner box whose output is to the inverter. The inverter must interpret the power of the array and perform a global MPPT operation. While this is acceptable where there is no mismatch, in reality power is lost by operating at a mean value, rather than each operating at an optimal value.

Parallel PV is an alternative to the series string, but in order to provide the required input voltage for the inverter, the PV-module itself must output that voltage. Since the PV-module is comprised of individual photovoltaic cells of approximately 0.6V each, it would require over 600 such cells to achieve a 380Vdc output. Boosting the PV-module's output voltage became the subject of investigation and, in 2007 the company developed a boost DC-DC converter that accepted a range of PV-module outputs and converted their low voltage/high current power to a high voltage/low current output. This converter can transfer the power to a high voltage DC (HVDC) bus and aggregate the current, not stack the voltages.

A. HIGH GAIN BOOST DC-DC CONVERTER

The Converter is a high gain, DC-DC boost converter that converts the low voltage/high current output of a PV-module and outputs the power as high voltage/low current. The immediate benefit .is that the Converter equipped PV-module can be connected in parallel with other such equipped PV-modules and can directly feed a high voltage DC (HVDC) bus on which other sources and loads can be attached. The PV-module now becomes an independent power generator, unaffected by other PV-modules attached to the same bus.

Boosting a PV-module's output to >350Vdc has a number of challenges. The output voltage of the PV-module is dependent on the technology and number of cells, and can vary between 15Vdc and 120Vdc for commercially used PV-modules, so, an efficient, high gain boost circuit is required. The PV-module's power output is dependent on its operation at its maximum power point, which varies with voltage, which in turn varies with irradiance and cell temperature, so the converter front end must perform impedance matching with the source in order to achieve Maximum Power Point Tracking (MPPT). The boost converter must operate at greater than 95% efficiency or it is not economically feasible.

The Converter employs a tapped inductor topology to achieve a high gain boost, unattainable with a traditional boost circuit. The gain for a traditional fly back boost converter is given by:

$$Vo/Vin = 1/(1-D) \tag{1}$$

However, this gain is limited by the duty cycle, which as it approaches unity, degrades the efficiency, rendering it unusable for maximum energy harvesting. The tapped inductor topology was chosen because the gain is high at a reduced duty cycle, as can be seen in the gain equation below:

$$Vo/Vin = 1 + D/n(1-D) \tag{2}$$

Where n=turns ratio of the primary and secondary windings.

The MPPT function is performed with a two-stage algorithm. A basic Perturb and Observe (P&O) is performed to initiate the MPPT operating point. Then, a windowing algorithm performs minute adjustments as slow moving temperature or irradiance changes are experienced. If a fast transient forces the MPPT outside of this window, the system performs a P&O to determine the new window range. An

MPPT efficiency of 99.9% across the Converter's operating range has been achieved with this method. The output capacitance of the converter behaves as a distributed capacitance to the inverter and helps isolate the MPPT function from the both.

Efficiency of conversion is critical to the economics of the solution, and in order to achieve a flat efficiency curve across the full power range of the PV-module, a dual phase switching network is employed, with the phases 180° apart. Each phase switches at 50 kHz, giving an effective 100 kHz switching frequency for the filter elements. The flyback is operated in Discontinuous Conduction Mode (DCM) and its operation is similar to the traditional boost with minor modifications to the filter elements.

The Converter achieves a CEC rated efficiency of 97.9% with a peak efficiency of 98.3% the graph below shows the efficiency curves for a range of PV-module output voltages and across the full power spectrum.

Both input and output voltage and current are measured and digitized for the MPPT function as well as Over Current Protection (OVP), Over Voltage Protection (OVP), and PV-module level data collection. The converter's free-wheeling diode also performs an OR'ing function to the bus to prevent back feed of the bus voltage into the PV-module.

The resulting topology enables the Converter to self-level to the required bus voltage without the need for an external controller or command center. The load is operated at a fixed, constant voltage and each Converter provides sufficient gain to present that voltage to the load, self-compensating for any IR drops experienced in the transmission wires or connectors between the Converters and the load.

In this configuration, the Converter acts as a current source and hence, multiple converters can be present on the same bus without interaction with each other. This also means that the power source, the PV-module, for each converter is independent of the bus and its neighboring converters, so PV-modules of differing technologies, power and other characteristics can be placed on the bus. A block diagram of the Converter is presented below.

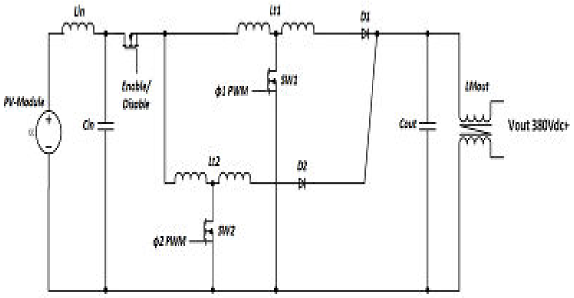


Fig.1: DC-DC Converter

The Converter employs an optional Power Line Communications circuit with CANBUS protocol that can transmit and receive data. This is used to receive control functions such as enable and disable, as well as to transmit power and energy harvesting data to a central collection point. Transformer less inverters that cannot modify their input voltages without additional buck-boost circuitry.

III. INTEGRATING BATTERY STORAGE

A microgrid can have multiple energy sources and multiple loads operating on the same bus and this can create challenges, especially when some of these sources are variable, renewable energy sources such as solar and wind. Instability of source power causes system wide disruption unless mechanisms are in place to provide backup power and stabilize the delivery. Additionally, variable loads that are coming on and off line create fluctuations in the bus that have to be smoothed. Battery storage helps provide such stability and back-up power, and helps smooth bus voltage variations.

However, in many respects, battery banks are analogous to the PV-module, except now the power flow is bidirectional. A typical LiIon-based chemistry battery pack of 1.5kWh to 2.5kWh, operates at 48-50Vdc and at currents that can approach 100A, depending on the charge/discharge operations. In order to reach the 380Vdc bus voltage, the batteries are typically series connected until that voltage is attained. This quantizes the battery pack into large sized capacities of 15-20kWh. In addition to the larger energy resolution, there are challenges with charging and discharging such series connected batteries, including cell balancing, cell monitoring, battery replacement and power control.

Ideally, individual battery packs could be bus connected if their operating voltage is sufficiently high. Boosting the voltage of each battery pack now offers some of the same benefits as a vBoost equipped PV-module. Each battery pack is now independent of any other battery pack and can be added or removed with minimal effect on the overall power distribution. The individual battery pack can be more easily controlled, monitored and operated.

However, as stated above, the battery has bidirectional power flow and needs to receive its recharge power from the same bus that it provides power to. Since the bus voltage is 380Vdc, a buck DC-DC converter is needed to down convert to the battery pack's 48Vdc and at currents up to 100A.

The buck and boost operation can be performed with either a bidirectional DC-DC converter, or with discrete buck and boost converters. Bidirectional DC-DC converters offer smaller size and operational ease, however at a potentially lower round trip efficiency. Also, the buck converter should have an isolated topology to prevent battery direct connection to the high bus voltage. Discrete buck and boost converters offer control flexibility, but with added complexity and cost. Communications between converters, the battery's Battery Management System (BMS) and overall system controller is essential to coordinate the charge/discharge functionality and synchronize the overall power distribution and delivery.

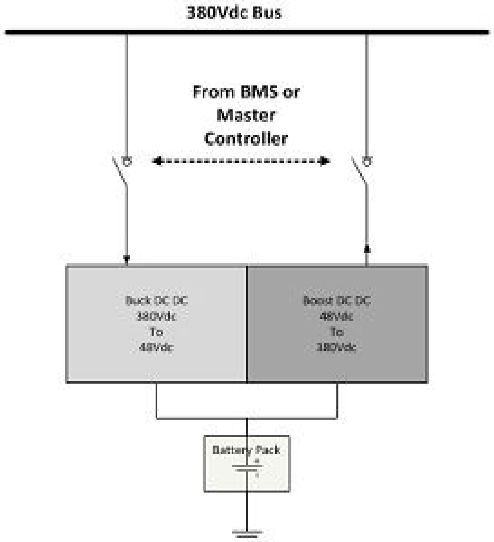


Fig.2: Bidirectional DC-DC 380Vdc/48Vdc for Battery Pack Charging/Discharging

Challenges exist in the development of such a system. In many cases, the battery is the source of bus voltage stability and this bus voltage control is lost during the charging process. Complex charge/discharge algorithms or controllers will be necessary to maintain bus stability and direct the power flow between disparate sources and variable loads. This higher control level is also necessary where multiple microgrids, or DC buses, are tied together and current flow is controlled by imposing voltage drops between the buses.

Continued development is needed to provide optimum solutions for a diverse range of scenarios. This method offers the advantage of small unit sized battery packs, typically 1.5-2.5 kWh that can be nuilt up as necessary. This is also advantageous when maintaining or replacing batteries, removing just the necessary pack, not bringing down the whole bank for maintenance.

IV. INTEGRATION INTO MICROGRIDS

Integrating renewable energy and storage into a DC microgrid should be made as easy as possible. Today, it is made difficult due to the complexities of connecting PV-modules and battery cells in series in order to reach the bus operating voltage. Using a high gain DC-DC boost converter like the one described herein, alleviates a considerable amount of those complexities and also provides additional operations and maintenance tools to ensure that the components are performing optimally.

There are however, continued challenges. The PV is a non dispatchable energy source and therefore only as good as the atmospheric conditions prevalent at the moment. Complex algorithms are needed for high reliance on renewable energy to ensure that sufficient storage backup is maintained to avoid blackouts. The ability to predict availability and match it to usage will become increasingly important as renewables become more integrated into the microgrid.

DC Microgrids are significantly easier than their AC counterparts but still not without their integration challenges. The control of the bus voltage, its regulation and its tie-in with other microgrids needs to be fully addressed.

DC Microgrids that are not tied to a grid will increase in adoption, especially in developing nations where extension of an existing grid will be prohibitively expensive. In many case, the microgrid will be the only viable option for rural electrification, so it is equally important that design and construction of such microgrids be done by the labor force at hand, which in most cases, will be unfamiliar with current electricity supply design and construction.

As DC Microgrids make inroads into urban areas, real estate that can be dedicated to renewable energy will be harder to find. Technologies such as Building Integrated PV (BIPV) with includes windows, facades, parking structures and rooftops will be increasingly important and so a cost effective method of design and construction is imperative.

V. MATLAB/SIMULINK RESULTS

Case: 1Battery discharging case

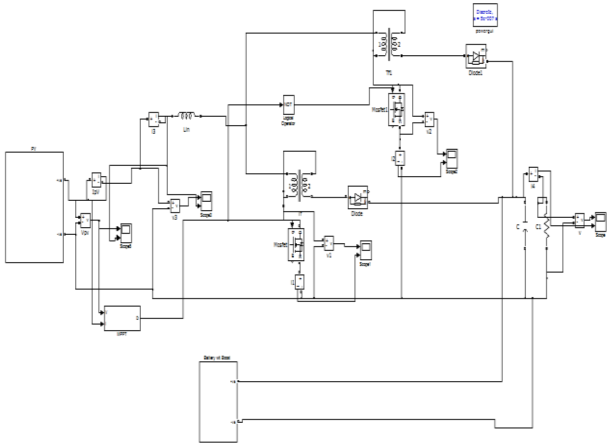


Fig.3 MATLAB/SIMULINK circuit for battery discharging condition

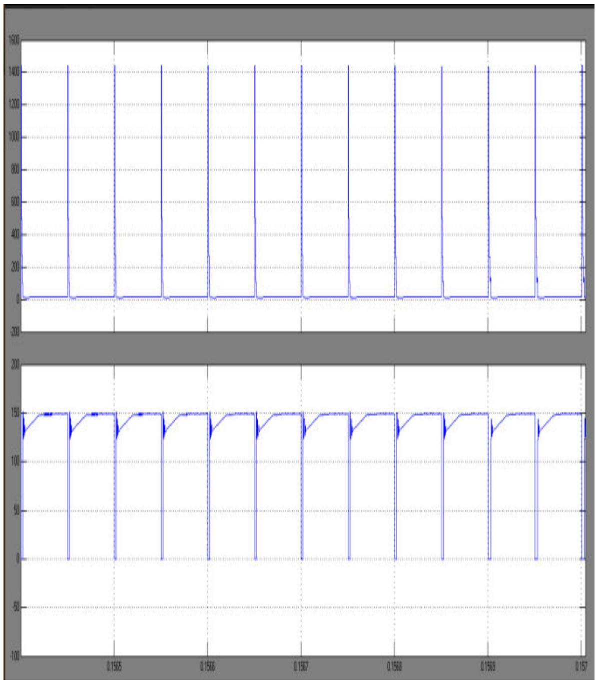


Fig.4 Voltage across the switch S1 Voltage and current

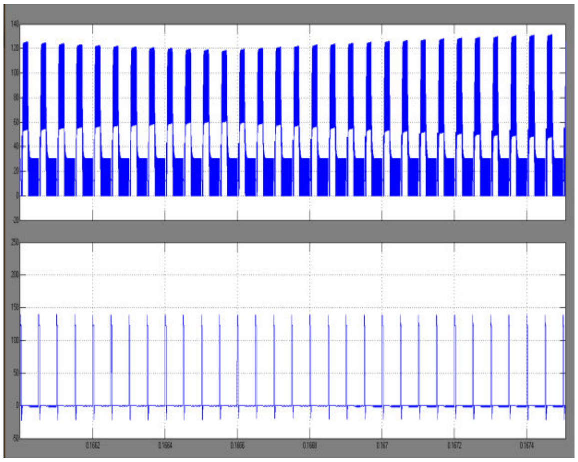


Fig.5 Voltage across the switch S2 Voltage and current

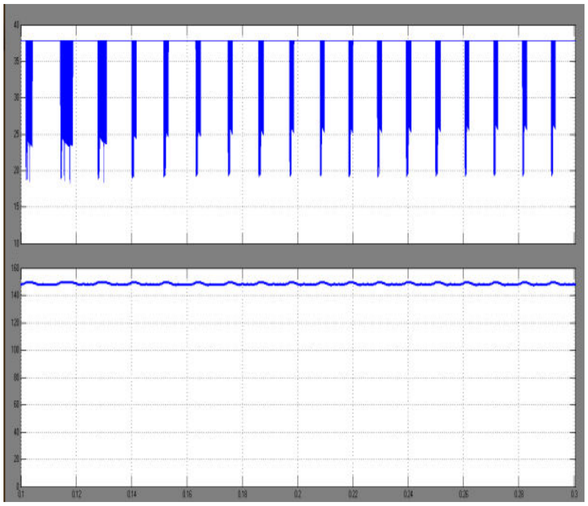


Fig.6.PV voltage and current

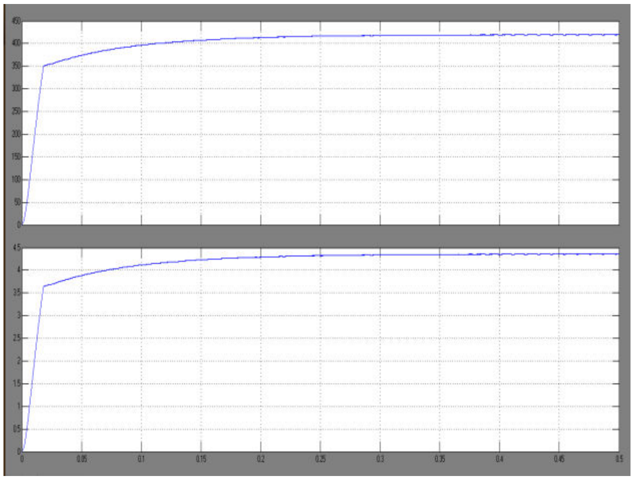


Fig.7.Output voltage and current

Case: 2Battery charging case

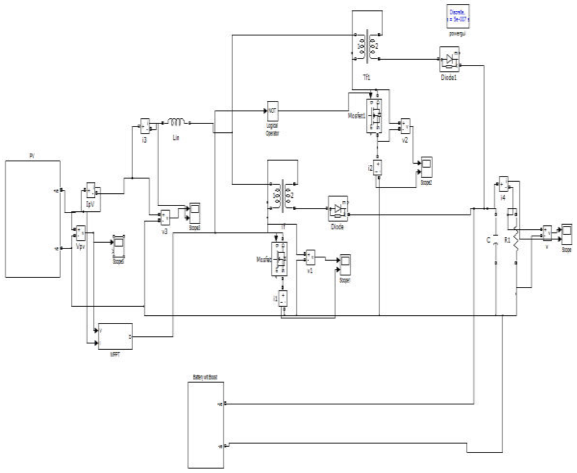


Fig.8 MATLAB/SIMULINK circuit for battery charging condition

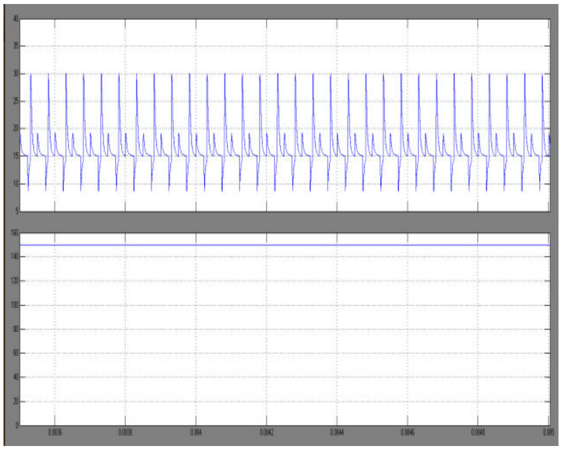


Fig.9 PV Voltage and Current.

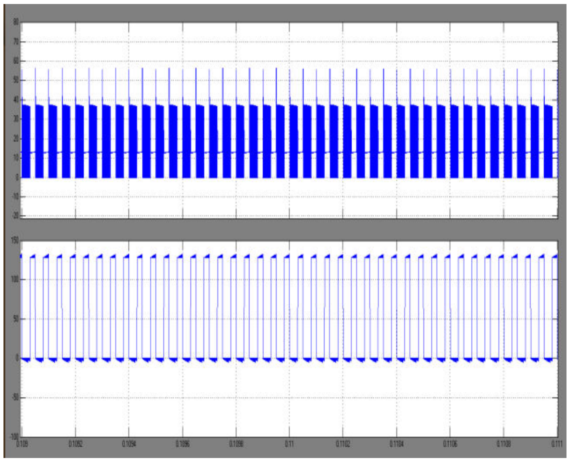


Fig.10 Voltage across the switch S1 Voltage and Current.

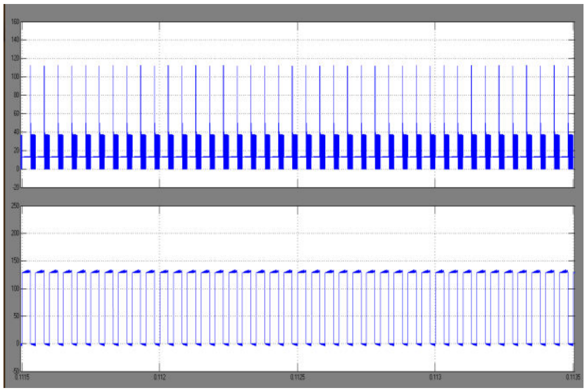


Fig.11Voltage across the switch S2 Voltage and current.

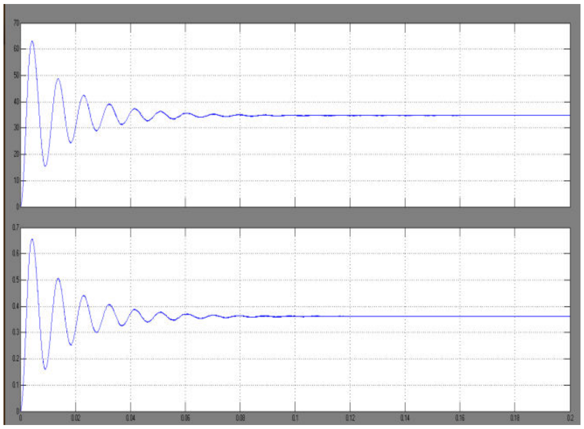


Fig.12 Output voltage and current

Case:3 Conventional model

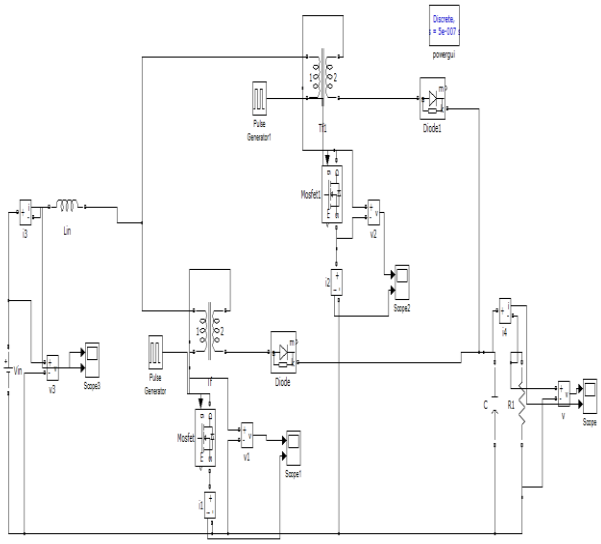
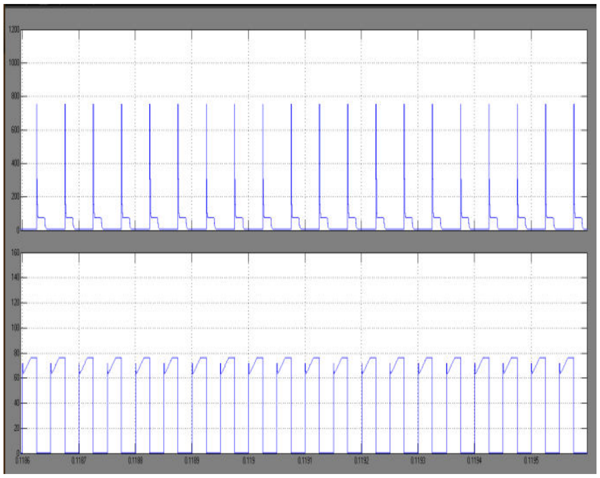


Fig.13 MATLAB/SIMULINK circuit for conventional model



Fi.14 Voltage across the switch S1 Voltage and current

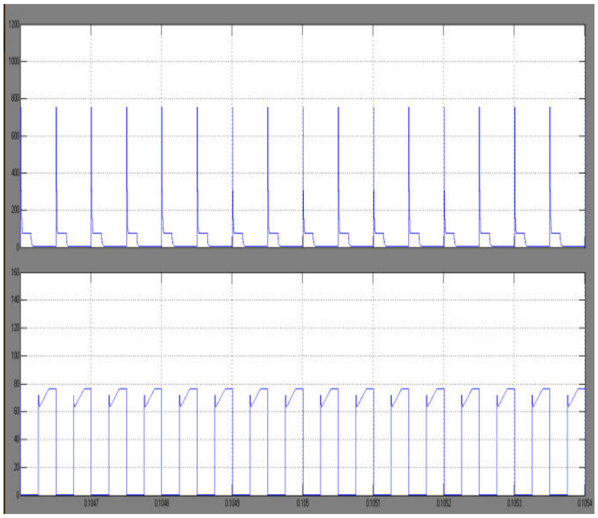


Fig.15 Voltage across the switch S2 Voltage and current

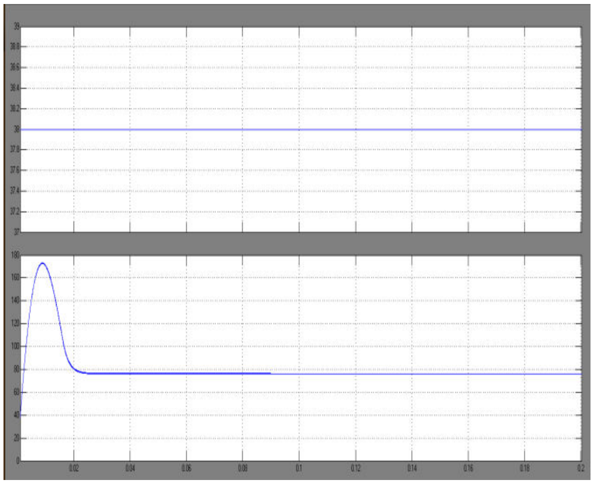


Fig.16 PV voltage and current

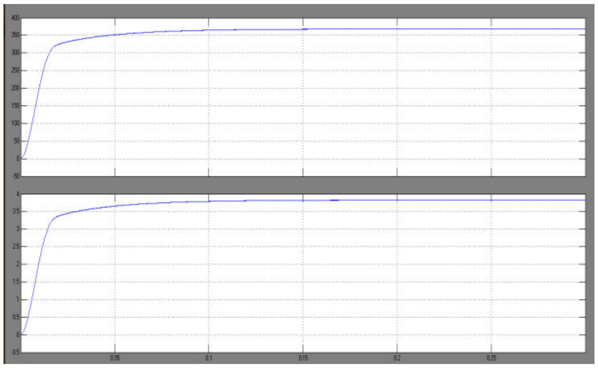


Fig.17 Output voltage and current

Case:3Proposed model

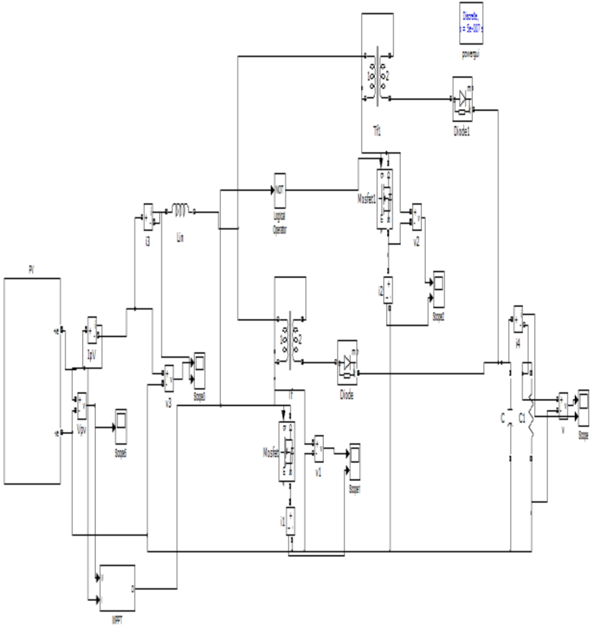


Fig.18 MATLAB/SIMULINK circuit for proposed model

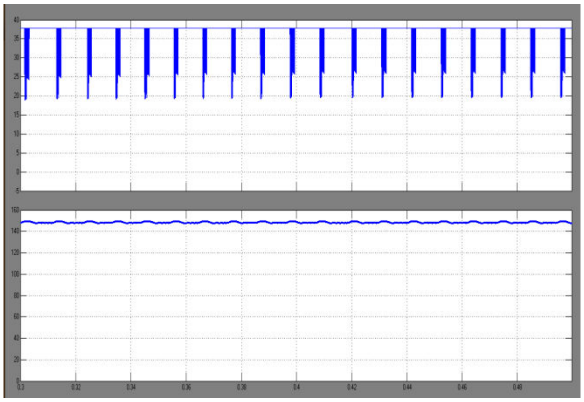


Fig.19 PV voltage and current

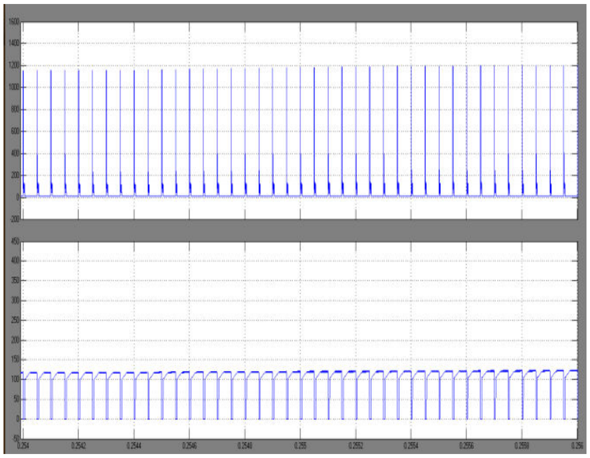


Fig.20 Voltage across the switch S1 Voltage and current

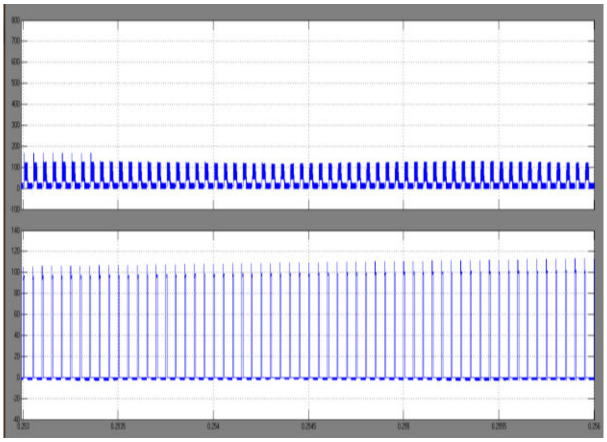


Fig.21 Voltage across the switch S2 Voltage and current

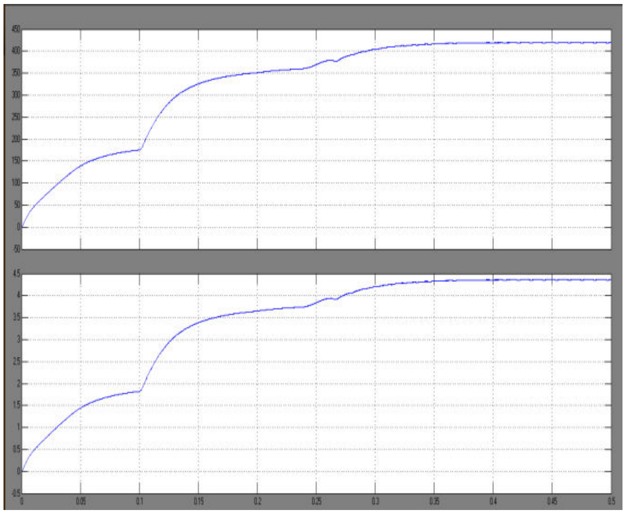


Fig.22 Output voltage and current

Case 4 Grid connected multilevel inverter

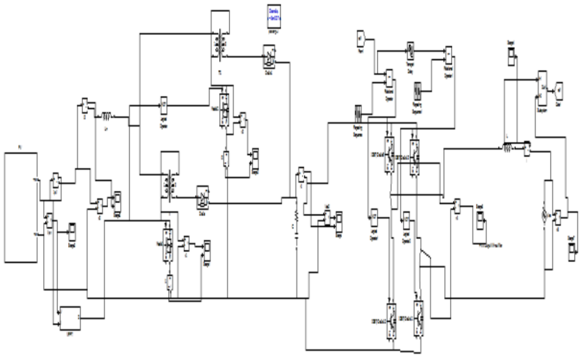


Fig.23Grid connected multilevel inverter.

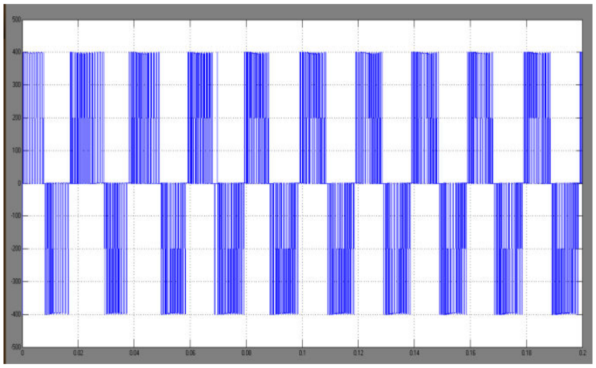
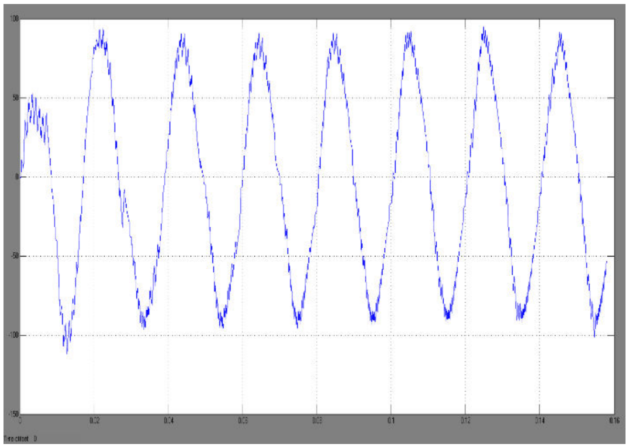


Fig.24 Inverter output voltage.



Fgi.25.Gird Current.

VI.CONCLUSION

The performance of PV/Battery hybrid energy conversion system has been demonstrated with the application of modified Instantaneous symmetrical components theory to μG-VSC proposed in this paper, an efficient control strategy is also proposed for battery converter to regulate the dc bus voltage tightly, under varying solar isolation and dc load conditions. This paper has presented the theoretical analysis of steady state, related consideration, simulation results, and experimental results for the proposed converter. The proposed converter has successfully implemented an efficient high step-up conversion through the voltage multiplier module. The interleaved structure reduces the input current ripple and distributes the current through each component. In addition, the lossless passive clamp function recycles the leakage energy and constrains a large voltage spike across the power switch. High boost conversion ratio has been achieved with relatively less duty cycle and with small size when compared to conventional topologies. High efficiency of step-up DC/DC converters can be achieved by decreasing duty cycle (lower conduction losses)and reducing voltage stress on switches (cheaper and lower RDS−on switches) applying soft switching technique minimizing switching losses) and utilizing active clamp circuits(recycling the energy stored in parasitic inductances).

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