GRID CONNECTED SOLAR PV SYSTEM WITH HIGH VOLTAGE GAIN FIVE LEVEL INVERTER

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Abstract – *Power electronics converters were developed for integrating the photovoltaic PV arrays and utility grid. An efficient converter is required to convert the low voltage DC into AC for grid interconnection of PV systems. This paper presents a high voltage gain five level inverter for grid connected solar PV systems. The proposed converter system is the combination of a symmetric dual switch DC-DC converter and a single phase five level PWM inverter. The topology of dual switch DC-DC converter is simple in structure and has high step-up voltage gain by operating in parallel charge and series discharge. The circuit configuration of single phase five level PWM inverter has reduced number of components and low harmonic components compared with that of traditional full bridge three level PWM inverter under the condition of identical supply DC voltage and switching frequency. The proposed topology provides a boosted AC voltage and is used for grid connected systems. Simulations are carried out using MATLAB/SIMULINK environment for analyze various performance parameters and the proposed converter is simulated for an input voltage of 48 V, 1kW.*

Key Words: PWM, Multi-level inverters, DC-DC converter, Photovoltaic, Grid.

1. INTRODUCTION

In long-term general plans, electricity generation based on the simple resource of fossil fuel is considered as unsustainable. It is one of the major driving forces behind the increasing use of renewable energy sources such as wind, geothermal, ocean, hydropower, biomass power, and photo-voltaics in public systems. Solar, wind, geothermal, tidal, hydro, and other renewable energy sources are unlimited by nature. Among those, the PV source is one of the most important. It will provide one of the largest contributions to electricity generation among all other sources because it is clean, emission-free, and very reliable. In a solar energy conversion system, the generation voltage is so far from the grid voltage. After the inverter stage, a transformer is primarily employed to step up the AC voltage to fulfil grid requirements for effective synchronization. However, the presence of a 50Hz transformer increases system volume and losses, bulks up the system, and reduces overall efficiency, especially in bad weather. High step-up gain DC-DC converters are the most promising and attractive converters for renewable energy systems in order to eliminate transformers.

While it is difficult to accomplish both a high voltage conversion ratio and a good efficiency with a standard boost converter, many topologies have been designed to enable a high step-up. In both isolated and non-isolated topologies, there are a variety of high step-up DC-DC converters that can achieve high voltage gain. Many high step-up DC-DC converters have been explored and developed to achieve high voltage gain in both isolated and non-isolated topologies. The weaknesses of insulation type converters, such as high volume, low efficiency, and high cost, are refined by using a series connected forward-fly back converter architecture [3]. For maximum boosting voltage gain, it has a series linked output. Large turn's ratios, on the other hand, may increase the transformer's leakage inductance, resulting in voltage spikes and severe voltage stress on power devices. Non-isolated DC-DC converters are favored in this situation due to the benefits of a simple electric energy conversion method, high efficiency, and cheap cost [4]. Because of the multistage power conversion, cascaded DC-DC converters have a large gain. However, the output diode reverse recovery problem is significant in this design, resulting in system instability and excessive voltage stress on power devices [5].A passive lossless clamping circuit is used in a high step-up DC-DC converter with active linked inductor network to reduce voltage spikes and recycle leakage energy. As a result, the cost of components increases. [6]. The DC-DC converters based on switched capacitor/switched inductor can achieve limitless gain and have lesser energy in the magnetic element, resulting in weight, size, and cost savings for the inductors. However, as the voltage gain ratio rises, the number of capacitors and diodes in these systems increases as well. In addition, current spikes can occur in the working state, which might lead to EMI issues. [7].Then, recently, a symmetric dual switch high step-up DC-DC converter with a simple construction was created, which addresses the drawbacks of another dc-dc converter. It has a dual output and low component voltage stress [8].

In the current scenario, the energy storage requirement is provided solely by DC power. For various uses, this DC electricity is converted to AC. For combining solar PV arrays with the utility grid, power electronics converters were developed. PV system grid connections necessitates the use of an efficient converter to convert low voltage DC to AC. Multilevel inverters have become extremely popular in PV systems in recent years. They provide a number of advantages over traditional inverters, including the ability to lessen voltage stress on each power component by using numerous levels on the DC bus. In these energy conversion systems, multilevel inverters are becoming increasingly important. The output voltage of classic three-level PWM inverters has three values: zero, positive, and negative supply dc voltage levels. Aside from that, their harmonic reduction is restricted. [9] Any number of voltage levels are series connected to form an inverter phase leg in a cascaded multilevel H-bridge type. The requirement of component count is a common shortcoming of traditional multilevel inverters. As the number of output voltage levels grows, the need for driver circuits, heat sinks, and protective circuits grows as well. [10]. Researchers devised a number of multilevel inverter topologies with fewer switches to address these issues. A single phase five level PWM inverter, for example, has a simple structure and fewer switches. They have five output voltage levels: zero, half, and full supply dc voltage levels. When compared to standard full-bridge three-level PWM inverters, it can reduce harmonic components [11].

In this study, a symmetric dual switch DC-DC converter [8] and a single phase five level PWM inverter [11] are combined to provide a high gain DC-AC converter system that produces boosted AC voltage at the output for renewable energy applications such as grid integration.

2. Proposed converter Configuration

The suggested converter is depicted in Fig 1 as a simple block diagram, consisting of a solar panel with MPPT tracking and grid interconnection via converters.

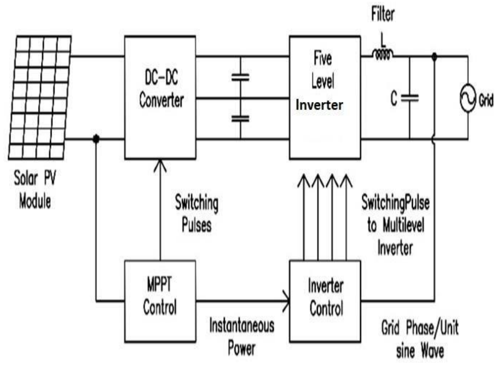

Fig -1: Block diagram of Proposed Converter

Figure 2 shows a schematic of the proposed system, which includes a PV module, symmetric dual switch DC-DC converter, and single phase five level PWM inverter. The inverter receives the power generated by the solar panel via a converter with a high voltage gain. The converter-inverter drive system is a two-stage power conversion system that uses a symmetric dual switch DC-DC converter instead of a traditional high-boost DC-DC converter to step up the panel's poor load voltage to a steady high voltage (dc).A dual switch high step up DC/DC converter has a simple circuit layout and may obtain a high step-up voltage gain by working in parallel charge and series discharge. Due to parasitic capacitance and inductor resonance, this DC-DC converter has a severe requirement for parameter constancy, or it will result in excessive voltage stress on the switches. It can achieve switch and capacitor voltage balance in both constant and dynamic states. Balanced construction is used instead of asymmetric high gain converters, which helps to reduce system EMI.

After that, the output of the DC-DC converter is fed into a five-level PWM inverter. To reduce harmonic components of the output voltage and load current, a single phase five level PWM inverter is given. In the traditional complete bridge inverter, one switching element and four diodes were added. The DC-DC converter boosts low voltage DC to high voltage DC, which the five-level inverter then converts to AC. A symmetric dual switch DC-DC converter connects the PV arrays to the multilevel inverter. A utility grid is the load. A LC filter is used to filter the current injected into the grid. The injected current must be sinusoidal with low harmonic distortions. In order to generate sinusoidal current, sinusoidal PWM is used because it is one of the most effective methods. The features of this system are high voltage gain, lesser number of elements, reduced component stress and losses, compact size etc….

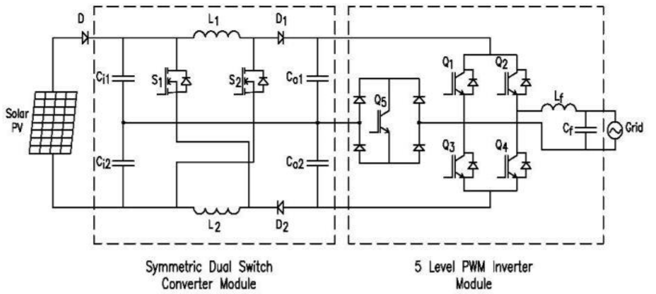

Fig -2: Schematic of proposed system

2.1. Symmetric dual switch DC-DC Converter

The circuit configuration of the DC-DC converter is demonstrated in Fig 3 with symmetric topology. The converter changes the connection of inductors L1, L2 by controlling the on-off of switches S1 and S2 to get high voltage gain. This contains V*i* input dc, controlled switch S1, S2, L1, and L2 inductors, input capacitors Ci1,Ci2,output capacitorsCo1 ,Co2, and load resistance R. In mode1 [t0, t1] when the switches are ON and the diodes are off, the inductors L1, L2 are charged by the input power Vi and the current in the inductors will increase linearly. Voltage across inductors can be given as:

$$L_1 \frac{di_{L1}}{dt} = L_2 \frac{di_{L2}}{dt} = V_i \qquad (1)$$

In mode 2 [t1, t2] at t1 the switches are turned off and diodes are ON power in an induction system is discharged through a diode into load. Voltages across the inductors are:

$$V_{L1} = V_{Ci1} - V_{Co1} \qquad (2)$$

$$V_{L2} = V_{Ci2} - V_{co2} \qquad (3)$$

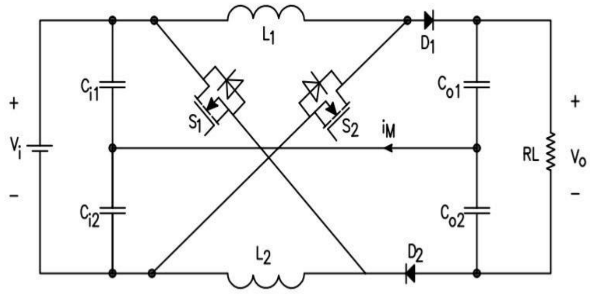

Fig -3: Symmetric dual switch Converter

The equivalent circuits of mode 1 and mode 2 of DC-DC converter are shown in Fig. 4(a), and Fig. 4(b). The wave forms of Continuous Conduction Mode (CCM) is shown in Fig. 5.

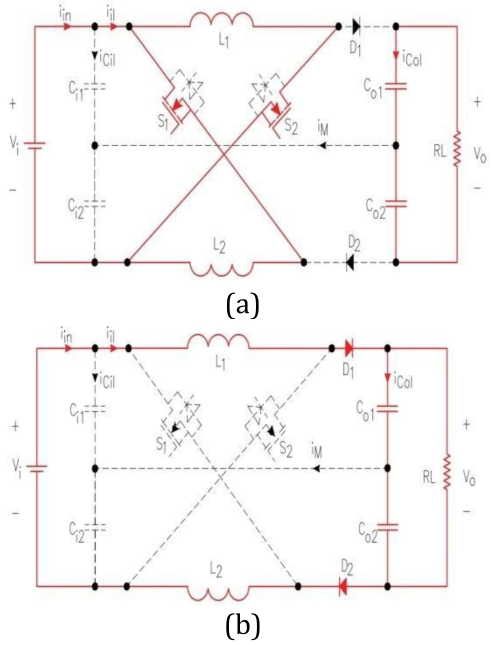

Fig -4: Operating modes of symmetric dual switch DC-DC converter (a) mode1 (b) mode2

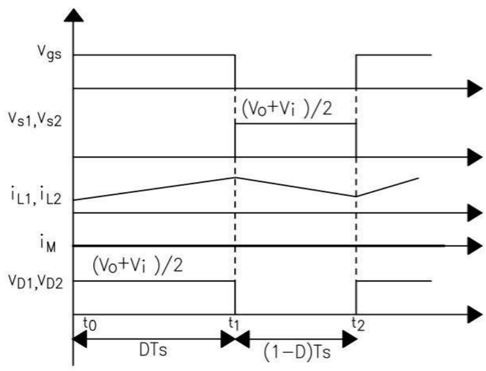

Fig -5: Waveforms of CCM Operation

Applying voltage-second balance on the inductors L1, L2

$$D.V_i + (1-D).(V_{Ci1} - V_{Co1}) = 0 \quad (4)$$

$$D.V_i + (1-D).(V_{Ci2} - V_{Co2}) = 0 \quad (5)$$

By simplifying equations (4), (5) the voltage gain is given by

$$G = \frac{V_o}{V_i} = \frac{1+D}{1-D} \quad (6)$$

The DC-DC converter duty cycle can be calculated as follows

$$D = \frac{G-1}{G+1} \quad (7)$$

2.2. Single phase five level inverter

In the proposed system, a single phase 5 level PWM inverter [11] is utilized to decrease the harmonic components of output voltage and load current. PWM inverters may control both output voltage and frequency at the same time. It has a straightforward design and a small number of switches. Figure 6 shows the single phase five level inverter's circuit diagram. It is made up of one switching element and four diodes that are added to a traditional full bridge inverter and connected to the dc power supply's center tap. By properly controlling the auxiliary switch, it may generate half the level of dc supply voltage. There are five different output voltage levels: zero, half, and full supply dc voltage levels. As a result, it's known as a single phase five-level PWM inverter. TABLE I shows the output voltage based on the switch ON/OFF situations.

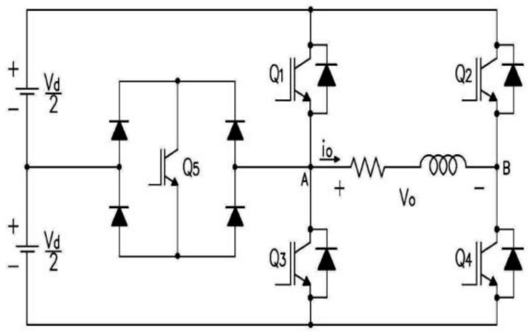

Fig -6: Single Phase Five Level PWM Inverter

When switches Q1 and Q4 are turned ON, the positive terminal of source is connected to node A and the negative terminal of the source is connected to node B. This generates output voltage Vo = Vd across the load terminal. The output voltage V0=Vd2 is produced by switching ON switches Q5 and Q4. Zero states output is obtained by switching ON switches Q3 , Q4 or Q1,Q2.Similarly to obtain the negative half cycle in the next states, switches Q5, and Q2 are turned ON. The negative terminal of the input source is connected to node A and positive terminal of the source to node B and so output voltage Vo =-Vd2. By switching ON Q2 & Q3 an output voltage Vo =-Vd is obtained. So a five-level step wave is generated at the output terminals. The gate pulses to the inverter switches can be generated using SPWM technique.

Table -1: Switch on off states

SWITCHES ON	NODE A VOLTAGE	NODE B VOLTAGE	OUTPUT VOLTAGE
Q_1 Q_4	V_d	0	V_d
Q_5 Q_4	Vd/2	0	+Vd/2
Q_3 Q_4 or Q_1 Q_2	0 or V_d	0 or V_d	0
Q_2 Q_5	0	Vd/2	- Vd/2
Q_2 Q_3	0	V_d	- V_d

2.3. GRID INTEGRATION CONTROL

Grid is an infinite-capacity voltage source. The technique of discovering effective ways to distribute fluctuating renewable energy to the grid is known as grid integration. Grid synchronization is made up of a DC-AC converter and a control device that regulates the flow of electricity between the PV array and the grid. If solar power is to be delivered to a power grid, it must first be converted to alternating current using a DC-AC converter. Grid voltage, waveform, and frequency must all be monitored. To ensure proper power flow, the converter must be constructed to synchronize its AC frequency with the grid. Grid current is in phase with grid voltage for synchronization, and the power factor is always close to unity. The goal of the converter is to provide a sinusoidal AC output with adjustable magnitude and frequency. Then there's a control unit that manages the power flow between the PV array and the grid, as well as the inverter's synchronization and grid connection, as well as the power quality. Figure 7 depicts a block diagram of grid integration control with solar PV.

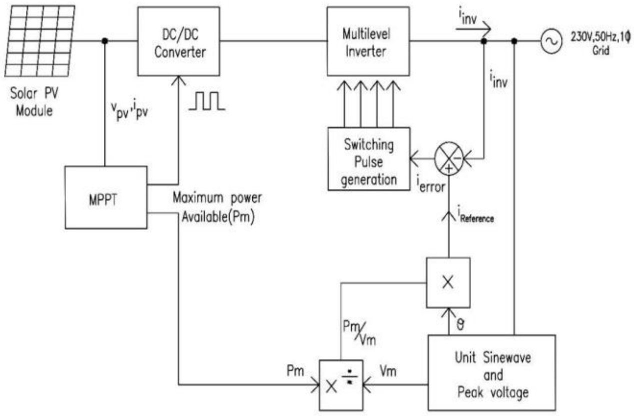

Fig -7: Block diagram of grid integration control

Solar power sources can be controlled by MPPT to generate maximum power. The solar energy is fed into a DC/DC converter, which then feeds the output to a five-level PWM inverter. The required value of current is multiplied with unit sine wave in synchronization for creating reference current, and the peak value of grid voltage and maximum power from MPPT are divided. The created reference current is then compared to the real current to get the instantaneous current error, which is used to generate a switching pulse to inject the current. Grid current is in phase with grid voltage for synchronization, and the power factor is always close to unity. One of the issues with PV generation systems is that the amount of electric power generated by solar arrays varies with weather conditions, i.e., solar radiation strength. To tackle the aforementioned problem, a maximum power point tracking (MPPT) approach with quick response qualities and the ability to make optimal use of the electric power generated in any conditions is required. To extract maximum power from PV arrays and transfer it to the inverter, the perturb and observe approach is used.

3. SIMULATION

The proposed topology of the converter is simulated in MATLAB using the parameter listed in Table 2.

The proposed converter system was designed for a power rating of 1 kW, input voltage 48 V, output voltage 350 V and switching frequency of 50 kHz. The duty cycle of the converter under the operating condition is 0.7.Solar PV is used as input source. Table 3 shows the specification of solar PV with power of 500W ,maximum power voltage of 48.63V, maximum power current of 10.28A,open circuit voltage of 59.01V, short circuit current of 10.87A ,irradiance of 1000W/m2 and temperature of 25oC. Here the number of module in parallel is 2, and obtained a power of 1KW.

Table -2: MATLAB Parameters

COMPONENTS	SPECIFICATIONS
Input voltage	48V
Output voltage	350 V
Rated power	1 kW
Switching frequency	50 kHz
Inductors (L1,L2)	240 µH
Input capacitors (Ci1,Ci2)	1000 µF/50 V
Output capacitors (Co1,Co2)	470 µF/250 V
Load resistor	125 Ω

Table -3: MATLAB Parameters for solar panel

PARAMETERS	VALUES
Solar Panel	500W
Vmp	48.63V
Imp	10.28A
Voc	59.01V
Isc	10.87A
Irradiance	1000W/m2
Temperature	25oC
No: of module in parallel	2

Figure 8 shows simulation of grid synchronization circuit with irradiance of 1000w/m2and 600w/m2. Figure 9 shows variation of irradiance level with respect to time. In the figure step variation occurs at 0.4 sec.

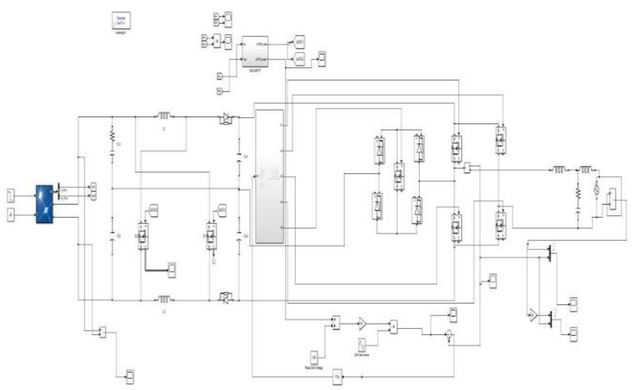

Fig -8: Simulation of grid synchronization of proposed converter with solar PV

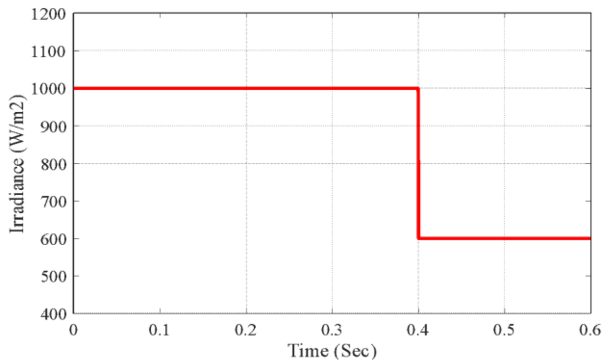

Fig -9: Variation of irradiance level with respect to time

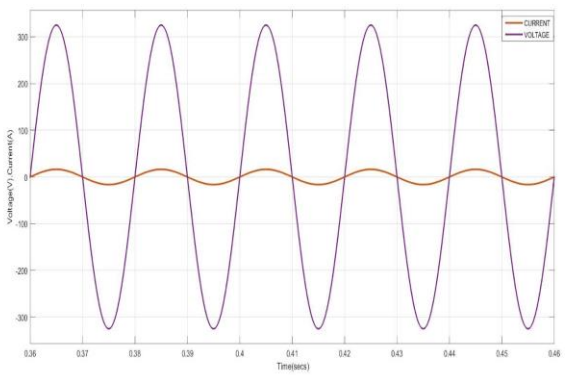

Fig -10: Grid voltage and Grid current

Figure 10 shows the waveform of grid voltage and grid current. And obtained as Ig is in phase with Vg. The grid voltage is 325 V.

4. CONCLUSION

The research proposes a DC-AC converter system for grid-connected solar PV systems by combining two existing converters, a symmetric dual switch DC-DC converter and a single phase five level PWM inverter with high gain. A boosted AC output voltage is provided by the unique proposed converter technology. Increased voltage gain, reduced switch count, low current and voltage stress on the power switches, reduced conduction loss, and a wide range of applications are among the benefits of the suggested system. The results are obtained after a 1kW grid linked integrated converter system is constructed and simulated using MATLAB/SIMULINK.

The proposed integrated converter system has applications in induction motor drives, standalone systems, and other renewable energy-based systems.

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