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PV To Grid Connected Multilevel Inverter With Hybrid Modulation Technique

Sumit Balmik[1], Sachindra Verma[2]

[1]Student, [2]Professor

[1,2]NRI Institute of Research and Technology, Bhopal

Abstract— In this article, a grid-connected photovoltaic system based on multilayer inverters (MLI) is modeled. The cascaded T-type inverter is responsible for developing the MLI topology. Connecting the PV sources in series raises the input voltage, making it challenging to connect other MLI circuits to the grid. Three-level buck-mode operation is produced by this cascaded T-type multilevel inverter (CT2MLI), which has the following benefits: a low peak inverse voltage (PIV), a low total harmonic distortion (THD), a low switching loss, and a minimal number of switches. The perturb and observe (P&O) MPPT technique is used to get the maximum power from a PV array. To simplify the gate pulse generation process, CT2MLI employs a hybrid level-shifted and phase-shifted pulse width modulation (PWM) approach. Low dv/dt stress across the switches, low peak inverse voltage (PIV), and low total harmonic distortion (THD). The maximum power point tracking (MPPT) technique perturbs and watches the PV array to obtain the greatest power. To simplify the gate pulse generation process, CT2MLI employs a hybrid level-shifted and phase-shifted pulse width modulation (PWM) approach. The efficiency of the control strategy for the grid-connected PV system based on CT2MLI is shown by the MATLAB simulation results.

Keywords— CT^{2}MLI, FFT Analysis, Photo Voltaic (PV) System, Pulse Width Modulation (PWM), T-Type Inverter.

I. Introduction

There is a significant shift in the energy system toward the widespread usage of green energy due to environmental concerns about CO2 emissions and global warming. Large-grid-dependent, centralized electric power systems will be supplemented with distributed, small-scale smart-grid-based energy generation systems in a sustainable future. Often, renewable energy sources like solar, tidal, and wind power are employed to achieve that objective. As solar energy is more available than any other fossil fuel substitute, the world is shifting toward solar solutions [1], [2].

Since photovoltaic sources provide DC power, which must be converted into AC via a DC to AC converter (inverter), power electronics are crucial for capturing solar energy. MLIs have garnered significant attention among various power converters for medium-voltage and high-power applications. Due to the fact that it has the ability to handle large voltages, low harmonic distortion, and far less voltage stress on semiconductor switches than applied voltage to a circuit [3]. Numerous topologies for MLI have been developed, including NPC-MLI, FC-MLI, MLDCL-MLI, T2MLI, and CHB-MLI. Because it raises the leveled AC output voltage, the cascaded H-bridge inverter topology is one of the most often utilized among them [3]–[5]. However, it necessitates an isolated DC-link input voltage for every cell.

The technique of varying a switch's ON and OFF duration at a fixed switching frequency is known as pulse width modulation. The literature has suggested a variety of modulation approaches for MLIs, including phase-shifted PWM, level-shifted PWM, discontinuous PWM, and others [6], [7]. LS-PWM has an uneven power distribution across each module [8]. D-PWM requires that the output waveform and switching time have a balanced relationship. Significant performance advantages of PS-PWM technology include high output waveform quality and balanced power distribution among modules. Conversely, low circuit efficiency and high frequency switching losses are some drawbacks of PS-PWM [8].

In order to address the challenges of directly connecting the higher PV output voltage of cascaded PV sources to the grid using traditional topologies and improve the power quality of PV systems, this study proposes a PV system that transmits electricity to the grid. There are two stages to this work: the first is a DC-DC boost converter using MPPT, and the second is a seven-level inverter. In order to reduce the number of switches and other factors, a CT2MLI is utilized in conjunction with hybrid LS-PWM and PS-PWM to generate a switching pulse that operates in buck-mode with a peak voltage of Vdc/2 [11]. The leveled output then goes through a specially made LCL filter, producing high-quality AC output, and is linked to the grid. Representation of this work using block diagram is shown in Fig. 1.

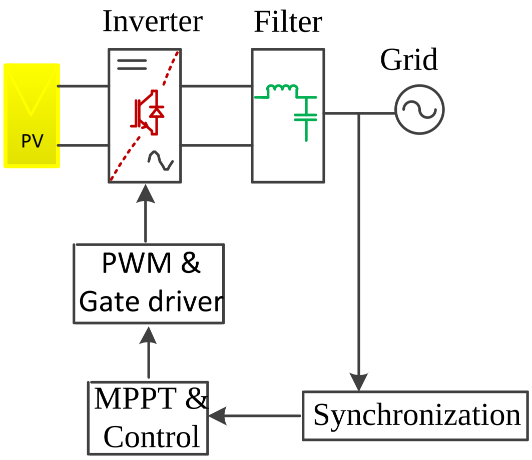

Fig. 1 block diagram of PV to grid connected system

The work is arranged as follows: part II presents circuit topology with T-type inverter operation. Part III, includes hybrid modulation technique as LS-PWM and PS-PWM. In section IV, the results of a PV to grid connected CT^2MLI based system are shown using MATLAB/Simulink. Finally, in part V, there are some closing observations.

II. CIRCUIT TOPOLGY

A. Design of Stage One DC-DC Boost Converter with MPPT

To get the most power out of PV sources, the MPPT algorithm is employed. The point on a current-voltage (I-V) curve where the solar PV device generates the highest output is called the MPP. The P&O technique measures the power extracted from the PV array on a regular basis [10]. To maintain a constant output voltage for grid-connected photovoltaic applications, a DC-to-DC boost converter is utilized. By lowering the ripples, the boost converter transforms a fluctuating PV voltage into a more steady DC voltage. To keep the output voltage constant, it uses feedback voltage.

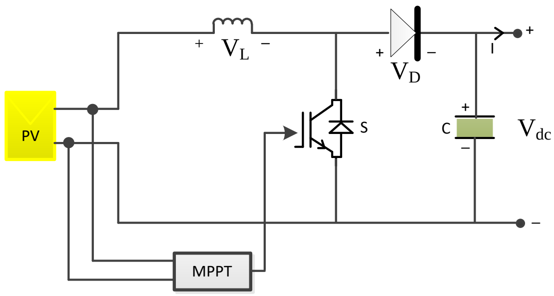

Fig. 2 DC-DC boost converter with MPPT

B. Design of Stage Two T-Type Inverter

This project makes use of a T-type inverter (T2I), which may be connected to a photovoltaic array and send power to the grid. A four quadrant operating bipolar and bidirectional switch (S1 and S4) and two unipolar and bidirectional switches (S2 and S3) are part of this topology [11]. Additionally, it features two capacitors (a dc-bus capacitor) that are linked after the DC-to-DC boost converter with MPPT, which is the first stage. In contrast to S1 and S4, which are rated for half of the DC-link voltage, S2 and S3 are rated for the whole DC-link voltage Vdc. Fig. 3 displays the three-level T2I topology.

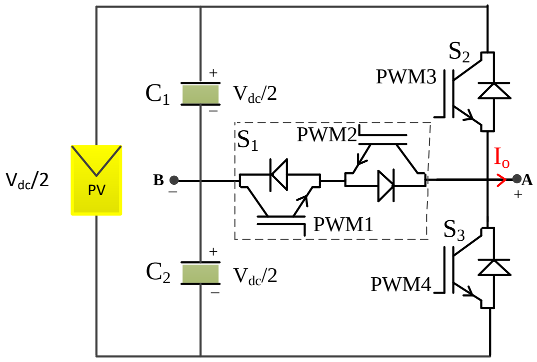

Fig. 3 T-type Inverter topology

This inverter gives three output voltage levels as $+V_{dc}/2$, 0, and $–V_{dc}/2$. Different switching states are shown in Fig. 4-6. By connecting three modules in cascade can create seven-level voltage as leveled output of the inverter. This cascaded system provides a seven-leveled voltage as $+1.5V_{dc}$, $+1V_{dc}$, $+0.5V_{dc}$, 0, $-0.5V_{dc}$, $-1V_{dc}$, $-1.5V_{dc}$. Table-1 shows the different switching states of inverter. During the positive and negative state only one device is conducting, that increase the efficiency of converter.

Table-1 Switching states of T-type converter

State	Voltage Level	Current Status	S_1	S_2	S_3	S_4	D_1	D_2	D_3	D_4
α	$+V_{dc}/2$	$I_o > 0$	0	1	0	0	0	0	0	0

		I_o< 0	0	0	0	0	0	1	0	0
β	0	I_o > 0	1	0	0	0	0	0	0	1
		I_o< 0	0	0	0	1	1	0	0	0
γ	$-V_{dc}/2$	I_o > 0	0	0	0	0	0	0	1	0
		I_o< 0	0	0	1	0	0	0	0	0

$+V_{dc}/2$ Level-
By turning ON switch S_2 and keeping other switch OFF, capacitors C_1 is connected in series through the load and C_2 is by passed, it gives $+0.5V_{dc}$ voltage at the output of inverter with positive load current I_o. For negative load current, D_2 gets turned ON.

0 Level-
By turning ON switch S_1 and D_4 and other switch OFF, capacitors C_1 and C_2 are by passed and zero voltage at the output of inverter with positive load current of I_o occurs. For negative load current I_o turned ON switch S_4 and D_1.

$-V_{dc}/2$ Level-
By turning ON switch S_3 and other switch OFF, capacitors C_2 is connected in series through the load and C_1 is by passed and it gives $-V_{dc}/2$ voltage at the output of inverter with negative load current I_o. For positive load current of I_o, D_3 gets turned ON.

III. HYBRID MODULATION TECHNIQUE

To provide a low and fixed switching frequency for high power and industrial applications, PWM should be used to provide sufficient switching pulses. Some switching techniques, such as hysteresis, have a variable switching frequency, resulting in annoying auditory disturbances. To modulate the measured reference signal, carriers are transferred vertically.

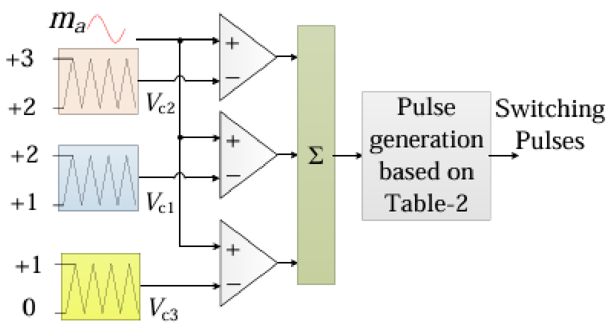

Fig. 4 Hybrid Modulation Technique

In this study, switching pulses are generated using a hybrid level-shifted and phase-shifted high frequency PWM method. As illustrated in Fig. 4, for 'm' level of output voltage including zero level output, '(m-1)' carrier signals are used, with phase shift of "(n-1)×360^0/N", where, 'n' belongs to corresponding n^{th} leg and 'N' is total no. of legs used to make cascade, all carrier signals are accountable for generating gate-pulses for associated voltage levels and switching states. In comparison to other topologies, the proposed technique assures that the converter has low and fixed switching frequency, resulting in reduced switching losses and good performance.

IV. RESULTS

This work proposed as a PV to grid connected system, processed in two stages where, stage one is the DC-DC boost converter with MPPT and second stage is the seven-level inverter. For this stage, three modules of T-type inverter are connected in cascade. This cascade connection of T^2I generates seven-level output voltage as $+1.5V_{dc}$, $+1V_{dc}$, $+0.5V_{dc}$, 0, $-0.5V_{dc}$, $-1V_{dc}$, $-1.5V_{dc}$. After this stage leveled output passes through designed LCL filter and AC output connected to grid.

This study uses a specific PV module with 1 parallel and 6 series connected strings to replicate a 2.5 kW power rating. According to the PV module, the maximum PV output voltage is 250V, with a peak-to-peak ripple of 50V approx. This high voltage ripple can cause to damage the system, degrade its efficiency, and increase system losses. To reduce this much higher ripple voltage DC-to-DC boost converter is employed. DC-DC boost converter's output voltage is ripple-free and as high as 300V shown in Fig. 8. The output of the DC-to-DC boost converter is regulated by perturb and observe method of MPPT. This converter worked as a first stage of proposed system and work on a 5kHz switching frequency. PV system generates power in a form of DC so here, required an inverter which converts this DC power into the leveled AC power. It is a second stage of the proposed method; this stage converts DC voltage into the leveled AC voltage using cascaded T^2I topology.

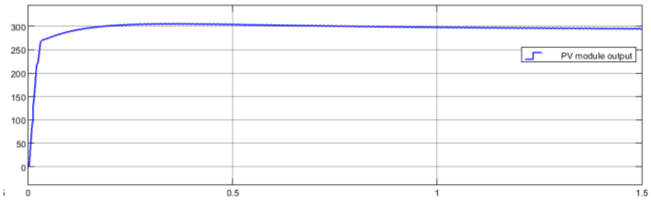

Fig. 5 Output voltage of DC-DC boost converter

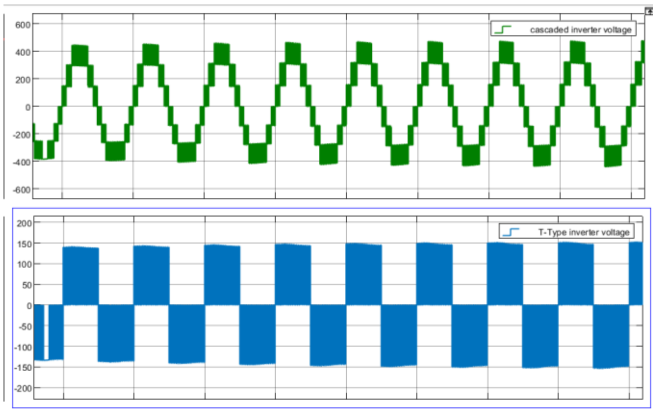

Fig. 6 Output voltage of T^2I topology (a) Cascaded seven-level output voltage waveform (b) Three-level output voltage

PWM switching pulse is applied to operate a three-level inverter using proposed hybrid LS-PWM and PS-PWM technique. The cascading of these three modules results in a seven-level voltage at the system's output, as present in Fig. 6(b). Grid parameters are shown in Fig. 7 and Fig. 8. Because of inverter current was measured before the LCL filter, there is some ripple in it. Grid voltage and grid current are depicted on the same axis, showing that both voltage and current are in phase and transmit active power to the grid. This proposed system simulates at 2.5 kW power rating and inverter working on 10kHz switching frequency. At this high frequency and specific power justified that, this system is highly efficient and reduces a power loss between the power converters. This work also decreases the harmonics of grid current and grid voltage by the use of LCL filter at the grid side.

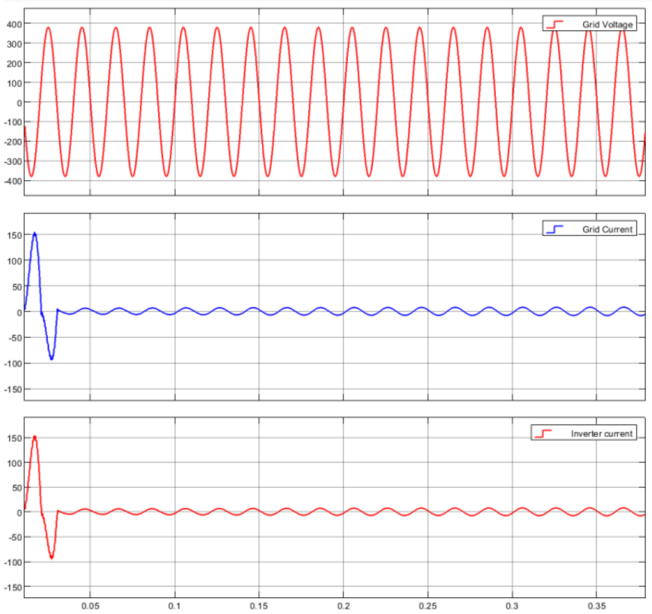

Fig. 7 Grid voltage, grid current, inverter current

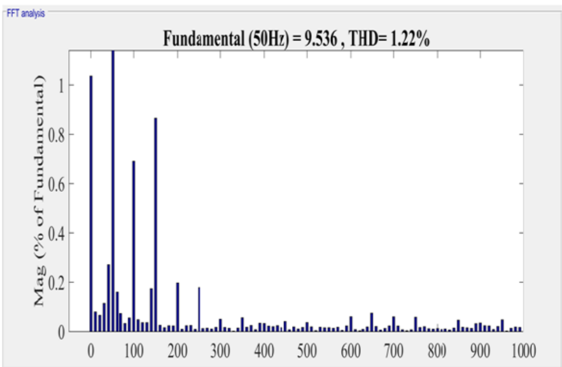

Fig. 8 FFT analysis of grid current

For verification of reduced harmonics, FFT analysis is done by using MATLAB platform. FFT analysis of grid current shown in Fig. 1. The FFT analysis of grid current shows maximum power component present at the 50Hz frequency also second maximum component present at the 150Hz frequency but its only 0.9%. So, 99.1% component present at the grid frequency so it’s justified, that it reduces the harmonics.

V. CONCLUSION

For the connection of renewable energy source to the grid, requires a power electronic converter which is developed by cascaded T-type inverter. PV system generates a power in the form of DC so here required an inverter which converts this DC power into the leveled AC. The control method for the cascaded T-type inverter with PV arrays as separate DC sources is developed in this paper. Cascaded T-type inverter that worked with the hybrid PWM as combination of LS-PWM and PS-PWM strategy simplifies the switching states for cascaded multilevel system. By using this improved selection mechanism as the modulation method, the simulation results show that the capacitor voltages can be balanced. Moreover, the leveled output voltage reduces the harmonic distortion. A detailed analysis of T-type inverter with respect to THD is done. It is evident from the result that the T-type inverter topology using maximum constant boost control technique generates a high-quality output voltage waveform, minimized THD and good reliability.

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