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Original Article

Improvement of Power Quality in Single Stage Grid Connected PV System with Novel Configuration of Multilevel Inverter

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Abstract *- Electric power is essential for doing many tasks and it will become eco-friendly to produce electricity through Photovoltaic (PV) panels. There is a main challenge to injecting power produced by PV panels into the utility grid for its best utilization. Using multi converters will increase the system size and cost; hence Single Stage Grid Connected (SSGC) PV system can be a viable solution for many issues. The inverter can play a major role in SSGC configuration, and it will do many jobs as per instructions from the control unit. Hence, an efficient inverter and its novel control method must be implemented to manage power flow from the PV system to the utility grid as well as to improve power quality at the local load bus system. To fulfill these objectives, a multilevel inverter can be a feasible solution. But, unfortunately, multilevel inverters suffer from the high number of switching devices, which increases system size, cost and complexity. Hence, a novel configuration of multilevel inverter is considered in this paper, which can be configurate with less number of switching devices as compared with conventional models. A 7-Level Parallel Inverter (7-LPI) and its control algorithm are implemented in this paper to improve the power quality at the load bus in the SSGC PV system under various operating conditions. Unbalanced load compensation, along with control of voltage, is done with the proposed method under various operating conditions. Hardware-in-Loop (HIL) simulation using OPAL-RT devices is conducted to evaluate the system's response under different operating conditions.*

Keywords *- Power quality, 7-Level Parallel Inverter, Grid connected PV system, PV system, SSGC.*

1. Introduction

Electrical power production through PV panels can be a feasible solution for many problems, including pollution. Usually, a PV system will be established to produce the required power [1-3], and there is no requirement for energy storage devices for grid-connected systems.

Using multiple converters in a grid connected PV system will increase size, complexity as well as cost. Hence Single-Stage Grid-Connected (SSGC) PV systems are proposed by many scholars. The inverter is only a power electronic converter in the configuration of the SSGC PV system.

The inverter will be placed in between the load bus and PV system, and the control of the inverter can able to work as power transmission from PV panels [4, 5] to the grid as well as a Maximum Power Point Tracking Device (MPPTD) with proper control methodology. However, conventional or two-level inverters exhibit poor performance and inject much harmonics into electric grids which causes power quality issues. Hence, multilevel inverters are commonly used for various applications, including SSGC PV systems. However, conventional multilevel inverters are suffering from more number of switching devices, which increases the cost, complexity and size of the system [6]. Therefore, a novel configuration, namely a parallel inverter, is adopted in this paper which consists of a very small number of switching devices as compared with other configurations.

A seven-level parallel inverter (7-LPI) is designed along with its control methodology to use in the SSGC PV system in this paper to improve the power quality at the local load bus [17]. In general, many loads, including reactive power, unbalanced loads, and nonlinear loads, are operating at the local load bus, which causes power quality issues on the grid side.

Therefore, the proposed control of 7-LPI is designed to overcome these issues. Hence, quality power can be supplied to loads, as well as the grid cannot suffer from these loads [17, 18]. Apart from this, the inverter must be operated as MPPTD for the PV system. Configuration of the 7-LPI requires only 6 numbers of switching devices in a phase/leg. A new control mechanism for a 7-LPI is introduced to deliver high-quality power at the load bus.

The rest of the paper is arranged by providing a system description along with the configuration of a 7-LPI in section 2. The implementation of the novel control mechanism of 7-LPI is introduced in section 3. Section 4 showcases the utilization of OPAL-RT modules and the establishment of Hardware-in-the-Loop (HIL) for presenting diverse results [17, 18]. Finally, Section 5 contains the summarized conclusion. The paper includes a number of helpful references in its ending.

2. System Description and Configuration

Figure 1 depicts the configuration of a 7-LPI, which makes use of 6 switches in each phase. A significant advantage of this arrangement is the reduced number of switching devices needed for each level per leg, specifically (m-1) devices. This specific inverter design is widely utilized for the conversion of high-power DC to AC [18]. A schematic model of the proposed system is depicted in Figure 2. An SSGC PV system is employed with 7-LPI to obtain a quality voltage profile which is near to sinusoidal.

A straightforward closed-loop control system based on RMS voltage is implemented to regulate the load voltage. The specifications for the PV unit are detailed in Table 1. The P&O-based algorithm is implemented to force the inverter to work as an MPPTD of a PV system. A Point of Common Coupling (PCC) is established to connect all AC loads. From Figure 1, step V_{dc} can be when switch S_{A1} is switched ON. When the switch S_{A2} is switched ON, the output will be connected to 2/3 V_{dc}. Like this will be repeated for all 6 switches, and only one switch is sufficient to switch ON per leg at any instant to get the output.

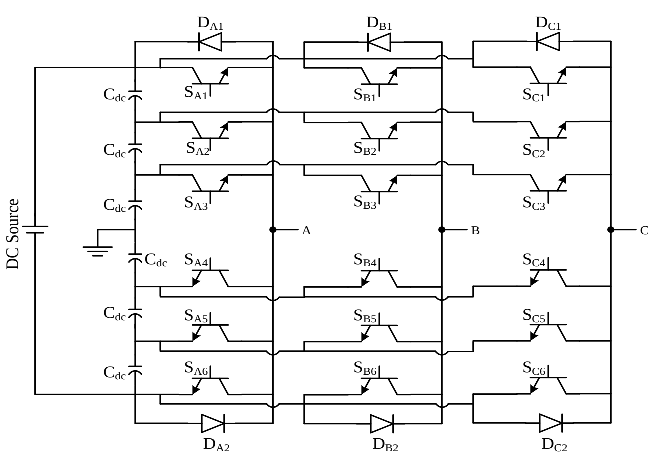

Fig. 1 Configuration of a 3-phase 7-LPI

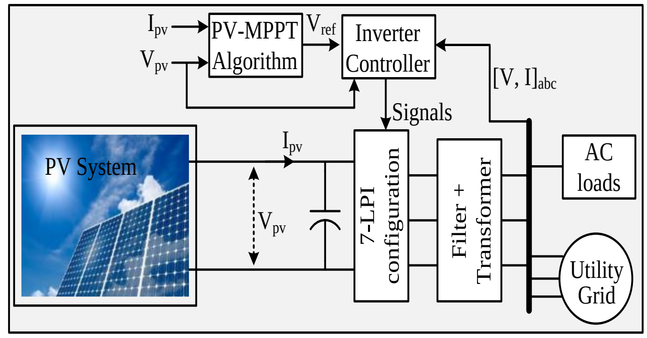

Fig. 2 Hybrid SPSS configuration with 7-LPI

Table 1. Ratings of PV unit [7-10].

Parameters	Values
V_{oc}	36.9 V
I_{sc}	8.01 A
V_{mpp}	30.30 V
I_{mpp}	7.10 A
Series Resistance	0.0044 Ω
Shunt Resistance	0.9822 Ω
Cell Diode Voltage	0.5371V
Series Modules	22
Irradiance G^*	1.0 kW/m^2
Rated Power	4.732 kW

3. Control Strategy

The control unit proposed in the study can be observed in Figure 3. Each phase's RMS voltage is compared with its respective reference signals to generate modulation indexes using a PI controller. Additionally, an NSPWM technique is implemented, involving the comparison of carrier waves with their reference waves [17], as depicted in Figure 4. Pulses AT1 to AT3 are generated by comparing the reference and carrier signals [17].

While a traditional SPWM technique is a viable option for inverter control, each switch receives a pulse only when it is ON during the SPWM process [17]. In the proposed method, the continuous generation of switching pulses is not necessary. Therefore, NSPWM is implemented using gates. The regular ON period for each device is 1/(K-1) of the total time, where 'K' represents the total number of switches. Meanwhile, all other switches within the same phase remain in the OFF state [17].

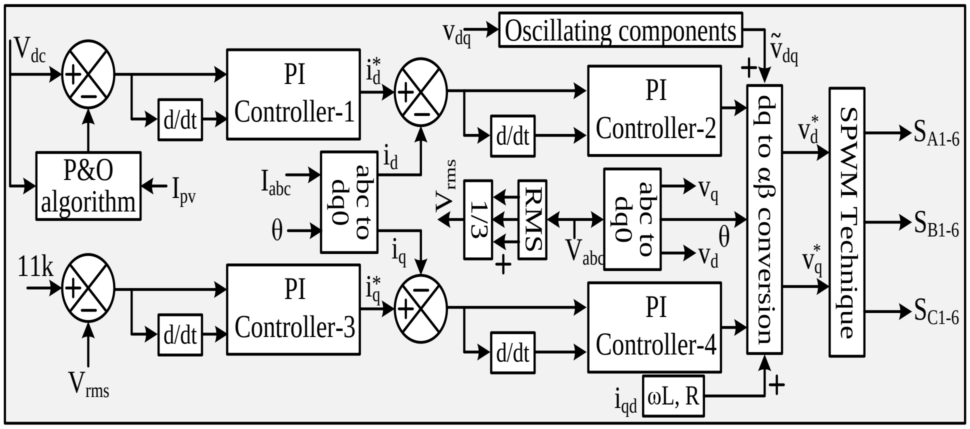

Fig. 3 Proposed control methodology of a 7-LPI

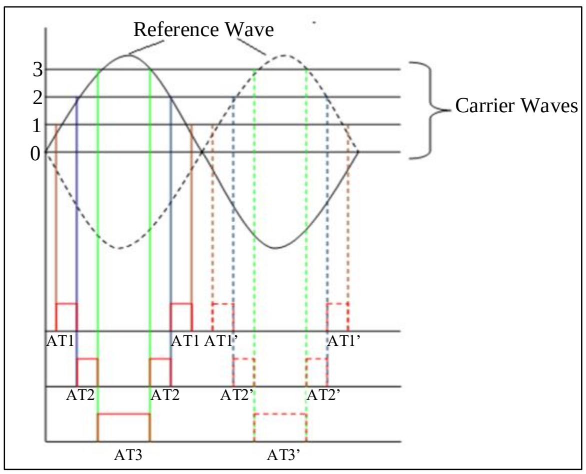

Fig. 4 NSPWM methodology

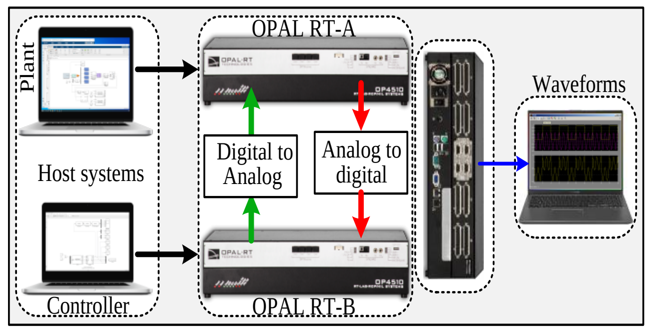

Fig. 5 HIL configuration

4. Various Results

The study demonstrates an enhancement in system performance across various scenarios through the utilization of Real-Time Simulators (RTS) [3, 6]. The RTS components, including OPAL-RT units, are utilized to establish a Hardware-in-the-Loop (HIL) setup in the laboratory. To offer a real-time testing environment for intricate controllers, HIL is set up using two OPAL-RT modules. The plant, depicted in Figure 2, is integrated into OPAL-RT unit 'A' (OPAL RT-A), while all controllers are integrated into OPAL-RT module 'B' (OPAL RT-B).

Analog signals from the plant are digitized using data cards and utilized as input to the controller unit. The control unit is capable of stimulating the proposed method to produce corresponding pulses for switching devices. The digital pulses are then converted back to analog signals and used as input signals for the plant through external data cards [17]. A laptop is employed instead of an oscilloscope for enhanced visualization of the desired outcomes. Figure 5 showcases the basic HIL configuration employing two OPAL-RT devices. The parameters for modeling the proposed method are sourced from references [11-16].

4.1. Case A: Variation in Load

At t = 2 sec in this situation, the load current increased fourfold, leading to an analysis of the output currents, voltages, and modulation indexes. Initially, the load current was 4.0Amps, but it reached a peak of 16.23Amps, as shown in Figure 6.

However, the load voltage remained constant at 11.0KV due to the implementation of a controller reference signal. Figure 7 demonstrates minimal fluctuations in the load voltage (line to line). The modulation indexes corresponding to this can be observed in Figure 8.

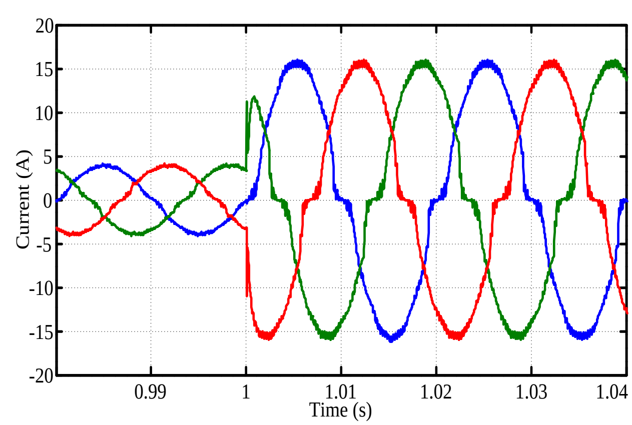

Fig. 6 Inverter current

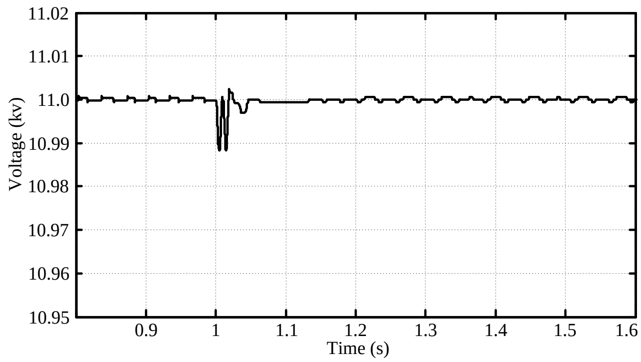

Fig. 7 Load voltage

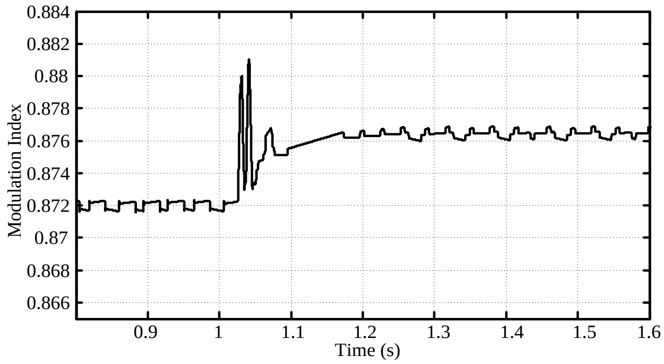

Fig. 8 Modulation indexes

4.2. Case B: When the Load is Unbalanced

The SPSS has been tested with an imbalanced load. The load bus is linked to a three-phase unbalanced load, as shown in Figure 9. During this process, the RMS voltage at the load bus stays consistent, as shown in Figure 10.

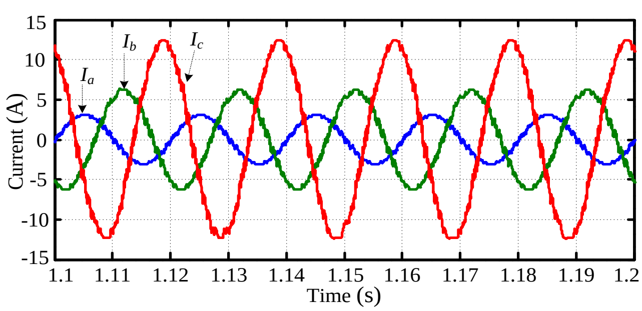

Fig. 9 Currents

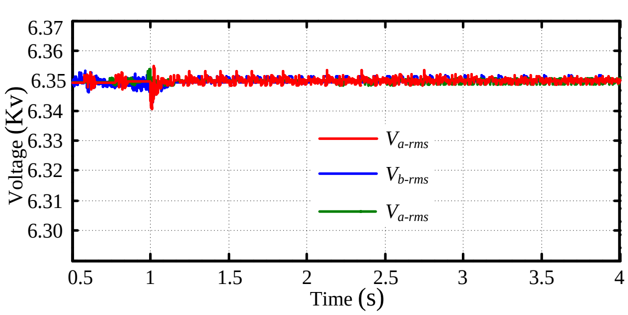

Fig. 10 Voltages

4.3. Case-C: Variations in Sources and Load Simultaneously

In practical scenarios, the loads at the load bus and irradiances consistently fluctuate randomly, as depicted in Figure 11. Under these circumstances, the controllers are required to maintain stable voltages at both the DC-link and load bus, as indicated in Figure 12. Furthermore, the instantaneous voltage profile is visible in Figure 13, whereas the corresponding current of phase A [17] is illustrated in Figure 14.

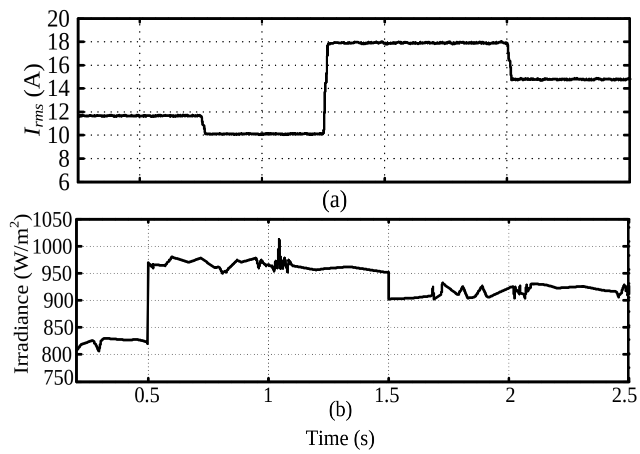

Fig. 11 Random changes in (a) Current, and (b) Irradiance.

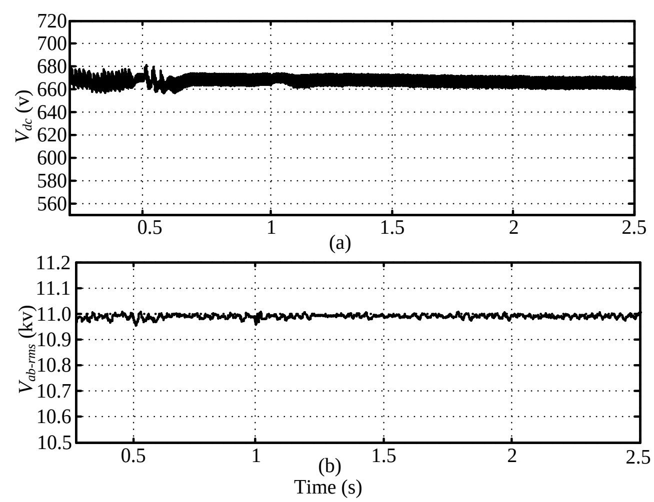

Fig. 12 Voltages (a) DC, and (b) AC.

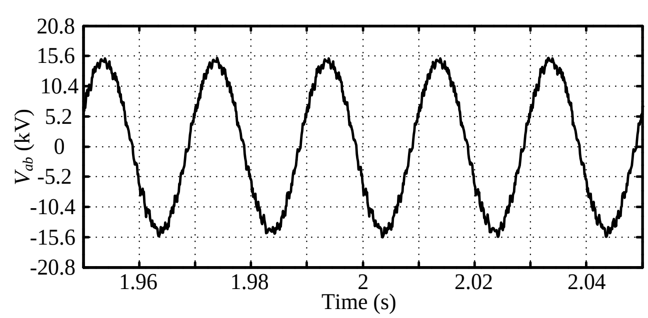

Fig. 13 Voltage profile

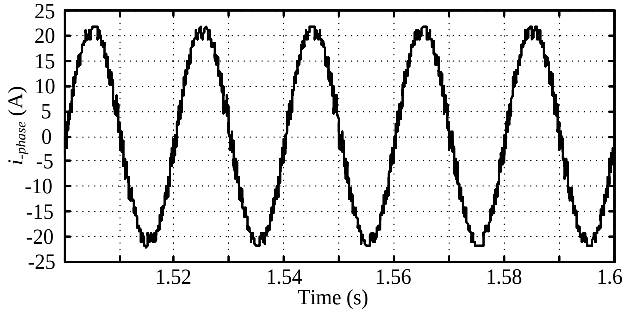

Fig. 14 Instantaneous phase current

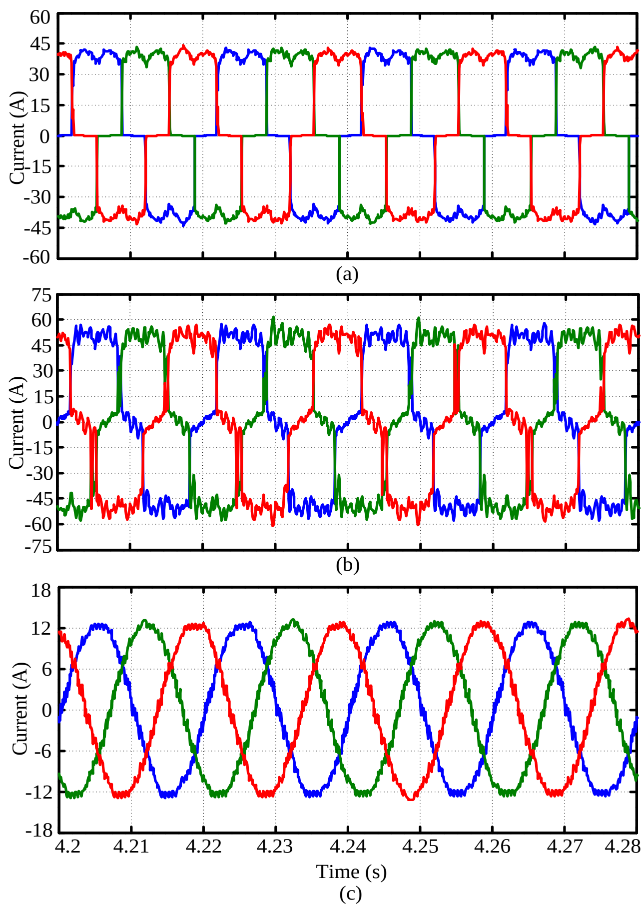

Fig. 15 (a) Non-linear load currents, (b) Currents flowing through inverter, and (c) Grid currents.

4.4. Case-1: Performance under Unbalanced Nonlinear Load

A nonlinear load at the PCC with the profile shown in Figure 15 (a) is examined in the case study. Using the suggested controller, the adjusted nonlinear currents will be pumped through the inverter to lessen the nonlinear impact on the grid. Grid currents may then become sinusoidal and harmonic-free as a result. Figures 15(b) and (c) show the matching grid and inverter currents, respectively [18]. This objective can be accomplished by configuring the inverter controller to function as an active power filter [18].

4.5. Case-2: Phase Voltage of 7-Level Output

The case study examines the profile of phase voltage. The voltage is captured without a filter to obtain 7 levels. Figure 16 shows the 7 levels in phase voltage [18].

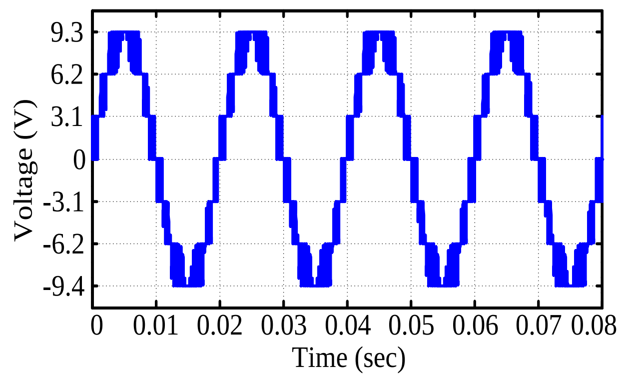

Fig. 16 Phase voltage of 7 levels

5. Conclusion

The standalone system utilizes a novel multilevel inverter configuration known as the parallel inverter to enhance power quality. This paper focuses on the implementation of a 7-LPI. Additionally, the SSGC PV system is developed, along with a straightforward control method, to ensure power quality at the PCC. PI controllers are utilized in the proposed control method. The paper also includes results obtained from HIL simulations conducted under different case studies. The proposed method demonstrates satisfactory performance, even when subjected to variations in speed, irradiances, and loads, including unbalanced load conditions.

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