Power Quality Analysis Using Active NPC Multilevel inverter in PV sourced stand alone micro grid system

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Abstract - *In order to connect solar arrays to the utility grid, power electronic converters were created. The PV array's direct current power must be converted into the alternating current needed for loads by inverters. These days, multilevel inverters are quite common in photovoltaic systems. Compared to ordinary inverters, multilevel inverters provide several benefits, particularly for high power applications. The advantages include enhanced output waveforms due to the nearly sinusoidal output voltage waveforms created by the multilevel inverter, and minimal overall harmonic distortion. To enhance power quality, the ANPC multilevel inverter performance is assessed. This paper provides the results of the simulation demonstrated that the suggested ANPC Multilevel inverter produces fewer harmonic in the micro grid system when validated against conventional inverters. The proposed system is simulated in MATLAB/Simulink software 2018b.*

Key Words: SPV, Multi level inverter, SPWM.

1. INTRODUCTION

A photovoltaic system, often identified as a PV system, is a device that uses sunshine to generate energy. Solar cells are devices that directly convert solar energy into electrical power. The materials used to make these cells are semiconducting. These materials absorb solar energy, which causes electrons to be released from their atoms. This allows the electrons to move through the material and generate electricity [1-2]. The cells use direct current (DC) to convert the power. A DC-to-AC inverter is required for a PV system that is correlated to the grid. The PV array's [3] DC power will be converted into alternating current using this device. One of the previously stated power sources is a photovoltaic system. The distribution network is affected in several ways by the DC-to-AC converter. Because the inverters' capacitance is excessively high, harmonic issues arise. High harmonic currents and voltages result from resonance issues that arise when harmonics occur. Multilevel inverters are an excellent option for PV system applications that require DC-to-AC conversion. This is because of the fact that it offers a good number of benefits. Power losses are eliminated and transformerless multi-level inverter topologies take the role of voltage source inverters. In order to see an increase in power quality, the result of the multilevel inverter simulation will be compared to that of a traditional inverter, with a particular emphasis on total harmonic distortion (THD). Thus, the multilevel inverter's best level will be determined.

A Proposed three leg 5L Active NPC multi level inverter with sinusoidal PWM technique produces low THD by applying switching states is used to convert the DC quantities to three phase AC quantities which is provided to local loads in PV system.

2. Multilevel Voltage-Source Inverters

Power electronic converters known as multilevel voltage-source [4] inverters (VSIs) are employed in a variety of settings, including as renewable energy systems, motor drives, and the transmission of high-voltage direct current (HVDC). These inverters are made to synthesize an output voltage waveform from many different DC voltage sources, giving rise to a stepped or multilayer waveform. When compared to conventional two-level inverters, multilevel inverters provide the benefit of producing an output voltage that is almost sinusoidal, with a lower harmonic content and less voltage stress on the switching components. They are therefore especially well-suited for applications requiring high voltage levels and high-quality voltage waveforms. The different multilevel inverters are

Diode-Clamped Multilevel Inverter (Neutral-Point Clamped Inverter): This type of multilevel inverter uses diodes and clamping diodes to connect several DC voltage sources in series. The voltage levels at the output are determined by the number of voltage sources used and the clamping diode [5] configuration. Common configurations include two-level, three-level, and five-level inverters. They are relatively simple and cost-effective but are limited in scalability.

Flying Capacitor Multilevel Inverter: Flying capacitor inverters use capacitors to create intermediate voltage levels between the DC voltage sources. The voltage levels are controlled by dynamically adjusting the charging and discharging of the capacitors [6]. Flying capacitor inverters can achieve a high number of voltage levels and are suitable for medium-voltage applications. FC not used in RES since they need more capacitors which increase complexity of techniques to balance.

Hybrid Multilevel Inverter: Hybrid multilevel inverters combine two or more of the above-mentioned topologies to take advantage of their specific benefits. For example, a hybrid inverter may combine a diode-clamped inverter [7-8] with a cascaded H-bridge inverter to accomplish a balance between complexity, cost, and performance. The main disadvantage is the use of isolated DC sources for each H bridge.

3. Proposed Active Neutral Point Clamped-5Level converter

The ANPC-5L converter one leg in three phase shown in Fig. 1 has been paid more and more attention since it was proposed, and is the combination of two types of inverters. One is the FC three-level inverter and the other is the active NPC three-level inverter. The advantages of this inverter consist of low switching losses and the convenience of capacitor voltage balance. Switches are connected in series in this topology switch at fundamental frequency, while the others switch at carrier frequency. Meanwhile, the switching cost of this topology is low because the stress of the switches is $V_{DC}/4$, while V_{DC} is the voltage of DC-link. Moreover, if different switching states are chosen appropriately, the voltage of floating capacitors is easy to balance. Researchers have carried out a lot of work on ANPC-5L modulation technology, flying capacitor voltage control, neutral-point voltage control, and other issues. The modulation strategy of the ANPC-5L inverter is simple and reliable most of the time. On the other hand, less attention has been paid to the voltage stress of switching devices in ANPC-5L converters, and the voltage stress of switching devices is very important for the safe and reliable operation of inverters. Meanwhile, under the conventional modulation scheme, the analyzed inverter has the security risk of overvoltage in the power device when switching to dead time at the zero-crossing point of voltage when the output current is inductive, which affects the commutation safety. Each leg consist of 6 semiconductor switch and totally for multi 5-level inverter of 3 leg need 18 switches used to operate.

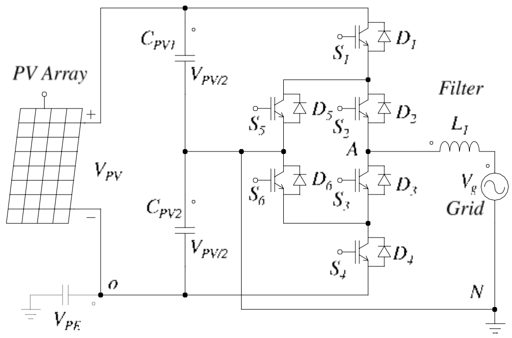

Fig. 1: ANPC-5L converter

5. Sinusoidal PWM

Phase-Shifted Pulse Width Modulation (PS-PWM), often referred to as Phase-Shifted Sinusoidal Pulse Width [9-10] Modulation (PS-SPWM), is a technique used in power electronics and motor control to regulate the voltage or current supplied to a load, typically in applications like inverters and motor drives. It is a modulation technique that generates a quasi-sinusoidal resultant waveform with reduced harmonic distortion.

In traditional PWM (Pulse Width Modulation), a square wave with a fixed frequency is generated, and the duty cycle of this square wave is adjusted to control the average voltage or current supplied to the load. This can result in a waveform with significant harmonic content. In PS-PWM, multiple PWM [11] signals are generated, each with the same frequency but with a phase shift relative to one another of 120 degree each. These phase-shifted PWM signals are typically sinusoidal in shape. The phase-shifted PWM signals are then combined, usually by summing them together. The result is a composite waveform that approximates a sinusoidal waveform. By adjusting the phase shifts and amplitudes of the individual PWM signals, controlling of the shape and magnitude of the output waveform is done. One of the primary advantages of PS-PWM is its ability to reduce harmonic distortion in the output waveform. By appropriately choosing the phase shifts between the PWM signals, certain harmonic components can be cancelled out, leading to a smoother, more sinusoidal output. PS-PWM permits the accurate control over the output voltage or current, making it proper for applications where a clean and controlled waveform is required. PS-PWM is commonly used in high-power applications, such as variable frequency drives (VFDs) for motors and grid-tied inverters for renewable energy systems. It helps improve the overall efficiency and reduce electromagnetic interference (EMI) in these systems.

6. Switching states in a 5-level multi-level inverter

Switching states [12] in a 5-level multi-level inverter involve configuring the switching devices (typically insulated gate bipolar transistors or IGBTs) in different combinations to generate the desired output voltage levels. Multi-level inverters are commonly used in high-power applications where higher voltage and lower harmonics are required. A 5-level inverter typically has five voltage levels, which are achieved by varying the states of the switching devices. The most common configuration is the Active Neutral-Point Clamped (ANPC) inverter, which provides five voltage levels (0, ±Vdc/2, ±Vdc).

Working of switching states in a 5-level ANPC inverter is

Zero Voltage State (ZVS): In this state, all of the upper and lower switching devices are turned off. This results in an output voltage of 0V. First Voltage Level (+Vdc/2): To achieve this voltage level, the upper switches of one leg are turned on while the lower switches are turned off. The other legs remain in the ZVS state. Second Voltage Level (-Vdc/2): To achieve this voltage level, the lower switches of one leg are turned on while the upper switches are turned off. The other legs remain in the ZVS state. Third Voltage Level (+Vdc): In this state, both the upper and lower switches of one leg are turned on. The other legs remain in the ZVS state.Fourth Voltage Level (-Vdc): In this state, both the upper and lower switches of one leg are turned on, but the polarity is reversed compared to the third level. The other legs remain in the ZVS state.

By carefully controlling the switching states of the legs of the inverter, the desired output voltage waveform is generated with five different voltage levels. The specific switching sequence and PS-PWM technique is used as a control strategy and the requirements of the application, such as minimizing harmonics and achieving a particular output voltage is obtained.

In order to minimize switching losses and minimize harmonic distortion, the inverter's switching states are determined with the use of pulse width modulation (PWM) methods. The 5-level inverter's performance and efficiency are greatly impacted by the selection of modulation technique and control strategy [13–15], which is superior to the traditional way. As eight switches are often utilized, the suggested architecture uses six switches each leg. This benefit lowers switching and conduction losses. Particular consideration should be given to THD in PV applications. The inverter's switching states are displayed in Table 1.

Table 1: The switching states of 5-level multi inverter

Inverter Output Voltage	Sw1	Sw2	Sw3	Sw4	Sw5	Sw6
+2	1	1	0	0	0	1
+1	1	0	1	0	0	1
+1	0	1	0	0	0	1
+0	0	0	1	0	0	1
-0	0	1	0	0	1	0
-1	0	0	1	0	1	0
-1	0	1	0	1	1	0
-2	0	0	1	1	1	0

7. Simulation

The simulation parameters are provided in the Table 2.

Table 2: Simulation parameters

Parameters			Values
PV Source	Voltage		120 V
	Power		90 KW
	Boost Converter	Inductor	58 µH
		Capacitor	2.2 mF
		Switching Frequency	10 KHz
Load	Voltage		415 V
	Frequency		50 Hz
Load Arrangements	Linear Loads	ABC	50 KW
	Non Linear Load	R	10Ω
	Unbalanced Loads	Phase - A	15Ω
		Phase - B	8Ω
		Phase - C	12Ω

The PV source is connected to the boost converter and provided to active NPC inverter. The inverter supplies the load. The unbalanced load is disconnected initially until t=0.7s. The PV power reduced as the irradiation reduced from 1000W/m2 to 900W/m2 at t=0.8s and recovered at t=0.9s. The PV Voltage, current and power is shown in the Fig. 2 waveforms.

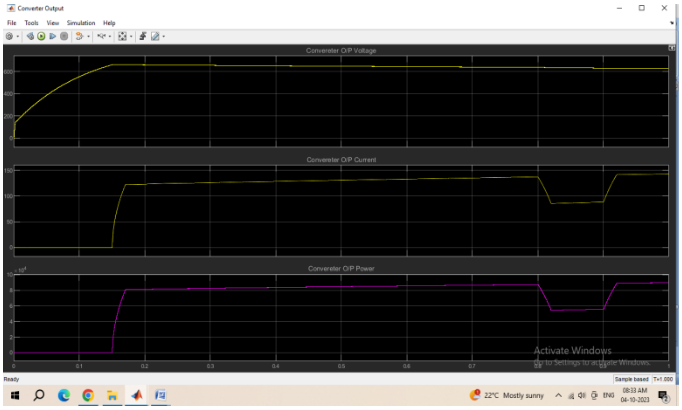

Fig. 2. PV Voltage, Current and Power with UPQC

In this base system with UPQC the reference voltage of amplitude 415V and frequency 50 Hz is compared with the load voltage and the error is provided to hysteresis control which generates the pulses for the voltage source inverter which is connected in series with the system. In the reference dc voltage of amplitude 400V is compared with the measured dc voltage and the error is provided to PI control which generates the Power loss which is again compared with measured power oscillations so as to generate the power compensation signal which is used to generate reference compensation current and compared with output filter current and the error current is provided to hysteresis control which generates the pulses for the voltage source inverter which is connected in parallel with the system. Hence the voltage sag is removed as well as the oscillations in current waveforms are minimized. Simulation circuit of Base system with UPQC with conventional inverter is depicted in Fig. 3.

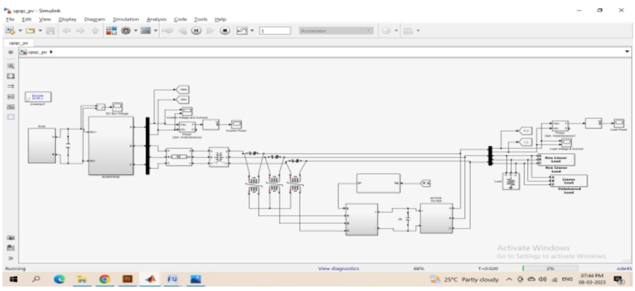

Fig. 3. Simulation circuit of Base system with UPQC

The %THD of the load current with upqc with conventional inverter is 1.2% shown in Fig 4. Simulation circuit of base system with UPQC with 5-level inverter is shown in Fig. 5. In the proposed base system with upqc with 5L-ANPC gate pulses are given to each switch as of Table 1 shown. Phase shift of 120 degree applied for each leg. The load voltage and current with upqc with 5L-ANPC is shown in Fig. 6. The %THD of the load current with upqc with five level mli is around 0.39% shown in Fig. 7. Modulation index is taken as 1.

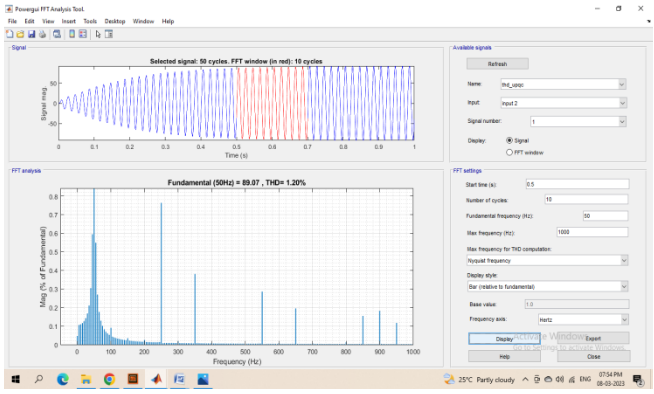

Fig. 4. %THD of load current with upqc with conventional inverter.

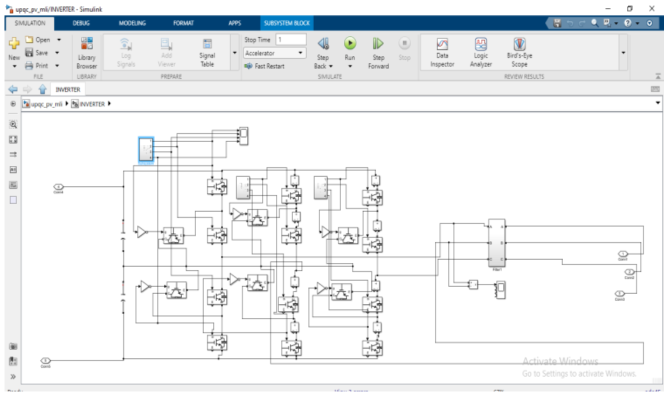

Fig. 5. Simulation circuit of Base system with UPQC with 5-level inverter.

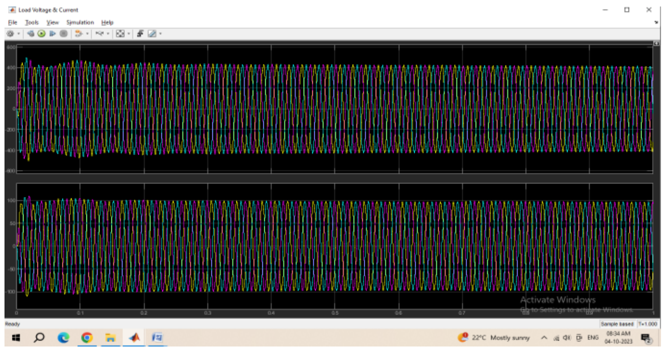

Fig. 6. load voltage and current with upqc with 5L-ANPC MLI.

In the time interval of t=0.8s to 0.9s, the generated power is reduced due to the reduction in irradiation and during this interval, upqc injects the power. The efficiency of the system during steady state conditions are around 78.65%. The comparison of proposed system with five level anpc and conventional inverter is shown in Table 3.

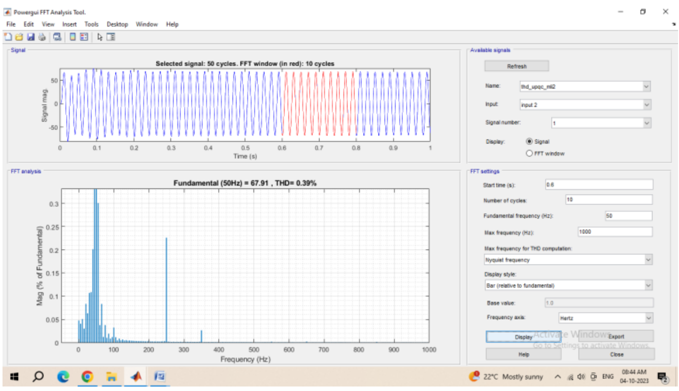

Fig. 7. %THD of load current with upqc with 5L-ANPC MLI.

Table 3: The comparison of five level ANPC and Conventional inverter

SN	Inverter level	Load Power(KW)	Power Loss(KW)	%Efficiency	%THD	No of Switches
1	2 level	67	21	76.54	1.2	6
2	5 level	70	19	78.65	0.39	18

Table 4: The comparison of SPWM with other PWM technique

Ref/Year	Voltage	fs	Output level	Strategy	THD
[16]/ 2015	450V	5kHz	5	Proportional resonant control	<2%
[17]/ 2020	600V	10kHz	5	Multi modulation SPWM	<5%
Proposed Method	400V	5kHz	5	SPWM	0.5%

The Table 3 presents a comparative analysis between ANPC and Conventional inverter schemes. It can be appreciated that load power improved by 3KW and power loss reduced by 2KW. There is improvement of efficiency by 2.11% . THD is shown as 0.39% which show the improve in the power quality and system strength. The Stress on the switches is reduced by using medium voltage high power transistors.

The authors in [16-17] show two control methods based on proportional resonant control and multimodulation SPWM to lower THD. The proposed method had reduced maximum total harmonics to 0.39% which formulate the system much more reliable and efficient in performance.

8. Conclusion

Numerous benefits led to the acceptance of multilevel inverter use in PV systems in the power grid. A multilevel inverter with more levels will function better inside the system. In this paper, based on the calculations and findings presented in the analysis, a 5-level multilevel inverter performed as a standard inverter by 2.11% in terms of efficiency and THD by 0.39%.

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