

Solar PV and Battery Storage Integration Using a NPC Inverter

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Abstract:

In this paper, a novel configuration of a five-level neutral- point-clamped (NPC) inverter that can integrate solar photo voltaic (PV) with battery storage in a grid-connected system is proposed. The strength of the proposed topology lies in a novel, extended unbalance five-level vector modulation technique that can generate the correct ac voltage under unbalanced dc voltage conditions. This paper presents the design philosophy of the proposed configuration and the theoretical framework of the proposed modulation technique. A new control algorithm for the proposed system is also presented in order to control the power delivery between the solar PV, battery, and grid, which simultaneously provides maximum power point tracking (MPPT) operation for the solar PV. The effectiveness of the proposed methodology is investigated by the simulation of several scenarios, and THD is calculated for both levels including battery charging and discharging with different levels of solar irradiation.

Index Terms:

Battery storage, solar photovoltaic (PV), space vector modulation (SVM), three-level inverter, and five-level inverter, maximum power point tracking (MPPT).

1. Introduction:

Due to the world energy crisis and environmental problems caused by conventional power generation, renewable energy sources such as photovoltaic (PV) and wind generation systems are becoming more promising alternatives to replace conventional generation units for electricity generation [1], [2]. Advanced power electronic systems are needed to utilize and develop renewable energy sources. In solar PV or wind energy applications, utilizing maximum power from the source is one of the most important

functions of the power electronic systems [3]–[5]. In three-phase applications, two types of power electronic configurations are commonly used to transfer power from the renewable energy resource to the grid: single-stage and double-stage conversion. In the doublestage conversion for a PV system, the first stage is usually a dc/dc converter and the second stage is a dc/ac inverter. The function of the dc/dc converter is to facilitate the maximum power point tracking (MPPT) of the PV array and to produce the appropriate dc voltage for the dc/ac inverter. The function of the inverter is to generate three phase sinusoidal voltages or currents to transfer the power to the grid in a grid-connected solar PV system or to the load in a stand-alone system [3]–[5].

In the single-stage connection, only one converter is needed to fulfill the double-stage functions, and hence the system will have a lower cost and higher efficiency, however, a more complex control method will be required. The current normal of the industry for high power application is a three-phase, single stage PV energy systems by using a voltage-source converter (VSC) for power conversion [4]. One of the major concerns of solar and wind energy systems is their unpredictable and fluctuating nature. Grid-connected renewable energy systems accompanied by battery energy storage can overcome this concern.

This also can increase the flexibility of power system control and raise the overall availability of the system [2]. Usually, a converter is required to control the charging and discharging of the battery storage system and another converter is required for dc/ac power conversion; thus, a three phase PV system connected to battery storage will require two converters. This paper is concerned with the design and study of a grid-connected three-phase solar PV system integrated with

battery storage using only one five-level converter having the capability of MPPT and ac-side current control, and also the ability of controlling the battery charging and discharging. This will result in lower cost, better efficiency and increased flexibility of power flow control.

II. STRUCTURE OF A THREE-LEVEL INVERTER AND ITS CAPACITOR VOLTAGE CONSIDERATIONS

A. Three-level Inverter:

Since the introduction of Three-level inverters in 1981 [6], [7], they have been widely used in several applications, such as: motor drives, STATCOM, HVDC, pulse width modulation (PWM) rectifiers, active power filters (APFs), and renewable energy applications [7], [8]. Fig. 1(a) shows a typical three phase three-level neutral-point clamped (NPC) inverter circuit topology.

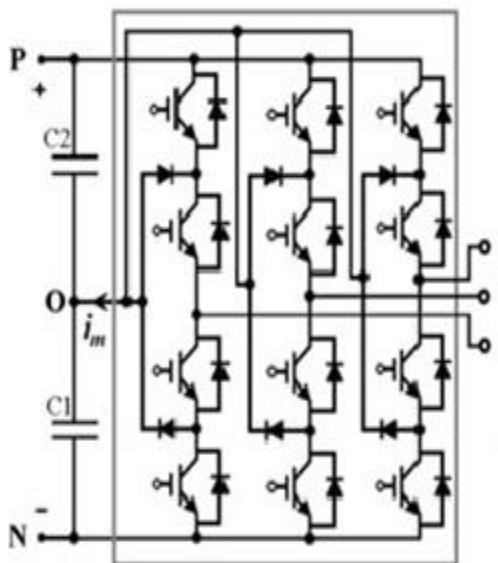


Fig. 1. Typical three-level inverter (a) structure of circuit,

The converter has two capacitors in the dc side to produce the three level ac-side phase voltages. Normally, the capacitor voltages are assumed to be balanced, since as has been reported that unbalanced capacitor voltages can affect the ac side voltages and can produce unexpected behavior on system

parameters such as even-harmonic injection and power ripple [7], [9]. Several papers have discussed methods of balancing these capacitor voltages in various applications [6],[7],[9]–[16].

B. Balanced Capacitors Voltage:

Various strategies have been proposed to balance the capacitor voltages using modulation algorithms such as sinusoidal carrier based PWM (SPWM) or space vector pulse width modulation (SVPWM) [17]. In SPWM applications, most of the strategies are based on injecting the appropriate zero-sequence signal into the modulation signals to balance the dc-link capacitors [12], [13], [16], [18]. In SVPWM applications, a better understanding of the effects of the switching options on the capacitor voltages in the vector space has resulted in many strategies proposed to balance capacitor voltages in the three-level NPC inverter. These include capacitor balancing using conventional SVPWM, virtual SVPWM (VSVPWM) and their combination [14], [15], [19]. In vector control theory, ideally, the inverter must be able to generate the voltage output instantaneously, following the reference vector (V_{ref}), generated by the control system.

However, because of the limitation of the switches in the inverter, it is not possible to guarantee that any requested vector can be generated; as a matter of fact, only a limited number of vectors (27 vectors for five-level inverter) can be generated. To overcome such difficulties, in any space vector modulation (SVM) scheme such as SVPWM and VSVPWM, the reference vector V_{ref} is generated by selecting the appropriate available vectors in each time frame in such a way that the average of the applied vectors must be equal to the reference vector. Equation (1) shows the mathematical relation between the timing of the applied vectors and the reference vector.

$$\begin{cases} T_s \vec{V}_{ref} = \sum_{i=1}^n T_i \vec{V}_i \\ T_s = \sum_{i=1}^n T_i \end{cases} \quad (1)$$

Where T_s is the time frame and preferred to be as short as possible. It can be considered as a control update period where an average vector will be mathematically generated during this time duration. T_i is the corresponding time segment for selected inverter vector V_i and n is the number of applied vectors. Generally, the reference vector is generated by three different vector ($n = 3$), and (1) can be converted to three different equation with three variables T_1, T_2 , and T_3 to be calculated. Several vector PWM techniques presented in [6], [7], [9]–[11], and [13]–[15] apply similar technique of timing calculation. They are six long vectors (200, 220, 020, 022, 002, and 202), three zero vectors (000, 111, and 222), six medium vectors (210, 120, 021, 012, 102, and 201), six upper short vectors (211, 221, 121, 122, 112, and 212), and six lower short vectors (100, 110, 010, 011, 001, and 101). For generating V_{ref} , when one of the selections (V_i), is a short vector, then there are two choices that can be made which can produce exactly the same effect on the ac side of the inverter in the three wire connection (if voltages are balanced). For example, the short vector “211” will have the same effect as “100” on the ac side of the inverter. However, this choice will have different effect on the dc side, as it will cause a different dc capacitor to be chosen for the transfer of power from or to the ac side, and a different capacitor will be charged order charged depending on the switching states and the direction of the ac side current. For example, Fig. 2 shows the connection of the capacitors when “100” or “211” is selected, demonstrating how different capacitors are involved in the transfer of power. Capacitor balancing in most reported five-level NPC inverter applications is achieved by the proper selection of the short Vectors.

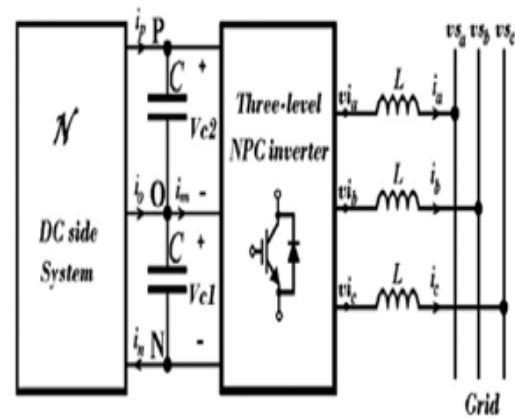
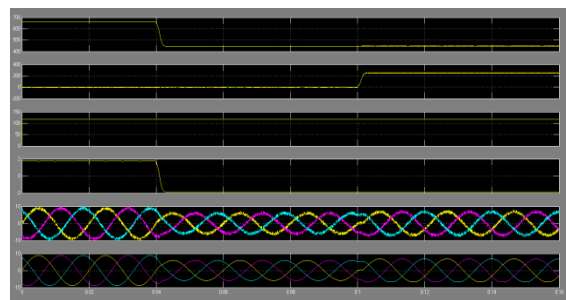


Fig.2 General diagram of a grid connected three-wire three-level inverter.

Although the control system is trying to ensure balanced capacitor voltages, should any unbalance occur during a transient or an unexpected operation, the above method will produce an inaccurate ac-side waveform which can be different from the actual requested vector by the control system. This can result in the production of evenharmonics, unbalanced current and unpredicted dynamic behavior. However, in some applications, the requirement of having balanced capacitor voltages may be too restrictive. It is possible to work with either balanced or unbalanced capacitor voltages. The method proposed in this paper is based on the freedom of having balance or unbalanced capacitor voltages. In such applications, it is important to be able to generate an accurate reference vector based on (1), irrespective of whether the capacitor voltages are balanced or not, to achieve the desired objectives of the system..

VI. SIMULATION RESULTS



Simulated results: (a) Active power injected to the grid. (b) Reactive power injected to the grid. (c) PV module DC voltage. (d) Battery current. (e) Inverter AC current. (f) Grid current.

VII. CONCLUSION:

A novel topology for a analysis of the five level and three level NPC voltage source inverter that can integrate both renewable energy and battery storage on the dc side of the inverter has been presented. A theoretical framework of a novel extended unbalance three-level vector modulation technique that can generate the correct ac voltage under unbalanced dc voltage conditions has been proposed. A new control algorithm for the proposed system has also been presented in order to control power flow between solar PV, battery, and grid system, while MPPT operation for the solar PV is achieved simultaneously. The results demonstrate that the proposed system is able to control ac-side current, and battery charging and discharging currents at different levels of solar irradiation. From the simulation results it has been analyzed that the three level NPC converters reduces the source current harmonic to 1.82% even it less than the IEEE STD 519, still the current suffers from harmonics. Hence a five level converter has been implemented and finally five level NPC converters reduce the source current harmonics to 0.56%. The effectiveness of the proposed 3 level NPC topology and control algorithm was tested using simulations and results are presented.

REFERENCES:

- [1] O. M. Toledo, D. O. Filho, and A. S. A. C. Diniz, "Distributed photo voltaic generation and energy storage systems: A review," *Renewable Sustainable Energy Rev.*, vol. 14, no. 1, pp. 506–511, 2010.
- [2] M. Bragard, N. Soltan, S. Thomas, and R. W. De Doncker, "The balance of renewable sources and user demands in grids: Power electronics for modular battery energy storage systems," *IEEE Trans. Power Electron.*, vol.25,no.12,pp.3049–3056,Dec.2010.
- [3] A. Yazdani and P. P. Dash, "A control methodology and characterization of dynamics for a photovoltaic (PV) system interfaced with a distribution network," *IEEE Trans. Power Del.*, vol. 24, no. 3, pp. 1538–1551, Jul. 2009.
- [4] A. Yazdani, A. R. Di Fazio, H. Ghoddami, M. Russo, M. Kazerani, J. Jatskevich, K. Strunz, S. Leva, and J. A. Martinez, "Modeling guidelines and a benchmark for power system simulation studies of three-phase singlestage photovoltaic systems," *IEEE Trans. Power Del.*, vol. 26, no. 2, pp. 1247–1264, Apr. 2011.
- [5] M. A. Abdullah, A. H. M. Yatim, C. W. Tan, and R. Saidur, "A review of maximum power point tracking algorithms for wind energy systems," *Renewable Sustainable Energy Rev.*, vol. 16, no. 5, pp. 3220–3227, Jun. 2012.
- [6] S. Burusteta, J. Pou, S. Ceballos, I. Marino, and J. A. Alzola, "Capacitor voltage balance limits in a multilevel converter-based energy storage system," in *Proc. 14th Eur. Conf. Power Electron. Appl.*, Aug./Sep. 2011, pp. 1–9.
- [7] L. Xinchun, Shan Gao, J. Li, H. Lei, and Y. Kang, "A new control strategy to balance neutral-point voltage in three-level NPC inverter," in *Proc. IEEE 8th Int. Conf. Power Electron. ECCE Asia*, May/Jun. 2011, pp. 2593–2597.
- [8] J. Rodriguez, S. Bernet, P. K. Steimer, and I. E. Lizama, "A survey on neutral-point-clamped inverters," *IEEE Trans. Ind. Electron.*, vol.57, no.7,pp.2219–230,Jul.2010.
- [9] A. Lewicki, Z. Krzeminski, and H. Abu-Rub, "Spacevector pulsewidth modulation for three-level npc converter with the neutral point voltage control," *IEEE Trans. Ind. Electron.*, vol. 58, no. 11, pp. 5076–5086, Nov.2011.
- [10] J. Pou, D. Boroyevich, and R. Pindado, "Effects of imbalances and nonlinear loads on the voltage balance of a neutral-point-clamped inverter," *IEEE Trans. Power Electron.*, vol. 20, no. 1, pp. 123–131, Jan. 2005.
- [11] Z. Huibin, S. Jon Finney, A. Massoud, and B. W. Williams, "An SVM algorithm to balance the capacitor voltages of the three-level npc active power



filter,” IEEE Trans. Power Electron., vol. 23, no. 6, pp. 2694–2702, Nov. 2008.

[12] J. Zaragoza, J. Pou, S. Ceballos, E. Robles, C. Jaen, and M. Corbalan, “Voltage-balance compensator for a carrier-based modulation in the neutral-point-clamped converter,” IEEE Trans. Ind. Electron., vol. 56, no. 2, pp. 305–314, Feb. 2009.

[13] W. Chenchen and L. Yongdong, “Analysis and calculation of zero sequence voltage considering

neutral point potential balancing in three level npc converters,” IEEE Trans. Ind. Electron., vol. 57, no. 7, pp. 2262–2271, Jul. 2010.

[14] S. Busquets-Monge, S. Somavilla, J. Bordonau, and D. Boroyevich, “Capacitor voltage balance for the neutral-point-clamped converter using the virtual space vector concept with optimized spectral performance,” IEEE Trans. Power Electron., vol. 22, no. 4, pp. 1128–1135, Jul. 2007.