ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

A New Configured Three Level NPC Inverter with Integrated Fuel Cell and Battery Storage

Racharla Naveen
M.Tech Student,
Department of EEE,
SSJ Engineering College.

Ch Vinay Kumar
Associate Professor,
Department of EEE,
SSJ Engineering College.

Abstract:

Fuel Cell is one of the favorable renewable energy resources and the multilevel inverter has been proven to be one of the important enabling technologies in Fuel Cell utilization. Fuel Cell systems are getting more and more widespread with the increase in the energy demand and the concern for the environmental pollution around the world. This paper proposes a Three level NPC (Neutral point clamped inverter) for Fuel Cell, connected battery across it and reference with Space vector pulse-width modulated (SVPWM) control scheme. Unpredictable and fluctuating nature of Fuel Cell system can be overcome by integrating Fuel Cell with the battery storage using three level inverter which is connected to the grid. Usually a converter is used for charging and discharging of the battery.

Index Terms:

Fuel Cell, NPC space vector pulse width modulation (SVPWM), three-level inverter.

I.INTRODUCTION:

In recent years, there has been an increasing interest in electrical power generation from renewable-energy sources, such as Fuel Cell photovoltaic (PV) or wind-power systems [1], [2]. The benefits of power generation from these sources are widely accepted.They are essentially inexhaustible and environmentally friendly. Among the different renewable energy sources possible toobtain electricity, Fuel Cell has been one of the most active research areas in the past decades, for grid-connected applications [3]–[9].

The exponential rate of growth in the worldwide cumulative Fuel Cell capacity is mainly due to enhancement in grid-connected inverter topologies.Fuel Cell systems require interfacing power converters between the Fuel Cell and the grid. These power converters are used for two major tasks. First, is to inject a sinusoidal current in to the grid. And second is to reduce the harmonics content inthe grid injected voltage and current. Normally there are two power converters [19]. The first one is a DC/DC power converterthat is used to operate the Fuel Cell at the maximum power point. The other one is a DC/AC power converter interconnect the Fuel Cell to the grid.The inverter is one of the power electronic system that commonly used in order to convert alternating current(AC) to direct current(DC).It can be single or Three phase system. These control involve utilizing the maximum power from Fuel Cell. Here, we mainly design and study the grid connected three phase Fuel Cell system integrated with the battery storage using three level inverter, AC side current control and ability to control the charging and discharging of battery. In this project we proposed Fuel Cell and battery storage integration with Three level NPC (Neutral point clamped inverter) with space vector pluse width modulation control strategy .The main purpose of this project is producing of high efficacy ,reduction of harmonics, improving max power quality.

II. PROPOSED SYSTEM:

A.Neutral-Point-Clamped (NPC) Multilevel Inverter:

One of the multilevel structures that has gained much attention and widely used is the Neutral-Point-Clamped multilevel inverter or also known as Diode Clamped multilevel inverter.

This structure wasfirst proposed by Nabae et. al in 1980 (Krug et. al., 2004; Marchasoni and Mazzucchelli, 1993). Figure1 shows the 3-level NPC inverter.Basically, NPC multilevel inverters synthesize the small stepof staircase output voltage fromseveral levels of DC capacitor voltages. An m-level NPC inverter consists of (m-1) capacitors on theDC bus, 2(m-1) switching devices per phase and 2(m-2) clamping diodes per phase. Figure 1 shows thestructure of 3-level NPC. The DC bus voltage is split into 3 levels by using 2 DC capacitors, C1 andC2. Each capacitor has Vdc/2 volts and each voltage stress will be limited to one capacitor level throughclamping diodes (Chaturvedi et. al., 2005; Lai and Peng, 1996).

The number of levels can be extended to a higher level by additional switching devices andwith these additions, the inverter will be able to achieve higher AC voltage, producing more voltagesteps that will be approaching sinusoidal with minimum harmonics distortion. During inverteroperations, the switches near the centre tap are switched onfor a longer period compared to theswitches further away from the centre tap as given in the switching states in Table 1. As the switch isfurther away from the centre tap the switching time is shorter.Another difference between theconventional 2-level and multilevel NPC is the clamping diode. In case of 3-level NPC inverter,clamping diode, D1 and D4 clamped the DC bus voltage into three voltage level, +Vdc/2, 0 and -Vdc/2 Diode, D4 balances out the voltage sharing between S4in and S4out, with S4in blocking the voltage acrossC1 and S4out blocking the voltage across C2

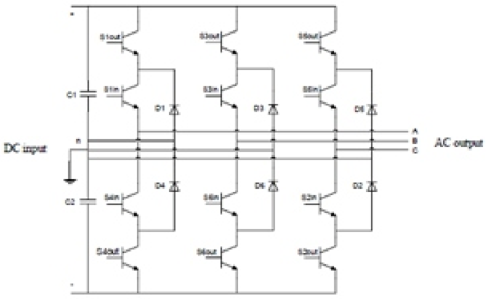

Figure 1: 3-level Neutral-Point-Clamped inverter.

NPC inverter has the following advantages as listed below (Rashid, 2001; Lai and Peng,1996):

1.For a high m-level, the distortion level of the harmonics content is so low that the use offilter is unnecessary.

2.Constraints imposed on the switches are low because the switching frequency may be lowerthan 500Hz.

3. Reactive power flow can be controlled.

4. Efficiency is high because all devices are switched at fundamental frequency.

5.Control method is simple for a back-to-back intertie system.

While the disadvantages are (Rashid, 2001)

1.The number of clamping diodes becomes excessively high with the increase in level.

2.It is becoming more difficult to control the power flow of the converter.

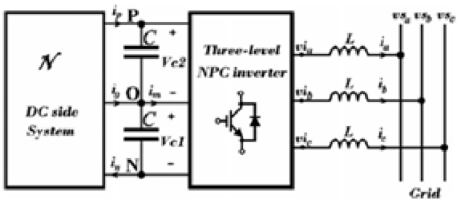

Fig: 2. General diagram of a grid connected three-wire three-level inverter

Fig. 2 shows a general structure of a grid-connected three-level inverter showing the DC and AC sides of the inverter. The DC side system, shown as N can be made up of many circuit configurations, depending on the application of the inverter. For instance, the DC side system can be a solar PV, a wind generator with a rectifying circuit, a battery storage system or a combination of these systems where the DC voltage across each capacitor can be different or equal. Mathematically, in a three-wire connection of a two-level inverter, the dq0 field, Vd , Vq and V0 of the inverter in vector control can be considered as having two degrees of freedom in the control system; because the zero sequence voltage,V0, will have no effect on the system behavior in both the DC and the AC side of the inverter.

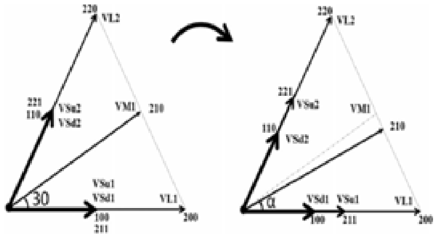

Fig: 3. Vector diagram in the first sector of Fig. 1(b) showing the change of the vectors using balanced dc and unbalanced dc assuming Vc1 < Vc2.

In the vector diagram shown in Fig. 1(b), capacitor voltage unbalance causes the short and medium vectors to have different magnitudes and angles compared to the case when the capacitor voltages are balanced. Fig. 3 shows the differences between twocases as highlighted in the first sector of the sextant in Fig. 1(b) for VC1 < VC2 . Vector related to the switching state _VI can be calculated as follows :

$$\vec{V}_I = \frac{2}{3}\left(V_{aN} + \vec{a}V_{bN} + \vec{a}^2 V_{cN}\right)$$

Whereas = ej(2 π3) and VaN , VbN and VcN are the voltage values of each phase with reference to “N” in Fig. 1(a). Assuming that the length of the long vectors ((2/3)V dc) is 1 unit and the voltage of capacitor C1, V c1 = hV dc, for 0 ≤ h ≤ 1, then the vectors in the first sector can be calculated using (2) and the results are given in (3)–(9)

$$\vec{V}sd1 = h \tag{3}$$

$$\vec{V}su1 = 1 - h \tag{4}$$

$$\vec{V}l1 = 1 \tag{5}$$

$$\vec{V}l2 = \frac{1}{2} + \frac{\sqrt{3}}{2}j \tag{6}$$

$$\vec{V}sd2 = h\left(\frac{1}{2} + \frac{\sqrt{3}}{2}j\right) \tag{7}$$

$$\vec{V}su2 = (1-h)\left(\frac{1}{2} + \frac{\sqrt{3}}{2}j\right) \tag{8}$$

$$\vec{V}m1 = \left(1 - \frac{h}{2}\right) + h\frac{\sqrt{3}}{2}j. \tag{9}$$

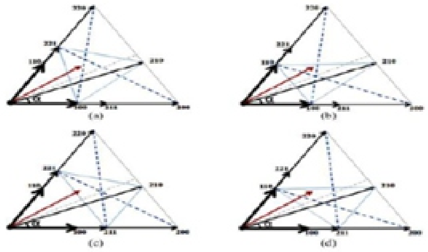

Fig: 4. Different possible vector selection ideas

Fig. 4 shows different possible vector selections to generate a reference vector (_V) in the first sector based on the selections of different short vectors. For example, to generate _V based on Fig. 4(a), one of following combinations can be selected with proper timing based on (1). The combinations are: (221–210–100), (221–220–100), (221– 200–100), (221–200–Zero), (000–220–Zero), (220–200–Zero), where “Zero” can be “000” or “111” or “222”. This demonstrates that there is flexibility in choosing the correct vector selections. Although all of these selections with suitable timing can generate the same reference vector, they have different impacts on the dc and ac side of the inverter in their instantaneous behavior.

III. PROPOSED TOPOLOGY TO INTEGRATE SOLAR PV WITH BATTERY STORAGE INTEGRATION:

Based on the discussions, two new configurations of a three-level inverter to integrate battery storage and Fuel Cell are proposed, where no extra converter is required to connect the battery storage to the grid connected Fuel Cell system. These can reduce the cost and improve the overall efficiency of the whole system particularly for medium and high power applications. The proposed system will be able to control the sum of the capacitor voltages (VC1 + VC2 = Vdc) to achieve the MPPT condition and at the same time will be able to control independently the lower capacitor voltage (VC1) that can be used to control the charging and discharging of the battery storage system. Further, the output of the inverter can still have the correct voltage waveform with low total harmonic distortion (THD) current in the ac side even under unbalanced capacitor voltages in the dc side of the inverter.

IV.CONTROL STRATEGY:

A Space Vector Modulation:

Space Vector Modulation is a technique where the reference voltage is represented as a referencevector to be generated by the power converter (Franquelo et. al, 2008). For the operation of 3-levelinverter, there are 3 switching states for each inverter leg; [P], [O] and [N]. [P] denotes that the uppertwo switches in leg A are on and the inverter terminal voltage, VANis+Vdc/2, while [N] means that thelower two switches are on with a terminalvoltage of -Vdc/2. Switching state [O] signifies that the innertwo switches are on with the terminal voltage equals to zero. There are a total of 27 combination ofswitching states for NPC inverter switching strategy for multilevel cascade inverters, based on the space-vector theory.

The proposed switching strategy generates a voltage vector with very low harmonic distortion and reduced switching frequency. [42], PWM technique for induction motor drives involving six concentric dodecagonal space vector structures is proposed. [43], novel space vector modulation (SVM) technique for a three-level five-phase inverter is based on an optimized five vectors concept. [44], switching strategy for multilevel cascade inverters, based on the space-vector theory. The proposed high-performance strategy generates a voltage vector across the load with minimum error with respect to the sinusoidal reference.

Two discontinuous multilevel space vector modulation (SVM) techniques are implemented for DVR control to reduce inverter switching losses maintaining virtually the same harmonic performance as the conventional multilevel SVM for high number of levels. [35], two carrier-based modulation techniques for a dual two-level inverter with power sharing capability and proper multilevel voltage waveforms were introduced. Their main advantage is a simpler implementation compared to SVM. [36], focused a novel 3-D space modulation technique with voltage balancing capability for a cascaded seven-level rectifier stage of SST.

V. SIMULATION RESULTS:

Simulation Circuit:

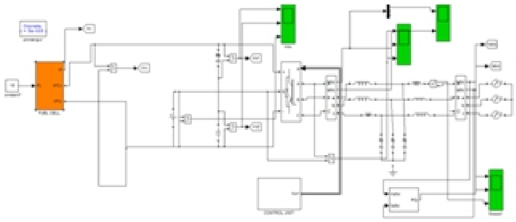

Fig.5. Matlab Simulation Circuit

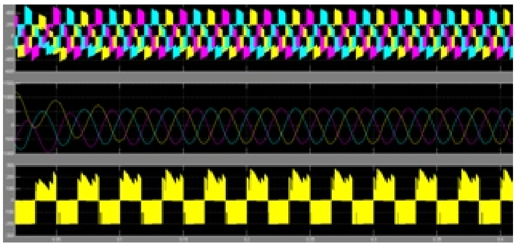

Fig.6. a)3 phase npc voltage levels, b) NPC 3 phase Current and c) Vao

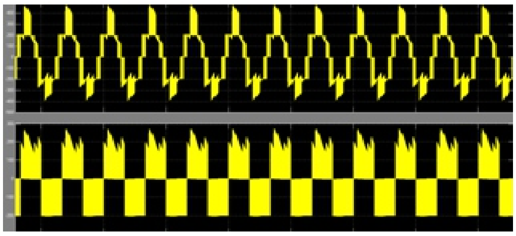

Fig.7. Vab-Phase to phase inverter voltage. (b) Vao-Inverter phase voltage reference to midpoint

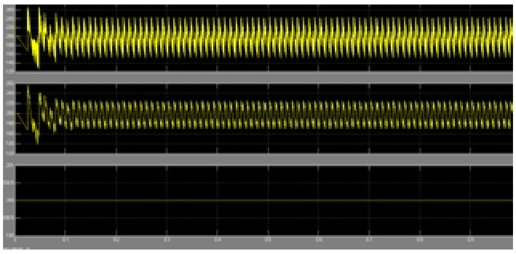

Fig.8. a)Vdc1 b)Vdc2 and c)Battery.

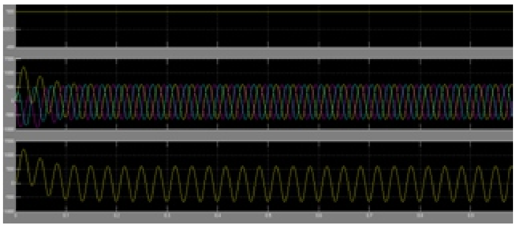

Fig.9. a)Power ,b)3 ph Grid Current & c)1 ph grid current.

VI. CONCLUSION:

A novel topology for a 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 Fuel Cell, battery, and grid system, is achieved. The effectiveness of the proposed topology and control algorithm was tested using simulations and results are presented.

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Authors Details:

RACHARLA NAVEEN Received B.Tech degree from PIRM Engineering College, chevella, Rangareddy, Telangana in 2009. Currently pursuing M.Tech in Power Electronics at SSJ Engineering College, V.N pally, RR dist., Telangana and he is a Research Fellow in DRDO, His area of interest in Renewable Energy sources and Power Electronics. He had an experience of 14 months as a Junior Research Fellow in Defence Production and Research.

CH VINAY KUMAR Obtained his B.TECH (EEE) degree from ST.MARTINS ENGG COLLEGE, HYD., M.Tech. (Power Electronics) from JNTU Hyderabad. Currently he is working as Assoc. Prof. in SSJ Engineering college, Hyderabad. His areas of interest include Power Electronics & Drives, Power systems and Facts. He is having 8 years of teaching experience