Hysteresis Control 3-Level SI-NPC Inverter with Wind Energy System

K. Selvakumar[1], R. Palanisamy[2], K.Vijayakumar[3], D.Karthikeyan[4], D.Selvabharathi[5], V.Kubendran[6]
Departement of Electrical and Electronics Engineering, SRM University, Kattankulathur, Chennai

Article Info

Article history:
Received Sep 17, 2017
Revised Nov 7, 2017
Accepted Nov 23, 2017

Keyword:

Diode-clamped three level inverter (DC-TLI)
Wind Energy System
Hysteresis Current control
dSPIC microcontroller

ABSTRACT

The system is a 3-level Neutral point clamped hysteresis current controlled Inverter with Wind energy as power source. The input DC Power for the multi-level inverter is drawn from wind turbine generator connected through a rectifier circuit. An inductor has been introduced for smoothening the DC output from the rectifier. The inverter uses Neutral Point Clamped topology. The switching pulses for the inverter are achieved by hysteresis current control technique. This system is advantageous over the conventional SPWM based system as the hysteresis current control allows to reduce the low frequency harmonics while also allowing to control the fundamental amplitude depending on frequency. The outputs for the system are verified using MATLAB simulations. The hardware for Hysteresis current control for the inverter is implemented by using a dSPIC microcontroller. The proposed system can be implemented in households for supplying backup power in case of power shortage and can also be used as a primary power source if wind flow is abundant. It is easy to implement, economical and provides clean energy.

Corresponding Author:

R. Palanisamy,
Departement of Electrical and Electronics Engineering,
SRM University, Kattankulathur, Chennai
Email: krspalani@gmail.com

1. INTRODUCTION

In the midst of the current energy crisis, the need for the use of Renewable energy sources has become utterly important for driving mankind and his machines. Reckless exploitation of the non-renewable energy sources such as fossil fuels since the Industrial age has caused an alarming downfall in the reserves of non-renewable sources of energy besides deteriorating the environment to a critical level[1]. Among various such renewable sources such as solar energy, tidal energy, geothermal energy and others, wind energy is one of the cleanest and efficient forms of energy. Wind energy can be generated in any part of the world where suitable environmental and terrain conditions can be achieved. Wind is caused by the uneven heating of the atmosphere by the sun, variations in the earth's surface, and rotation of the earth. The kinetic energy of wind can be converted to electrical energy to meet our requirements using a wind turbine [2]. Wind energy is the second fastest growing source of electrical energy in the world with a capacity of 432,883 MW (till the end of 2015).

The general structure of multilevel inverter is to integrate a sinusoidal voltage from several levels of voltage. It consists of an array of semiconductor devices and capacitor voltage sources, with output voltage in a stepped manner. In such inverters, parameters such as voltage magnitude can be controlled and harmonics can be supressed. Power rating can be enhanced by increasing the voltage level [3]. The concept of Multilevel inverters aims to reduce the harmonic content in output waveform without decreasing power output from the inverter. The most commonly used multilevel topology is diode clamped type. Diode clamped topology uses diodes as the clamping device to clamp DC bus voltage in order to achieve multiple steps in the output voltage. The main concept of this topology is to use diodes for limiting the voltage stress in the power device. A ‘n’ level inverter uses (n-1) number of voltage sources, 2(n-1) number of switching devices and (n-1) (n-2) number of diodes [4]. The voltage over each capacitor and each switch is Vdc. The quality of the output voltage can be improved by increasing the number of voltage levels and thus, the voltage waveform becomes closer to sinusoidal waveform[5].

In conventional inverters, as the demand for active power conversion and high frequency convertors are increasing the associated switching losses and harmonics content of the source are also been increasing. Hence for generating triggering pulses Hysteresis current control method is been introduced in the project. Due to its simple design, it is easy to implement and also has fast response time. By implementing this technique better stability and efficiency can easily be achieved as higher level harmonics are eliminated by the system. One of the other advantages of hysteresis current control technique is that upper and lower threshold level for the output waveform can easily be determined. Until the threshold has been achieved the output of the circuit remains constant. The existing system in this field include current regulator techniques which are based on the hysteresis control along with switch logic[6]; Current control technique for a single-phase five-level inverter with flying-capacitor topology [7]; hysteresis current controlled dual-buck half bridge inverter, hysteresis current method for active power filter based on voltage space vector and hysteresis-band current tracking control of grid-connected inverter[3];

The proposed system is a 3-level Neutral point clamped hysteresis current controlled Inverter with Wind energy as power source. The simulated input power is generated from a 6-turbine doubly-fed induction generator (DFIG) with a 9-MW(6x1.5MW) power rating. The power is fed to the inverter via 6-diode bridge rectifier. An inductor is introduced in series for smoothening the DC output current. This output is then fed to the input of the 3-Level Neutral Point Clamped inverter with hysteresis current control. The switching pulses for current control are obtained by using hysteresis current control technique for 6 pairs of IGBT switches with 2-Pairs on each leg. The output from each leg of the inverter is fed to the 3-phase load via inductors connected in series as to obtain smoother output the block diagram of the proposed system is shown in Figure 1.

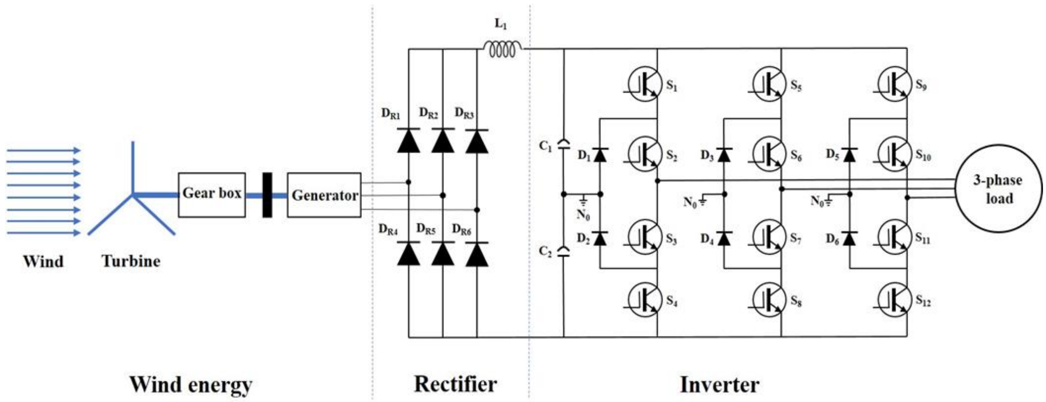

Figure 1. Block diagram of proposed system

2. WIND ENERGY SYSTEM

Wind energy is one of the fastest growing sectors in the field of renewable energy. The wind pattern across different regions in the world varies and so is the opportunity to harness wind energy in different regions across the globe. Wind energy is best harnessed in those regions where wind speed is sufficient and available always to drive the wind turbines [8]. A single wind turbine setup does not generate enough energy to supply power commercially. So many number of wind turbines are setup together in an area which collectively generate electrical energy. A group of wind turbines present in the same location to produce electricity is termed as Wind Farm. A wind farm may contain hundreds of standalone wind turbines which collectively produce power in the ranges of several Megawatts. This power can be then supplied commercially to the users via transmission and distribution systems. India has a vast reserve of wind power spread across North, South and West regions. The current installed capacity in India is 28,082.95 MW [9].

Several types of wind turbine designs have been developed since its initial development. The two basic types of wind turbines are Horizontal Axis Wind Turbine(HAWT) and Vertical Axis Wind Turbine(VAWT). In HAWT the blades run on an axis parallel to the ground and in VAWT the blades run on an axis perpendicular to ground. The Horizontal Axis Wind turbine is widely used in modern applications. A Wind turbine consists of several key components which can be widely classified as the Tower, Rotor Hub, Blades and Nacelle Enclosing (Low speed shaft, Gearbox, Generator and Electrical controls).

Amount of energy present in the wind widely varies due to three major factors: Wind speed, Wind Density and are swept by the wind turbine. The Wind energy equation can be formulated depending on these factors as:

$$P=0.5\rho AV3 \quad (1)$$

Where P is the wind power; ρ is the wind density; A is the area swept by the wind turbine and V is the velocity of air. Denser air will lead to more energy being received by the turbine. The air is denser at sea level as compared to higher elevations and cold air is denser than warm air. Turbines will produce more energy in areas where average temperatures are low and elevation is low. The area swept by the turbine is given by $A=\pi r2$, where r is the length of the blade. Larger the area swept by the turbine, more power is captured by the turbine. A small increase in the length of the blade thus leads to a large increase in the available power. Wind Power is directly proportional to the cube of wind speed. Thus, a small change in wind speed leads to a much larger change in the available power [10].

3. MULTI-LEVEL INVERTER

Modern day Multi-level inverters produce near sinusoidal output voltage using several levels of DC input voltage for High power medium voltage applications with lesser disturbance in voltage while functioning at lower switching frequencies in contrast to the conventional two-level inverters. As the number of levels in the output voltage waveform increases, it leads to smoother sinusoidal output voltage. Multi-Level inverters are in many ways advantageous over two-level inverters as they can generate output voltages with very low distortion and reduce dv/dt stresses, they can operate at both fundamental frequency and high switching frequency pulse width modulation, they have lower line-to-line and common-mode voltage steps and output current ripple for the same switching frequency is lower than that of a two-level inverter [11].

There are three major topologies available for multi-level inverters that are Cascaded H-Bridge topology, Flying Capacitor topology and Neutral Point Clamped or Diode Clamped topology. The proposed system incorporates Neutral point clamped Topology (Diode-Clamped Topology) [12]. The system is a Voltage Source Inverter as the input voltage level is maintained constant. The basic idea of this topology is to use diodes and generate multi-level voltages through different phases. The 3-Level approach reduces the complexity of the switching circuit. There are three legs present in the system with each leg comprising of four IGBT Switches connected in series. Two diodes are connected across each leg in parallel to prevent turning on of the wrong pair of switches [13]. The input Voltage is Vdc. Leg-1 has the following switches-S1, S2, S3 and S4. These switches can have three switching configurations; S1-S2 are ON and S3-S4 are OFF giving output +Vdc/2; S2-S3 are ON and S1-S4 are OFF giving output 0 as the diodes short circuit and no outputs is generated; S3-S4 are ON and S1-S2 are OFF giving output -Vdc/2. Similarly Leg-2 and Leg-3 have three configurations each for S5, S6, S7, S8 and S9, S10, S11 and S12 respectively. Combining all these switching sequences, total of 27 configurations can be achieved.

3.1. Mode of Operation with reduced switches

A total of 27 switching modes can be achieved using the 6-pairs of IGBT switches present on the three legs of the inverter. Four modes of operation are depicted in the following figures. In Figure 3(a), Switches S1-S2 are ON and S3-S4 are OFF in the first leg giving output +Vdc/2, current flows from Source-S1-S2-Load. Switches S7-S8 are ON and S5-S6 are OFF in the second leg giving output -Vdc/2, current flows from Source-S8-S7-Load. Switches S9-S10 are ON and S11-S12 are OFF in the third leg giving output +Vdc/2, current flows from Source-S9-S10-Load.

In Figure 3(b), Switches S3-S4 are ON and S1-S2 are OFF in the first leg giving output -Vdc/2, current flows from Source-S4-S3-Load. Switches S6-S7 are ON and S5-S8 are OFF in the second leg causing the diodes D3-D4 to short circuit giving output 0. Switches S9-S10 are ON and S11-S12 are OFF in the third leg giving output +Vdc/2, current flows from Source-S9-S10-Load.

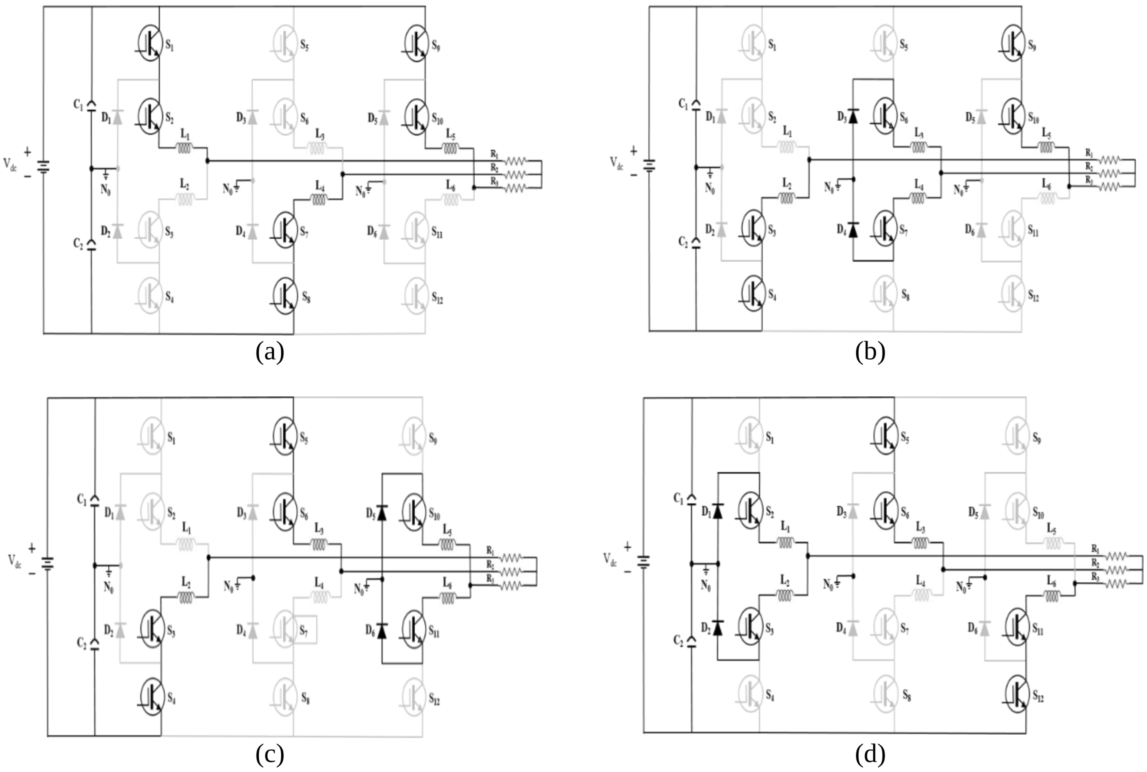

Figure 2. Modes of Operation (a)S1-S2, S7-S8, S9-S10 are ON; (b)S3-S4, S6-S7, S9-S10 are ON; (c)S3-S4, S5-S6, S10-S11 are ON; (d) S2-S3, S5-S6, S11-S12 are ON

In Figure 3(c), Switches S3-S4 are ON and S1-S2 are OFF in the first leg giving output -Vdc/2, current flows from Source-S4-S3-Load. Switches S5-S6 are ON and S7-S8 are OFF in the second leg giving output +Vdc/2, current flows from Source-S5-S6-Load. Switches S10-S11 are ON and S9-S12 are OFF in the third leg causing the diodes D5-D6 to short circuit giving output 0. In Figure 3(d), Switches S2-S3 are ON and S1-S4 are OFF in the first leg causing the diodes D1-D2 to short circuit giving output 0. Switches S5-S6 are ON and S7-S8 are OFF in the second leg giving output +Vdc/2, current flows from Source-S5-S6-Load. Switches S11-S12 are ON and S9-S10 are OFF in the third leg giving output -Vdc/2, current flows from Source-S12-S11-Load.

4. HYSTERESIS CONTROL

There are many different pulse width modulation techniques like space vector pulse width modulation, trapezoidal modulation, staircase modulation, delta modulation etc. which are been used for generating the triggering pulse for the system. Due to the increase demand in high frequency conversion and active power conversion the losses associated with these techniques are increasing hence the system becomes unstable. In order to increase the stability and to reduce the harmonics of the output waveform content the hysteresis current control method is implemented in this project. Hysteresis current control method is simple to implement and is also cost efficient is shown in Figure 3.

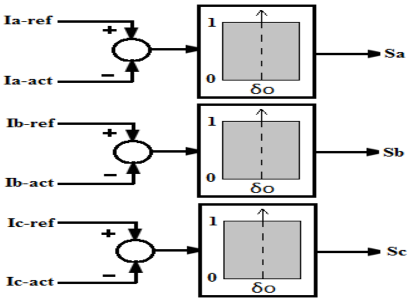

Figure 3. Hysteresis current control for proposed system

Hysteresis current control method is a type of control technique based on Schmitt triggering technique which switches precipitously between two states. the upper and lower states are pre-set, when the output of the system touches the upper limit the input to the circuit is turned off. Hence the output tends to decrease until it reaches the minimum threshold limit. When the output attains minimum threshold limit the input of the system is once again activated increasing the output once again. Hence the constant waveform is achieved at the output terminal of the system by operating between the pre-set limit the system behaves as per the scheme and makes the overall system highly stable.

5. SIMULATION RESULTS AND DISCUSSION

The modelling of the systems had been done using the MATLAB- Simulink 2016a. The generated output is verified by the hardware results. The generated waveforms have been shown below in Figure 4 shows the output waveform of the firing pulse from hysteresis controller of first leg of the inverter which are fed to the IGBT switches. In Figure 5 depicts the three-phase input to the inverter which is generated from the wind-turbine. In Figure 6 shows three-phase voltage output generated by the inverter, each phase of the output voltage waveform is shown separately in the scope and Figure 7 shows the three-phase current output generated by the inverter, each phase of the output current waveform is shown separately in the scope.

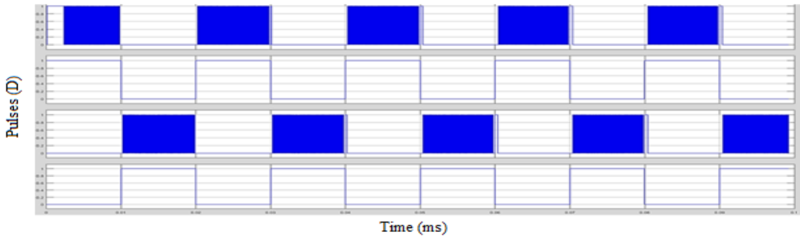

Figure 4. switching pulse generation using hysteresis current control

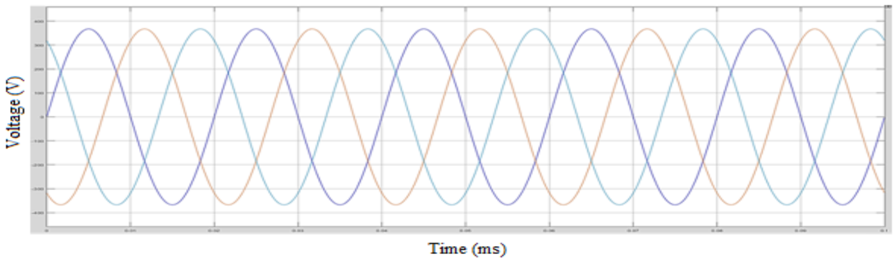

Figure 5. 3 phase output voltage of wind energy system

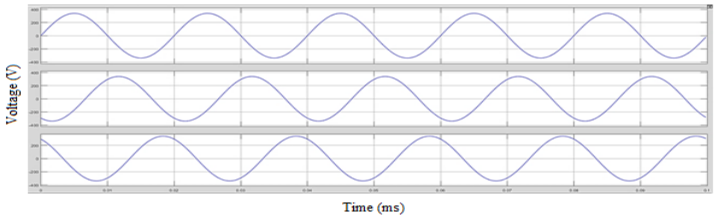

Figure 6. 3 phase output voltage with split inductor

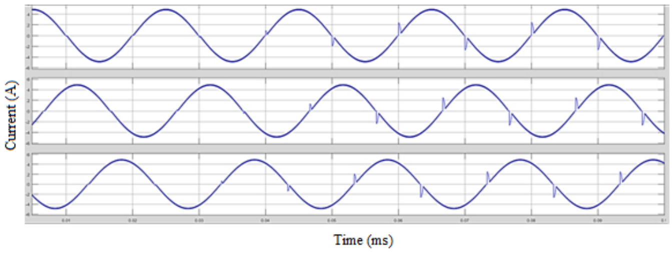

Figure 7. 3phase output current with split inductor

6. HARDWARE RESULTS AND DISCUSSION

To authenticate the simulation results of the proposed system, experimental setup Voltage Controlled 3 Level NPC-MLI Based HSVM with Grid Connected PV System was designed and tested. In Figure 8 shows 3 level stepped output voltage of NPC inverter and output current waveform of SI-NPC system is shown in Figure 9. in Figure 10 shows the experimental setup for the proposed system.

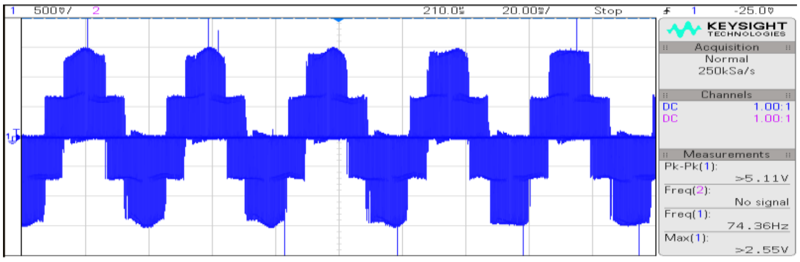

Figure 8. 3 level stepped output voltage of NPC inverter

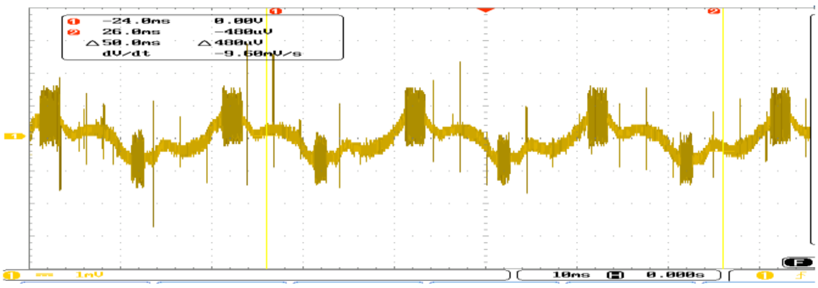

Figure 7. output current waveform of SI-NPC system

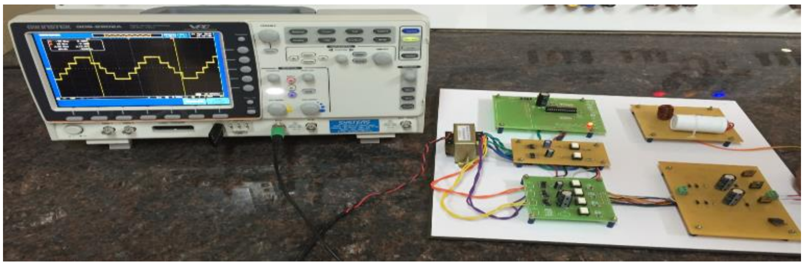

Figure 8. Experimental setup of the proposed system

7. CONCLUSION

In Conventional Inverters which use Sinusoidal Pulse Width Modulation, there are heavy losses due to presence of Harmonics. This causes system heating and reduces efficiency of the system. The proposed system is designed to overcome these problems and in turn improve the efficiency of the inverter. The wind energy system can be installed on a smaller level at households and other small institutions to generate clean and green energy. The system reduces heating and losses and the reduces the power wastage. The system can be used for different ratings by using suitably stepping p or stepping down by using a transformer setup. The simulations conducted show a voltage level of 350-400V for smaller applications. The system can also be used for higher power ratings in wind farms and industrial applications by using suitable equipment and corresponding parameters.

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