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Simulation and Analysis of a Hybrid Multilevel Converter with Solar Array by Using Hysteresis Controller

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Abstract:

This paper represents the analysis of Hybrid Multilevel Power Conversion system with source as solar array using hysteresis current controller. The Multilevel Inverter (MLI) has become popular in recent years for high power applications. In this paper a Hybrid multilevel inverter consists of a standard 3-leg inverter having solar array as source and H-bridge in series with each inverter leg with separate dc voltage source and RLC as load to observe the performance characteristics with Hysteresis controller. A hysteresis controller technique is developed to reduce the switching losses and proposed converter increases the number of levels with less number of switches compared to a traditional cascaded multilevel inverter. Simulation has been carried out in MATLAB/Simulink to study the performance of the proposed topology.

Keywords:

Hybrid Multilevel Inverter (MLI), H-Bridge, Modified PWM Technique, Hysteresis controller.

I.INTRODUCTION:

Numerous industrial applications have begun to require high power apparatus in recent years. Multilevel inverters (MLI) are the effective and practical solution for increasing power and reducing harmonics of AC wave form. It involves the concept of utilizing a large number of active semiconductor switches to perform the power conversion in small voltage steps for higher voltage and reduction in harmonic distortion. These multilevel inverters are implemented in many different ways; the simplest techniques involve the parallel or series connection of conventional converters to form the multilevel waveforms.

By using these multilevel inverters the number of levels is increased and the harmonic distortion of the output waveform decreases and it approaches to zero. These are extending their range of use in industry because they provide reduced energy consumption, better system efficiency, improved quality of product, good maintenance, and so on.The various topologies of multilevel inverters (MLI) are diode clamped, flying capacitor and cascaded H-bridge inverter. Besides these three basic topologies, other multilevel inverter topologies have been proposed. Most of these are hybrid circuits that are the combinations of two of the various topologies.Several pulse width modulation methods have been developed for the multilevel inverter structures. SPWM technique is the simplest technique that can be implemented in both two level and multilevel inverters.

Basically, in SPWM, carrier signal (triangular signal) is compared to give two states (high or low). SPWM is the most popular one for the industrial applications and a Modified PWM technique is also developed from the SPWM technique. This modified PWM technique is used in Hybrid multilevel inverters. The advantages of multilevel inverters is their smaller output voltage step, which results in high capability, lower harmonic components, lower switching losses, better electromagnetic compatibility and high power quality. Also it can be operate at both fundamental switching frequency and high switching frequency PWM. Today, multilevel inverters are extensively used in medium voltage levels with high-power applications. The field applications include use in laminators, pumps, conveyors, compressors, fans, blowers and mills. The induction motors are incorporated as a primary source for traction in electric vehicles. Designs for heavy duty trucks and many military combat vehicles that have large electric drives will require advanced power electronic inverters to meet the high power demands.

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Multilevel inverters are uniquely suited for these applications because of the high VA ratings possible with these inverters. In this paper a Three-phase Hybrid Five-level Inverter is proposed, developed from a conventional cascaded H-bridge inverter. The proposed topology reduces the number of power semiconductor switches. A Modified PWM technique is also developed to generate the gate pulses.

II.OVERVIEW OF A PHOTOVOLTAIC (PV) MODULE:

To understand the PV module characteristics it is necessary to study about PV cell at first. A PV cell is the basic structural unit of the PV module that generates current carriers when sunlight falls on it. The power generated by these PV cell is very small. To increase the output power the PV cells are connected in series or parallel to form PV module.

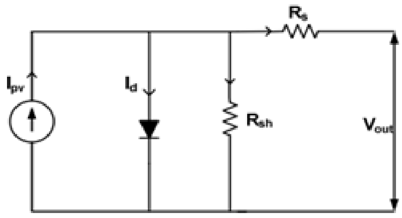

Fig 1: Equivalent circuit of PV cell

The main characteristics equation of the PV module is given by

$$I = I_{pv} - I_o\left[\exp\left(\frac{q(V+IR_S)}{\alpha KT}\right)-1\right]-\frac{V+IR_S}{R_{sh}} \quad \text{--(1)}$$

a. Effect of Temperature on the PV module:

Solar cells are very sensitive to temperature for all the semi conducting devices. As the temperature Increases reduce the band gap of a semiconductor, this will affect most of the semiconductor material parameters. The decrease in the band gap of a semiconductor with increasing temperature can be viewed as increasing the energy of the electrons in the material. Lower energy is therefore needed to break the bond. Reduction in the bond energy also reduces the band gap in the bond model of a semiconductor band gap. Therefore reduces the band gap by increasing the temperature.In a solar cell, by an increase in temperature the open-circuit voltage is the parameter mostly affected. The impact of increasing temperature is shown in the figure below.

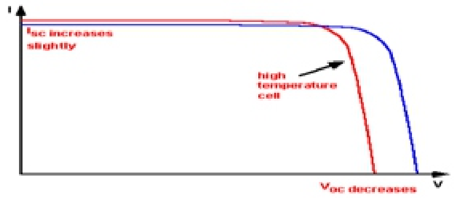

Fig 2: Effect of temperature on the I-V characteristics of a solar cell

The open-circuit voltage decreases with temperature because of the temperature dependence of I0. The equation for I0 from one side of a p-n junction is given by

$$I_o = qA\frac{Dn_i^2}{LN_D}$$

b. Effect of irradiation on the PV module

The I-V characteristics of the PV module under varying cell temperature at constant solar radiation (1000 W/m2)

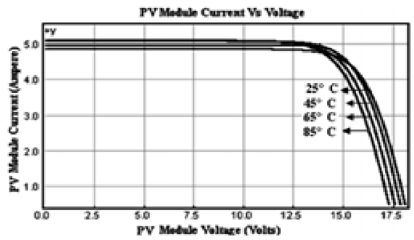

Fig 3: Current versus voltage at constant solar radiation G = 1000 W/m2

III. PROPOSED HYBRID MULTILEVEL CONVERTER TOPOLOGY

The proposed technology of the three-phase Hybrid Multilevel inverter includes a standard three leg inverter with a hysteresis controller and separate solar energy connected in series with a single H-bridge inverter. In the proposed six switch three-phase inverter is referred to as main inverter and the four-switch H-bridge inverter as auxiliary inverter. Low switching losses during PWM mode is required and main inverter will operate on square wave mode and the auxiliary inverter will operate on PWM mode. The PWM technique used for the Hybrid multilevel inverter is as the modified PWM technique. In Modified PWM technique, the reference wave is a combination of both sine and triangular wave and it is compared with a carrier triangular wave then the gate pulses are generated for operating the switches. The below figure shows the Proposed hybrid multilevel converter with the renewable solar energy resource.

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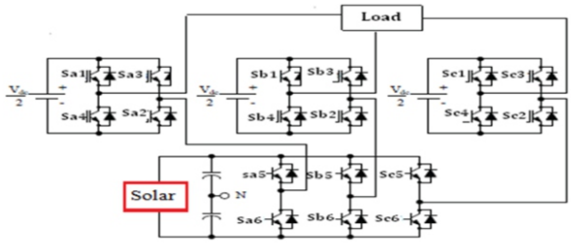

Fig 4: Proposed Hybrid multilevel converter topology

IV. HYBRID MULTILEVEL INVERTER:

The proposed topology of the hybrid multilevel inverter with solar energy is shown in fig.4, which includes a complete and a simplified single-phase topology. This structure includes a standard 3-leg inverter (one leg for each phase) with a dc power source +Vdc and an H-bridge in series with each inverter leg with a separate dc source (Vdc)/ 2.The output voltage V1 of this leg is either +Vdc/2 when Sa5 closed or –Vdc/2 when Sa6 closed. This leg is connected in series with a full H-bridge inverter, then the output voltage V2 of the H-bridge inverter is either +Vdc/2 when Sa1,Sa2 closed, 0 when Sa1,Sa3 or Sa2Sa4 closed, or –Vdc/2 when Sa3Sa4 closed. Switching pattern in one leg of the cascaded Hybrid 5-level inverter is given in Table II. An output voltage waveform of the Hybrid 5-level inverter topology is shown in fig.6 When the output voltage Vo =V1+V2 is required to be zero, one can either set V1 = +Vdc/2 and V2 = -Vdc /2 or V1 = -Vdc/2 and V2 = +Vdc/2.

S. No.	Voltage levels	On switches
1	0	$S_{a1}S_{a2}S_{6}$
2	$\frac{+V_{dc}}{2}$	$S_{a1}S_{a3}S_{a5}$
3	$+V_{dc}$	$S_{a1}S_{a2}S_{a5}$
4	$\frac{-V_{dc}}{2}$	$S_{a1}S_{a3}S_{a6}$
5	$-V_{dc}$	$S_{a3}S_{a4}S_{a6}$

Table 1: Switching states in one leg of the cascaded hybrid multilevellevel inverter

The below control diagram shows the proposed Modified pulse width modulation topology for a proposed hybrid multilevel converter.

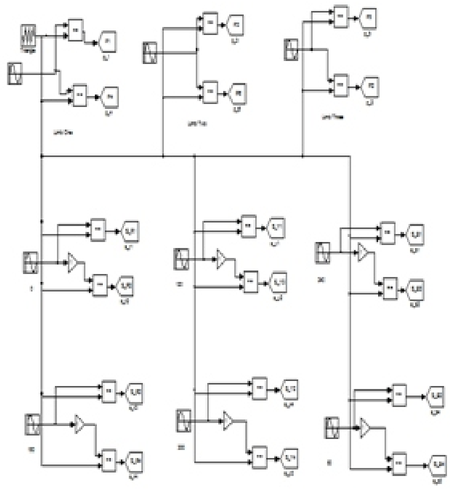

Fig 5: Modified PWM topology

The below figure 6 and 7 shows the proposed control diagram and hysteresis controller of a three phase converter respectively. The actual value of the current i has to be kept within the hexagon area. Each time when the tip of the i touches the border of the surface heading out of the hexagon, the inverter has to be switched in order to force the current into the hexagon area. The current error is defined as:

$$\underline{i}_e = \underline{i} - \underline{i}_{ref}$$

When the current error vector ie touches the edge of the hysteresis hexagon, the switch logic has to choose next, the most optimal switching state with respect to the following: 1) the current difference ie should be moved back towards the middle of the hysteresis hexagon as slowly as possible to achieve a low switching frequency; 2) if the tip of the current error ie is outside of the hexagon, it should be returned in hexagon as fast as possible

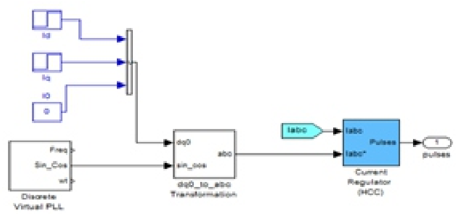

Fig 6: Proposed control diagram of a three phase converter

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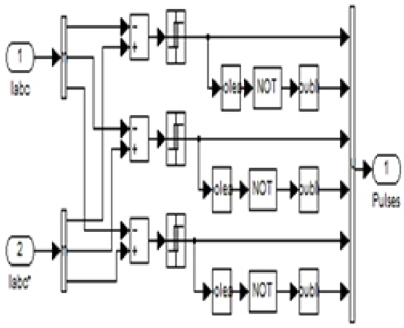

Fig 7: Hysteresis current controller

V. SIMULATION AND RESULTS:

The below figures shows the conventional hybrid multilevel converter topology without solar energy as shown in fig 8, and the corresponding waveforms such as output voltage, rotor speed and electromagnetic torque of induction motor load are shown in fig 9 & 10.

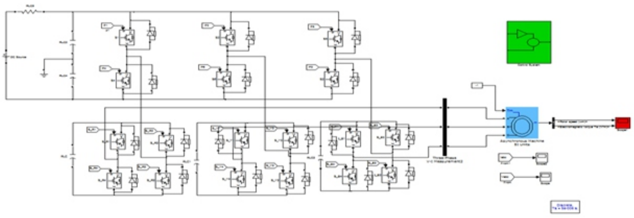

Fig 8: Simulation circuit diagram for a Hybrid multilevel converter with DC-Source.

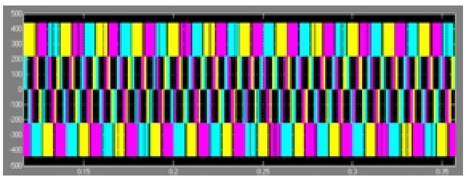

Fig 9: Output voltage for hybrid multilevel converter

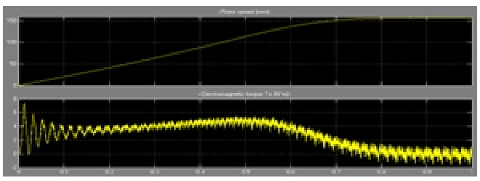

Fig 10: Rotor speed, Electromagnetic torque of an induction motor load

The below figures shows the proposed hybrid multilevel converter topology with the solar energy as shown in fig 11, and the corresponding waveforms such as output load voltage, load current, phase to phase voltage of a linear load are shown in fig 14.

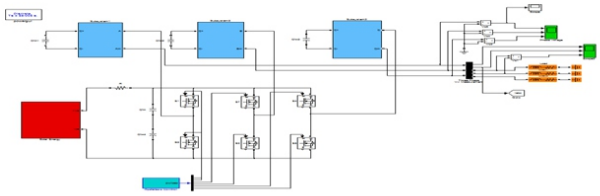

Fig 11: Proposed Hybrid multilevel converter with solar energy simulation circuit diagram

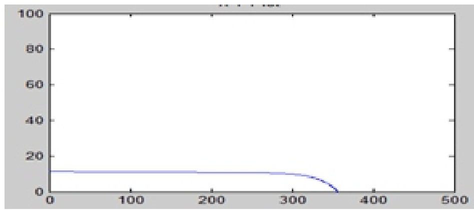

Fig 12: I-V characteristics of solar array

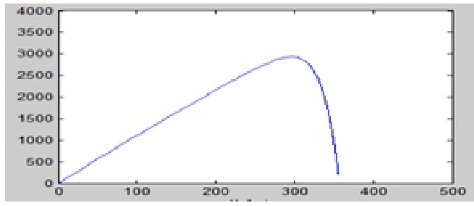

Fig 13: P-V characteristics of solar array

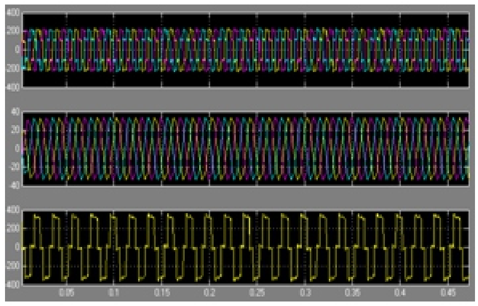

Fig 14: Waveforms of load voltage, current, phase to phase voltage

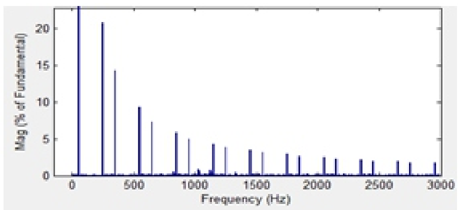

Fig 15: THD of a proposed converter

VI. CONCLUSION:

In this paper a three-phase cascaded H-bridge 5-level inverter and three-phase hybrid inverters connected to a

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linear load is presented with the solar source and observed the performance of the proposed system with the conventional system by using the renewable energy sources. The hybrid 5-level inverter consists of a three-phase inverter and a three h-bridge inverters. The hysteresis current controller technique has also been developed to reduce the switching losses. From the simulation results, several features of the proposed modulation strategies are observed. Also the proposed topology can reduce the number of required power switches compared to a traditional cascaded H-bridge 5-level inverter to get the same output voltage waveform. Thus the complexity and the cost of the circuit are decreased. The odd harmonics of 3rd, 7th, 9th, 11th, 13th, and 17th are reduced

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