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

Design of Five-Level Bidirectional Hybrid Inverter for High-Power Applications

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Abstract:

multi-level inverters are best suitable for high-power applications. This paper is devoted to the investigation of a hybrid multilevel power conversion system typically suitable for high-performance high-power applications. A new DC/AC hybrid multilevel bidirectional inverter is described in this literature. Five-level parallel connected bidirectional inverter is designed with inductors as coupling elements between inverter circuits and is described as coupling inductors. Two coupling inductors are used. The working of coupling inductors is that works only on half-cycle and currents are naturally set to zero in inductors after every cycle. The operation principle of five-level bidirectional inverter is observed with both inductive load and machine loads. The operating characteristics of the proposed converter is verified by simulation software and given in results section.

Key words:

Five-level inverters, bidirectional topology, High-Power Applications, parallel operation.

I.INTRODUCTION:

Multilevel converters are finding increased attention in industry and academia as one of the preferred choices of electronic power conversion for high-power applications [1]. They have successfully made their way into the industry and therefore can be considered a mature and proven technology. Currently, they are commercialized in standard and customized products that power a wide range of applications, such as compressors, extruders, pumps, fans, grinding mills, rolling mills, conveyors, crushers, blast furnace blowers, gas turbine starters, mixers, mine hoists, reactive power compensation, marine propulsion, high-voltage direct-current (HVDC) transmission, hydro-pumped storage, wind energy conversion, and railway traction. Converters for these applications are commercially offered by a growing group of companies in the field.

This paper is devoted to the investigation of a hybrid multilevel power conversion (HMPC) system for medium-voltage (4.16 kV) high-power (100 hp) applications. This system consists of one “hybrid cell” per phase. The hybrid cell is comprised of a five-level hybrid inverter [2] with dc-bus voltages configured in the ratio 2: 1 (2 V and V) and a combination of a passive diode bridge and an active IGBT rectifier front end. This work presents a new hybrid DC/AC five–level (5L) bidirectional switching cell Fig.1. It is called 5L– Bidirectional–Vienna (5L–BV) and can be connected between a voltage source and a current source.

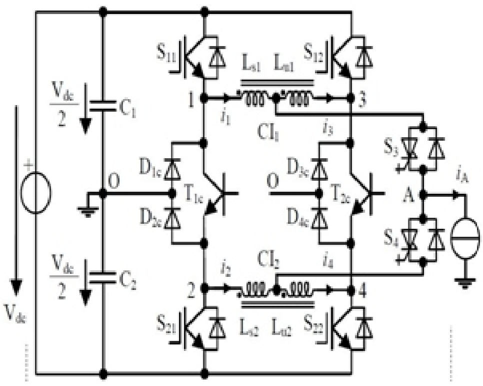

Figure 1: 5L–Parallel–Bidirectional Vienna (PBV) topology.

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A new hybrid five–level (5L) switching cell is proposed with inductive load and Asynchronous Machine. It is called 5L– Parallel–BV (PBV) converter and is based on two groups of stacked HF switching cells (according to 3L–BV cell) parallel connected by means of two coupled–inductors (CIs) and a basic 2L cell. The proposed 5L–PBV topology is an attractive solution mainly for low–voltage applications to increase the output current, while the switched current in the HF stage is reduced. It can be used to develop new bidirectional multilevel PWM converters (inverters and rectifiers) with enhanced performances.

The work is organized as follows. In section II presents a brief description of the hybrid multilevel inverter. The designing and operations of proposed 5L–PBV topologies are explained in section III. Section IV describes the control strategy. Simulation verification of inverter is given in section V. conclusion is described in Section VI.

II. PRINCIPLE OF THE HYBRID MULTILEVEL INVERTER:

The hybrid multilevel inverter combines an IGCT inverter with a 2.2-kV bus and an IGBT inverter with a 1.1-kV bus, as shown in Fig. 2. It may be easily verified that it is possible to synthesize stepped waveforms with seven voltage levels, viz.,-3.3,-2.2,-1.1, 0, 1.1, 2.2, 3.3 kV at the phase leg output with this topology. As shown in Fig. 2, the higher voltage levels (-2.2 kV to +2.2kV) are synthesized using an IGCT inverter while the lower voltage levels (-1.1 kV to +2.2kV) are synthesized using IGBT in converters.

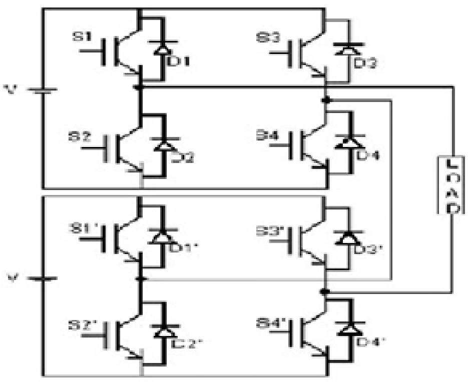

Figure 2: Simplified schematic of one leg of the hybrid multilevel inverter.

However, it is well known that the switching capability of thyristor-based devices is limited at higher frequencies [3]. Hence, a hybrid modulation strategy which incorporates stepped synthesis in conjunction with variable pulse width of consecutive steps has been presented in [2]. Under this modulation strategy, the IGCT inverter is modulated to switch only at fundamental frequency of the inverter output, while the IGBT inverter is used to switch at a higher frequency.

It is well known that the conventional six-pulse rectifier bridges suffer from a strong harmonic interaction with the utility. Therefore, present-day H-bridge multilevel inverters employed for feeding medium-voltage loads control the utility harmonic impact by means of specially designed transformers which provide an 18-pulse or a 30-pulse input current [4]. Hence, to simplify transformer design and interconnections combined with a low harmonic impact on the utility interface, it is proposed to use an active rectifier for the IGBT inverter along with a diode bridge front end for the IGCT inverter.

With this configuration, it is possible to use the IGBT rectifier as an active filter for the harmonics generated by the high-voltage passive rectifier, as well as a real power flow controller for the low-voltage converter, thereby regulating its dc-bus voltage irrespective of power interaction in the hybrid inverter. The control action for the hybrid multilevel rectifier can be partitioned into two tasks: reference generation and current control.

IIIVE-LEVEL BIDIRECTIONAL PARALLEL INVERTER SINGLE-PHASE TOPOLOGY:

The proposed five-level bidirectional parallel inverter with single phase output power is shown in figure 3. It is based on two cascaded stages controlled at different frequencies and two coupled–inductors (CL_1 andCL_2). The high–frequency (HF) stage is specific to a parallel connection of two groups of stacked switching cells according to 3L–BV concept, while the low–frequency (LF) stage is composed by a basic 2L switching cell. The principal DC supply voltage (V_dc) is split into two secondary DC–link voltage (V_dc/2) realized by two series–connected capacitors (C1 and C2). All the power devices are rated for half of the DC–link voltage (V_dc /2).

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The new 5L inverter can be connected between a voltage source and a current source to achieve a bidirectional transfer of electrical power [5]. Thus, it can be used to develop new PWM inverters/ rectifiers topologies.WhenV_r>0, the device S3 is turned on, while S4 is turned off. The input voltage applied to the parallel commutation cells (S11–SO1 and S12–SO3) is positive and equal to half of the DC–link voltage (V_dc /2). The middle point (O) of the series capacitors C1 and C2 is connected to the switches SO1 and SO3, and the average values of the voltages V1O and V3O are positive. When V_r>0, the power device S4 is turned ON, while S3 is turned OFF. It is observed that the middle point (O) of the series capacitors is connected to the switches SO2 and SO4. In this case, the average values of the voltages V2O and V4O are negative.

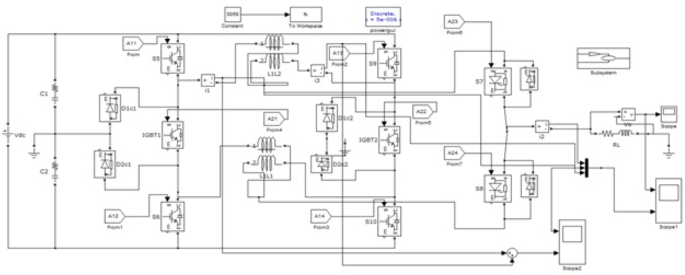

Figure 3: single-phase five-level bidirectional parallel inverter

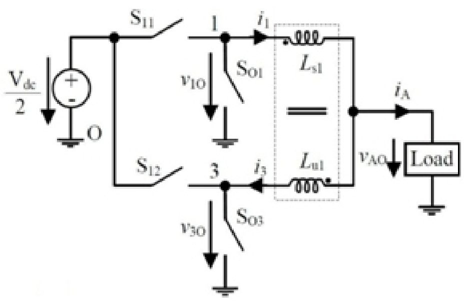

Figure 4: Equivalent magnetic circuit of 1-φ 5L–PBV inverter

The 5L–PBV switching cell is validated by numerical simulation for single–phase half–bridge PWM inverter with a RL load.

THREE-PHASE TOPOLOGY With RL load:

The three–phase 5L–PBV inverter with inductive (RL) load is proposed in this section and is shown in figure 5. An interesting property of the 5L–Parallel–Bidirectional–Vienna inverter is to use two CIs for each arm [6]. Thus, the CIs from an arm work alternatively only on a half–cycle and the currents in inductor windings are naturally set to zero after each cycle.

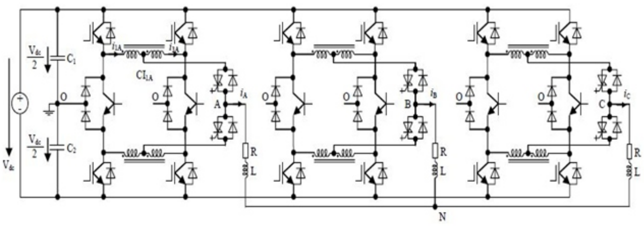

Figure 5: Three–phase 5L–PBV inverter

Three-phase topology with synchronous machine load:

Three-phase five-level bidirectional parallel inverter and three-phase asynchronous machine drive is connected as load to the proposed inverter. The circuit is shown in figure 6.

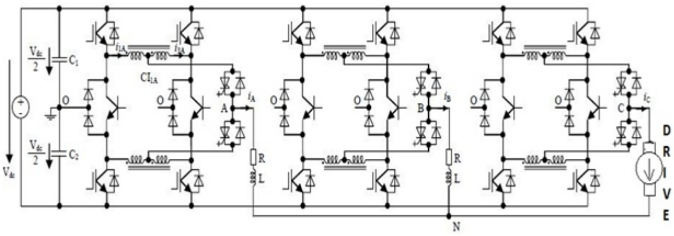

Figure 6: 3-φ, 5-level bidirectional inverter connected with Asynchronous machine drive.

IV.CONTROL STRATEGY:

Using a sinusoidal PWM (SPWM) strategy it is observed that 3L–BV topology has four switching states [7].The switch Tc is controlled at f_swon the entire cycle, while S1 and S2 are controlled at f_sw only half of cycle. The average switching frequency of S1 and S2 is equal to half of fsw (fav–S1=fav–S2=fsw/2); thus, S1 and S2 have both conduction and switching losses. The average switching frequency of Tc is equal to fsw (fav–Tc=fsw); for DC/AC conversion at unity power factor this device T switch at zero current. The active power devices S3 and S4 have only conduction losses; the switching losses are insignificant because they switch at low frequency equal to the reference voltage frequency (fr). The apparent (effective) switching frequency (fap) of the output voltage is equal to fsw (fap=fsw). The phase–shifted (PS) and level–shifted (LS) techniques are combined to control the 1–φ half–bridge 5L–PBV inverter.

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Thus, the control of active power devices is obtained from the comparison of the sinusoidal reference voltage with four carriers phase–level–shifted (PLS). Analyzing the ideal equivalent magnetic structures without energy storage, it can be seen for positive reference voltage that the voltage in the magnetic structure is

$V1O – VAO = VAO – V3O$

The output voltage is written as

$VAO = (V1O + V3O)/2$

The commutations are not ideal and the structure is supplied from two secondary DC sources (C1 and C2). Because of these reasons, the sum of the instantaneous voltages V1O and V3O is not perfectly constant and oscillations can occur in output voltage. The topology is controlled with Centered Space Vector PWM (CSVPWM), strategy which represents a better approach to center the vectors in each switching period. The phase–level–shifted (PLS) modulation can be extended to achieve CSVPWM by adding a common mode offset to the three–phase reference voltages VrA, VrB and VrC. The simulation circuit for control strategy proposed for generation of switching signals is shown in figure 7.

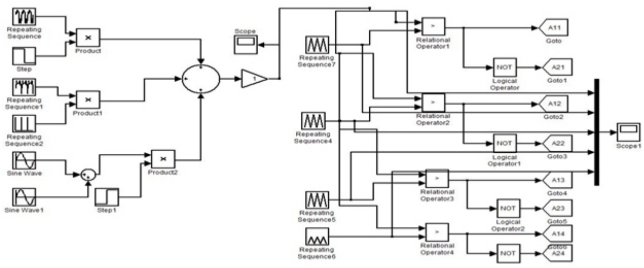

Figure 7: Simulation circuit of proposed control strategy

The voltage references are shifted into a common carrier band [0, 1] using the following modulo function

$Vref'' = (Vref' + 1) \text{ Mod } (1)$

Where (a mod b) delivers the remainder of the division (a/b)

The additional offset of the transformed references Vref'' ensures that the middle two space vectors of the switching sequence are centered in each switching period.

V.SIMULATIONS:

The simulation for single–phase 5-level half–bridge PWM inverter with a RL load is shown in figure 3. The simulation results are observed in following figures. The output voltage waveform is shown in figure8. And output current waveforms for three phases are shown in figure 9.

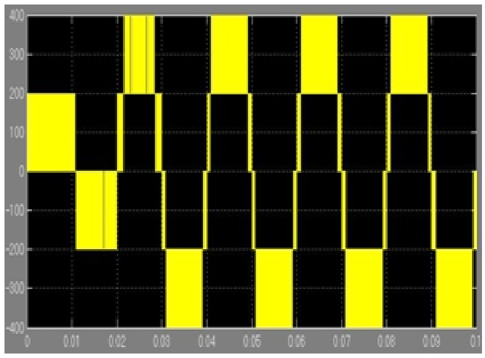

Figure 8: simulation result for output voltage of 1-φ 5-L inverter with RL load.

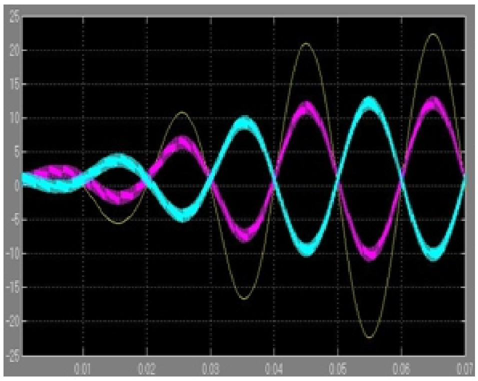

Figure 9: simulation result for output current of 1-φ 5-L inverter with RL load.

Further single-phase five-level bidirectional inverter is designed for three-phase supply. So 3-φ 5-L parallel bidirectional inverter is designed with RL-load in simulation software. Simulation results for three–phase proposed inverter are described using CSVPWM strategy. The simulation results for three-phase five-level parallel bidirectional inverter are described in below waveforms.

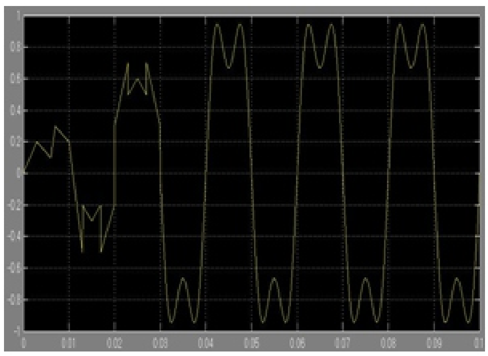

Figure 10: Reference voltage for phase A of 3-φ, 5-L parallel Bidirectional inverter with RL-Load

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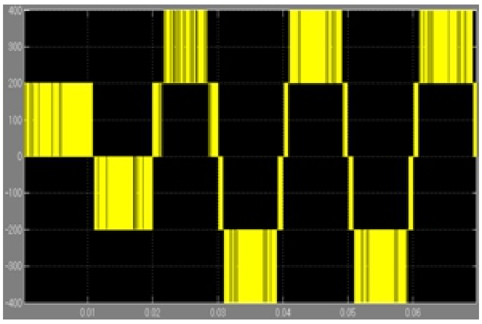

Figure 11: Phase output voltage of 3-φ, 5-L parallel Bidirectional inverter with RL-Load

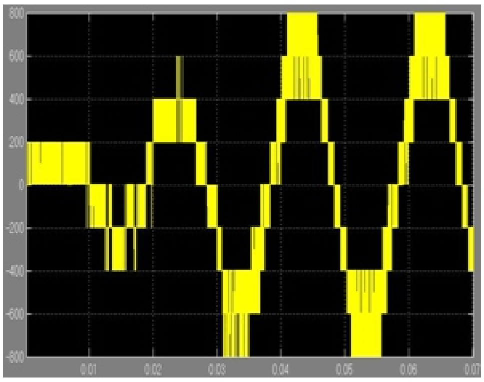

Figure 12: line–to–line op voltage of 3-φ, 5-L parallel Bidirectional inverter with RL-Load

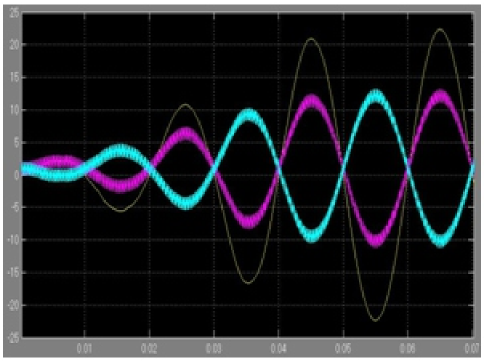

Figure 13: currents in the phases A and B, currents in the inductor windings of CI1A with RL-load

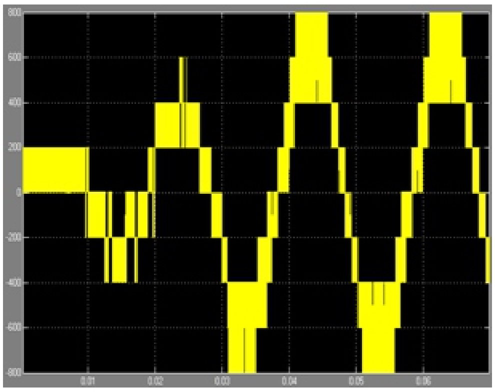

Figure 14: line–to–line output voltage with synchronous machine load

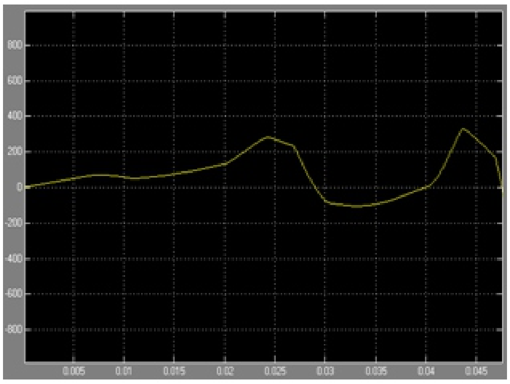

Figure 15: variation in the rotor speed

VI.CONCLUSION:

Using the multilevel approach, it is possible to reduce the maximum output current ripple by reducing the steps value of the output voltage and/or by increasing the output apparent switching frequency. In this proposed DC–AC multilevel hybrid bidirectional inverter is designed with inductive load and machine load.

The operation mode of the proposed concepts has been verified by numerical simulations both for single– and three– phase inverter topologies. The low harmonic content on the output voltage produces a major reduction concerning the volume and the cost of the output filter.

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ISSN No: 2348-4845
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