A Comparative Analysis on Six-Leg Single-Phase to Three-Phase Converter

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Abstract - In today's demanding world of power system more and more households and industries rely heavily on electricity than ever before. Along with this reliance and the advancements of technology comes a demand for more flexible energy options. Converter allows power conversion either AC to DC conversion , three-phase to single-phase conversion and vice versa as needed by the consumer . Many control methods are used for control of switch mode converters and the simple and low cost controller structure is always in demand for most industrial and high performance applications. Every control method has some advantages and drawbacks due to which that particular control method consider as a suitable control method under specific conditions, compared to other control methods. The control method that gives the best performances under any conditions is always in demand. Moving from the conventional power generation in large power plants to the new types of energy resources and specially the renewable energy, power electronic converters play an important role to facilitate DERs into ration into the grid. The different types controllers are reviewed in this work.

Index Terms - Power Converters, AC to DC conversion, DC to AC conversion ,AC to AC conversion, Inverter, Transfer less converter, transfer based converter.

I. INTRODUCTION

Over the years, the incrementing demand in power transmission capability in terms of voltage levels, have introduced the power transformers into the distribution and transmission networks. Nowadays, they are used to feed the majority of equipments and apparatus of society's daily use, from personal to public technological environments in the range of several VAs to GVAs, and a few mV to MV. Such flexibility have rendered transformers as one of the most vitals links from transmission and distribution generation to the consumers, while feeding electricity efficiently and reliably. In general, efficiency, costs, weight and dimensions are the main characteristics that determine the overall effectiveness of the transformers, whereas ongoing demands and specifications for a better, stable and interactive power transmission have rendered technological innovations based on smart devices and power electronic transformers to be deployed.

The devices which can convert electrical energy of DC form into AC form is known as power inverters. They come in all sizes and shapes, from a high power rating to a very low power rating, from low power functions like powering a car radio to that of backing up a building in case of power outage. Inverters can come in many different varieties, differing in power, efficiency, price and purpose. The purpose of a DC/AC power inverter is typically to take DC power supplied by a battery, such as a 12 volt car battery, and transform it into a 120 volt AC power source operating at 60 Hz, emulating the power available at an ordinary household electrical outlet.

DC-AC inverters have been widely used in industrial applications such as uninterruptible power supplies, static frequency changes and AC motor drives. Recently, the inverters are also playing important roles in renewable energy applications as they are used to link a photovoltaic or wind system to a power grid. Like DC-DC converters, the DC-AC inverters usually operate in a pulse width modulated (PWM) way and switch between a few different circuit topologies, which means that the inverter is a nonlinear, specifically piecewise smooth system. In addition, the control strategies used in the inverters are also similar to those in DC- DC converters. For instance, current-mode control and voltage-mode control are usually employed in practical applications. In the last decade, studies of complex behavior in switching power converters have gained increasingly more attention from both the academic community and industry. Various kinds of nonlinear phenomena, such as bifurcation, chaos, border collision and coexisting attractors, have been revealed.

The power electronic converter is the heart of a variable speed drive system. It is used to process the electrical power of utility grid and supply to the electric motor. This will act as an interface between the utility grids and the electric motor. Huge research effort is put to develop technically feasible and commercially viable power electronic converters. The rapid growth in the semiconductor material and switching devices has led to significant improvement in the power converters and also has helped in developing their several variants.

AC voltage regulators have limited use since they can only vary the voltage while the output side frequency is same as the input side frequency. The power semiconductor switching device used should have bi-directional power flow characteristics. Bi-directional switching can be obtained by connecting anti-parallel BJTs, or MOSFETs, or IGBTs. In some applications Triacs and Thyristor based voltage regulators are also used. Other ways of obtaining bi-directional power flow is shown in Fig. 1.1.

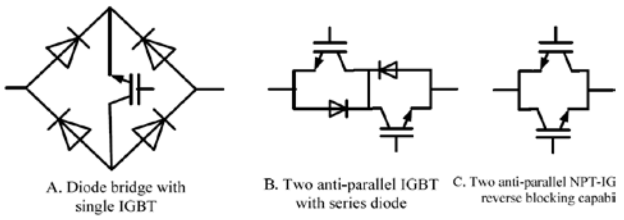

Figure 1.1 Possible Discrete implementation of a bi-directional switch.

Cyclo converter is fully controlled direct AC-AC conversion. Both output voltage magnitude and frequency are controllable. The maximum output voltage magnitude is same as input voltage magnitude while the output frequency is limited to 33% of the input frequency. Hence the application of cyclo converter is also limited but they are used where small speed control range is needed and is mostly used in high power drive system.

AC-DC-AC converter with diode based rectifier is most commonly employed in variable speed drive system because of its simplicity and low cost. Several types of diode based rectifiers are in practice but mostly three-phase bridge type rectifiers are the most common. The output of rectifier contains ripple that can be minimized by using a filter. The output of a rectifier is used to feed inverter system through DC link capacitor. Large values of DC link capacitors are usually used to offer constant voltage to the inverter. Rectifiers are uncontrolled but the inverter is controlled using different types of pulse width modulation.

AC-DC-AC converter with controlled rectifier or active rectifier called back-to-back converter is also employed where bi-directional power flow is required. The rectifier is controllable and the power factor can be controlled and can be even made unity. The source side current is sinusoidal. In case of regeneration of drive system, power can flow back to the utility grid and this is only possible when active rectifier is used. The output voltage magnitude is limited by the amount of DC link voltage and the type of PWM method employed.

Direct AC-AC converter system mostly called Matrix Converter consist of arrays of bi- directional power semiconductor switches (bi-directional switches are shown in Fig. 1.1). Three-phase utility grid system is connected to the output through the matrix arrays. Each leg has three bi-directional switches and any output can be connected to any input line through the switching action of bi-directional power switches. The voltage of input side appears at the output side and the current in any phase of the load can be drawn from any phase of the utility grid.

II. POWER CONVERTER

These converters have resonant elements such as inductors and capacitors that are connected in series and/or parallel to the primary of their power transformer. They must be controlled using variable switching frequency control. As a result, it is difficult to optimize their design (especially their magnetic components) as they must be able to operate over a wide range of switching frequency.

1. Current-fed PWM converters:

These converters have a boost inductor connected to the input of the full-bridge circuit; one such converter is shown in Fig. 2.1. Although they can achieve a near-unity input power factor, they lack an energy- storage capacitor across the primary-side dc bus, which can result in the appearance of high voltage overshoots and ringing across the dc bus. The lack of such a capacitor also causes the output voltage ripple that limits their application.

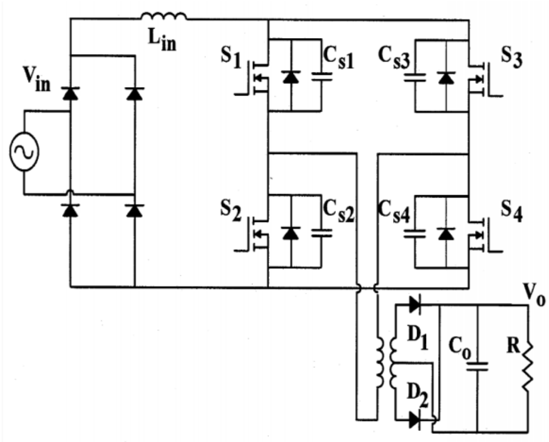

Figure 2.1 Boost-based current-fed AC-DC PWM integrated full-bridge converter

2. Current-fed PWM converters:

These converters have a boost inductor connected to the input of the full-bridge circuit; one such converter is shown in Fig. 2.2.

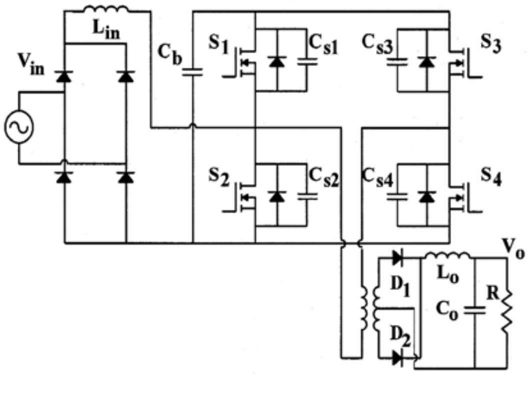

Figure 2.2 Voltage - fed PWM full-bridge Converter.

Although they can achieve a near-unity input power factor, they lack an energy- storage capacitor across the primary-side dc bus, which can result in the appearance of high voltage overshoots and ringing across the dc bus. The lack of such capacitor also causes the output voltage ripple that limits their application.

3. Voltage-fed PWM converters:

These converters have a large energy-storage capacitor connected across their primary- ide dc bus, as shown in Fig.2.3. These converters do not have the drawbacks of resonant and current-fed SSPFC converters. They operate with fixed switching frequency, and the bus capacitor prevents voltage overshoots and ringing from appearing across the dc bus and keeps the 120-Hz ac component from appearing at the output.

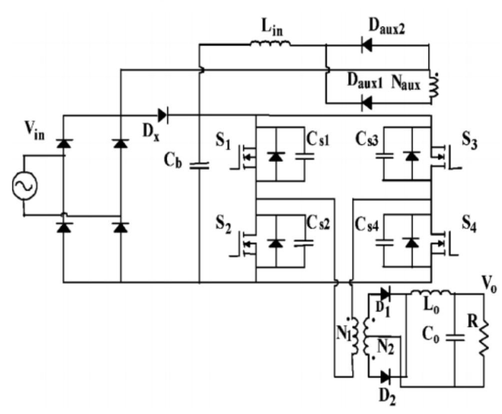

Figure 2.3 Voltage-fed PWM -bridge converter with auxiliary winding.

III. RELATED WORK

SR. NO.	TITLE	AUTHORS	YEAR	APPROACH
1	Six-leg single-phase to three-phase converter,	N. B. de Freitas, C. B. Jacobina, A. C. N. Maia and A. C. Oliveira	2016	The topologies is transformerless and the other is transformer-based
2	Three-phase bidirectional dc/ac converter using a six-leg inverter connected to a direct ac/ac converter	G. Waltrich, J. L. Duarte and M. A. M. Hendrix,	2015	Three single-phase high-frequency transformers are implemented to simplify the topology
3	Proportional-resonant control of a single-phase to three-phase converter without electrolytic capacitor	Hui Luo, Genping Wu and Quan Yin,	2015	A converter without electrolytic capacitor is studied
4	Single-phase to three-phase AC/DC/AC converter for an induction motor using a SEPIC PFC converter in DCM as rectifying stage	M. G. Ramírez and C. A. Cruz-Villar,	2015	Evaluates the performance of a SEPIC (Single Ended Primary Inductor Converter) derived PFC (Power Factor Correction) rectifier used as a front-end of an AC/DC/AC converter
5	Miniaturized Low-Voltage Power Converters With Fast Dynamic Response,	D. M. Giuliano, M. E. D’Asaro, J. Zwart and D. J. Perreault,	2014	A two-stage approach for power conversion that combines the strengths of variable-topology switched capacitor techniques
6	A New Power Conversion System for Megawatt PMSG Wind Turbines Using Four-Level Converters and a Simple Control Scheme Based on Two-Step Model Predictive Strategy—Part II: Simulation and Experimental Analysis	V. Yaramasu, B. Wu, M. Rivera and J. Rodriguez,	2014	To achieve a simple and optimal control performance, a simplified two-step model predictive strategy is proposed
7	A Simplified Finite-Control-Set Model-Predictive Control for Power Converters	C. Xia, T. Liu, T. Shi and Z. Song,	2014	An effective method to simplify the conventional FCS-MPC

N. B. de Freitas, C. B. Jacobina, A. C. N. Maia and A. C. Oliveira,[1] This exploration investigates the utilization of two different six-leg configurations of single-phase to three-phase converters. One of the topologies is transformerless and the other is transformer-based. The studied converters allow to feed the load voltage with sinusoidal voltages with constant amplitude and frequency and to operate with sinusoidal grid current with high power factor. The system model and pulsewidth modulation (PWM) techniques for one of the topologies are given. Control strategies for both topologies are provided. The studied topologies are compared with the conventional in terms of dc-link specifi- cation, voltages harmonic distortions, semiconductor losses, and other characteristics. Simulation and experimental results are provided to illustrate the operation of the systems.

G. Waltrich, J. L. Duarte and M. A. M. Hendrix,[2] In this study, a three-phase bidirectional dc/ac converter is proposed using a direct ac/ac converter and a six-leg converter, to avoid the use of dc-link capacitors and to increase the current capability at the dc side. To link the six-leg inverter to the direct ac/ac converter, three single-phase high-frequency transformers are implemented to simplify the topology, which will attract the industry. The direct ac/ac converter used in the study demonstrates reduced complexity and simpler modulation techniques compared with a conventional matrix converter. The analysis starts with the description of the proposed dc/ac converter for single phase, which is subsequently extended to a three-phase dc/ac converter. A 20 kW prototype was built to verify and to validate the theoretical study of the proposed converter.

Hui Luo, Genping Wu and Quan Yin,[3] A large electrolytic capacitor is always used to make dc-link voltage stable in a single-phase to three-phase power converter. However, the large electrolytic capacitor occupies a large volume and has a short lifetime as to the home appliances. And additional PFC circuit is needed to correct the grid current. In order to settle these issues, a converter without electrolytic capacitor is studied in this exploration. The q-axis current reference is modified for the high grid power factor operation. And the d-axis current reference is generated to achieve the flux-weakening control and to improve the waveform of the output currents and. Proportional-resonant controllers are adopted to obtain the better current performance. The simulation results verify the validity and feasibility of the proposed method.

M. G. Ramírez and C. A. Cruz-Villar, [4] One of the most common solutions to the problem of feeding a three-phase induction motor from a single-phase line is using AC/DC/AC converter. An AC/DC/AC converter is composed by two stages, rectifying and inverting. The rectifying stage, or front-end, is generally implemented using a diode bridge rectifier or a boost rectifier. This exploration evaluates the performance of a SEPIC (Single Ended Primary Inductor Converter) derived PFC (Power Factor Correction) rectifier used as a front-end of an AC/DC/AC converter. The purpose of using a PFC Rectifier as the front-end is to achieve a close to unity power factor and a low harmonics content. The circuit is designed from data obtained from a conventional AC/DC/AC converter. The designed circuit is build then tested in the laboratory. The results from the experiments show that, using the PFC rectifier, the power factor is close to unity and the %THD (Total Harmonic Distortion Percentage) is smaller than the obtained using a diode bridge front-end.

D. M. Giuliano, M. E. D’Asaro, J. Zwart and D. J. Perreault,[5] This exploration demonstrates a two-stage approach for power conversion that combines the strengths of variable-topology switched capacitor techniques (small size and light-load performance) with the regulation capability of magnetic switch-mode power converters. The proposed approach takes advantage of the characteristics of complementary metal-oxide-semiconductor (CMOS) processes, and the resulting designs provide excellent efficiency and power density for low-voltage power conversion. These power converters can provide low-voltage outputs over a wide input voltage range with very fast dynamic response. Both design and fabrication considerations for highly integrated CMOS power converters using this architecture are addressed. The results are demonstrated in a 2.4-W dc-dc converter implemented in a 180-nm CMOS IC process and co-packaged with its passive components for high performance. The power converter operates from an input voltage of 2.7-5.5 V with an output voltage of ≤1.2 V, and achieves a 2210 W/in3 power density with ≥80% efficiency.

V. Yaramasu, B. Wu, M. Rivera and J. Rodriguez,[6] In this exploration, a new medium-voltage power conversion system consisting of a four-level boost converter and four-level diode-clamped inverter is proposed for permanent magnet synchronous generator-based megawatt-level wind turbines. To achieve a simple and optimal control performance, a simplified two-step model predictive strategy is proposed. The high-power wind turbine requirements, which include maximum energy harvesting, balancing of dc-link capacitor voltages, net dc-bus voltage control, regulation of grid-reactive power, and the minimization of both switching frequency and common-mode voltage are expressed as cost functions. The best switching states are chosen and applied to the power converters during each sampling interval based on the minimization of cost functions..

C. Xia, T. Liu, T. Shi and Z. Song,[7] Finite-control-set model-predictive control (FCS-MPC) requires a large amount of calculation, which is an obstacle for its application. However, compared with the classical linear control algorithm, FCS-MPC requires a shorter control loop cycle time to reach the same control performance. To resolve this contradiction, this exploration presents an effective method to simplify the conventional FCS-MPC. With equivalent transformation and specialized sector distribution method, the computation load of FCS-MPC is greatly reduced while the control performance is not affected. The proposed method can be used in various circuit topologies and cases with multiple constraints. Experiments on two-level converter and three-level NPC converter verify the good performance and application value of the proposed method.

IV. PROBLEM STATEMENT

In the power distribution systems, the single-phase grid has been considered as an alternative for rural or remote areas, due to its lower cost feature, especially when compared with the three-phase solution. In huge countries like Brazil, the single-phase grid is quite common due to the large area to be covered. However, connect loads in a three- phase arrangement presents some advantages compared to the single-phase arrangement. Besides, farming operations usually involve three-phase motors. A suitable single-phase to three- phase converter is therefore essential in order to use these motors and to connect three-phase loads [1]. The lifetime of aluminium electrolytic capacitors is significantly dependent on environmental and electrical factors. The environmental factors include temperature, humidity, atmospheric pressure and vibration. Electrical factors comprise operating voltage, current ripple and charge–discharge duty cycle. Conditions, such as vibration, shock and humidity have little effect on the actual capacitor lifetime. At the same time, temperature (ambient temperature and temperature rise because of the current ripple) is the most critical aspect affecting the lifetime of aluminium electrolytic capacitors and the whole system in a negative way [2]. To reduce passive component size, high switching frequency is preferred. In order to allow high switching frequency and to improve converter efficiency, soft switching is necessary. Among those soft-switching techniques suitable for high power converter applications, phase-shift (PS) control technique is one of the best candidates.

V. CONCLUSION

Our lives have been greatly improved by the development of new technology. However, along with the development, the energy crisis around the world becomes more prominent. Various topologies for power converters reviewed and examined in this work. converters are widely used for electrical power conversion in many industrial applications such as for telecom equipment, information technology equipment, conventional and electric vehicles, space power systems and power systems based on renewable energy resources. For this six-leg three-phase converter, when the transformer secondary windings are connected together, current or voltage coupling exists among windings, therefore the interaction occurs among phases. This interaction is determined by the phase-shift angle between the legs of each full-bridge converter. To choose best converters to overcome issues discussed in problem statement is essential.

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