Overview of State of the Art of Reduced Parts Converter Topologies for Adjustable Speed Drives

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Abstract- **In this paper, various reduced parts converter topologies and control strategies for power factor correction and motor control are reviewed and systematic design methodology is developed. From this investigation, the converter topologies could be mainly categorized into cascade type and unified type. The detailed operational principles are examined and the performance comparison is derived to illustrate merits and limitations of the converters. Simulation results are provided to help the better understanding of the theoretical description and several experimental results are presented on prototype induction motor and brushless dc (BLDC) motor drives, along with cascade and unified type converters.**

Introduction

The main function of the static power converters is to change amplitude, frequency, and phase from one level to other one. There are four basic conversion functions that can be implemented, namely ac to ac, ac to dc, dc to ac, and dc to dc. Their main industrial applications cover variable speed motor drives, power factor corrector systems, static VAR generators, high voltage direct current transmission (HVDC), power supplies, high frequency induction heating systems, and etc. Based on the basic conversion functions, there is possibility of great variety of converter topologies and implementations, thus many power conversion circuits have been developed over the past two decades [1]- [12]. In addition, although the technical advantages of the static power converters are generally acknowledged, researchers are becoming aware of their cost and are exploring the possibility of cost reduction. As a result, several reduced parts converters have been introduced in industrial markets [13]-[20]. Due to the variety of the topologies and control strategies, it is very difficult to address all technologies in separate. Therefore, systematic analysis approach is highly desired. It requires the exact evaluation of limitations as well as merits with respect to performance and efficiency of the power converter and of its effect on the loads, such as ac motors.

In this paper, we review the reduced parts converter topologies for power factor correction and variable speed ac motor drives and they are compared with the conventional converter counterparts from the performance and efficiency points of view. Also, a systematic design methodology is developed for exact understanding of the component minimization process. From the detailed investigation and analysis of the existing topologies, all converters can be mainly categorized into two groups: one is cascade type and another is unified type. In cascade type, the PWM converter for power factor correction and the PWM inverter for speed control are connected in series with large DC-Link capacitor and two static power converters are operated and controlled in separate. In this type, specific number of switches, to compose the converter and inverter, are required. Therefore, the required number of switches cannot be reduced significantly. On the other hand, in the unified type, conventional concepts of pwm converter and inverter are merged together and same converter handles the functions of PWM converter (power factor correction) and PWM inverter (motor control) at the same time. As an added advantage, the input inductor, which is commonly used in the PWM converter for power factor correction, can be eliminated and replaced by the existing motor inductor. Therefore, this new concept can significantly reduce the number of components, compared to any conventional cascade type topologies. However, due to the merged control characteristic, the control strategy might be complicated. However, the high speed MIPS capability of the DSP controller, such as TI DSP TMS320 F243, can perform the task successfully. This means that there is no cost associated with the complex controls. Therefore, producing low cost adjustable speed drives is now possible. In this paper, we present all converter topologies and control strategies and explain their operational principles in detail. Also, simulation and experimental results are presented to support the theoretical description and to help the better understanding of the past and emerging static power converter topologies. Therefore, it is expected that this paper will pave the way for the production of low cost and high performance variable speed ac motor drives, in many commercial and consumer applications.

Reduced Parts Converter Topologies

PWM AC-DC Converters

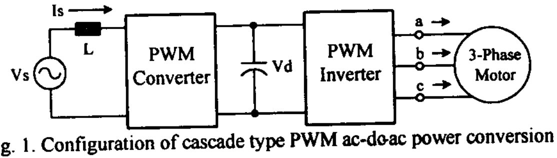
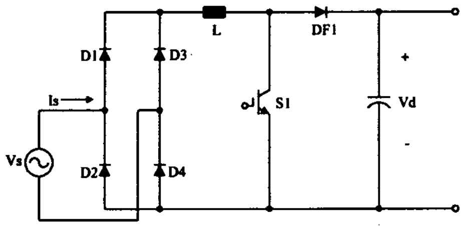
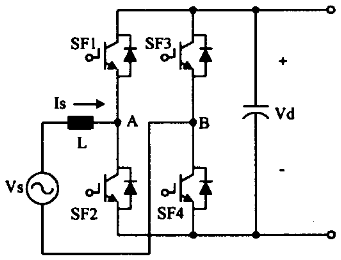


Fig. 1. Configuration of cascade type PWM ac-dc-ac power conversion system.

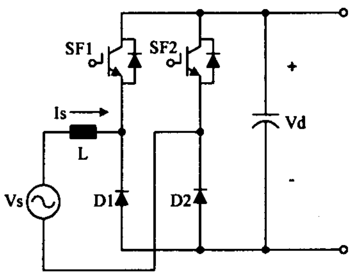
Fig. 1 shows the circuit configuration of cascade type PWM ac-dc-ac power conversion system for power factor correction and speed control. Many converter topologies and control strategies for PWM converter have been introduced [1]-[12] and they are described from Fig. 2 to Fig. 5, along with topologies, control methods, and characteristic voltage and current waveforms. Their performances should be evaluated by considering of number of switches, conduction and switching losses (efficiency), capability of regenerating operation, and DC-Link voltage utilization. From these criteria, half-bridge converter (voltage-doubler) can be regarded as a strong candidate among the component minimized PWM ac to dc converter topologies. In general, the main tasks of the PWM ac to dc converters are to synchronize with ac input voltage for unity power factor and to maintain DC-Link voltage to be a desired constant value. The overall characteristics are illustrated from Fig. 3 to Fig. 5.



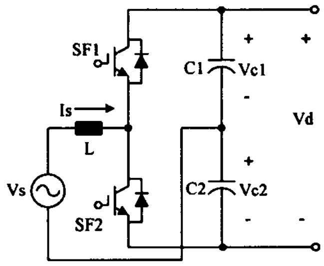
(a) Boost converter



(b) Full-bridge converter



(c) 2-swtich/diode type converter

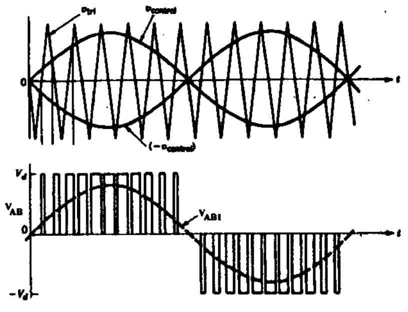


(d) Half-bridge converter (voltage-doubler)

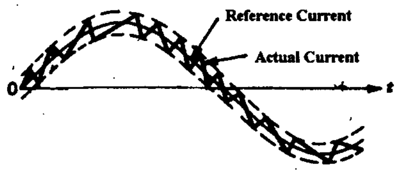
Fig. 2. PWM ac to dc converter topologies.

PWM DC-AC Inverters

For the PWM dc to ac inverter part, there are two major configurations to drive three-phase ac motors, such as six-switch and four-switch configurations as shown in Fig. 6. Due to the inherent voltage vector limitation in the four-switch inverter, the three-phase 120° balanced current profiles can be obtained using 60° phase shifted PWM control strategy as shown in Figs. 7 and 8 [13]-[14].



(a) Voltage controlled PWM



(b) Current controlled PWM

Fig. 3. PWM control strategies for the PWM ac to dc converters.

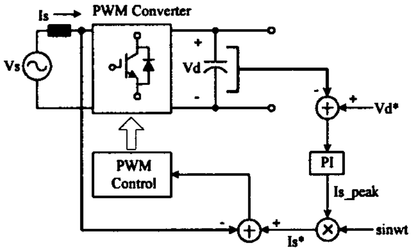


Fig. 4. Control block diagram of the PWM ac to dc converter.

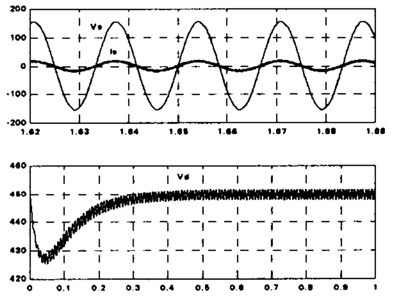
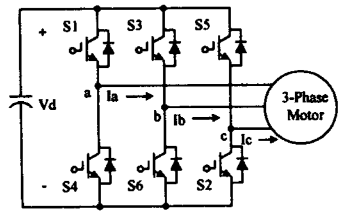
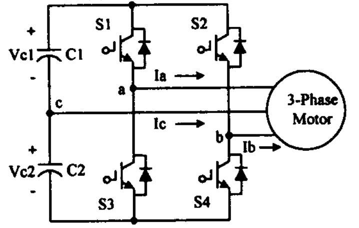


Fig. 5. Characteristics of the half-bridge PWM ac to dc converter (top: ac input voltage and current, bottom: output DC-Link voltage).

Based on the 60° phase shifted PWM, the operational characteristics are depicted in Fig. 9 for the induction motor drive and Fig. 10 shows the application of the four-switch inverter for the BLDC motor drive. In order to properly utilize the four-switch inverter topology in a certain application, it is very important to understand its operational limitations. The main limitations are lower voltage utilization and higher harmonic components. Consequently, it can result in the harmonic copper losses and the torque pulsations. Therefore, the four-switch inverter cannot be an alternative to the conventional configuration in all application areas, but can be a good choice in middle power range applications, in which a certain harmonic level can be tolerated.



(a) Six-switch inverter



(b) Four-switch inverter

Fig. 6. PWM dc to ac inverter topologies.

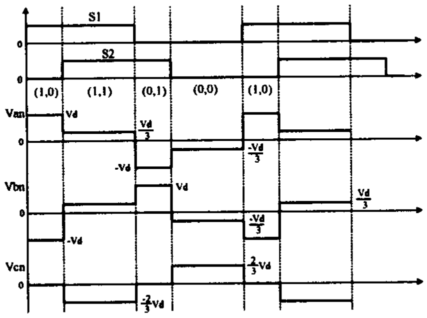


Fig. 7. Asymmetric operation of the four-switch inverter topology.

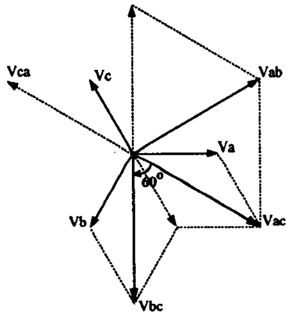
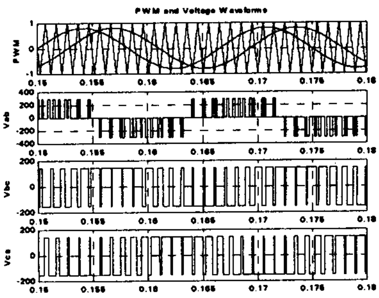
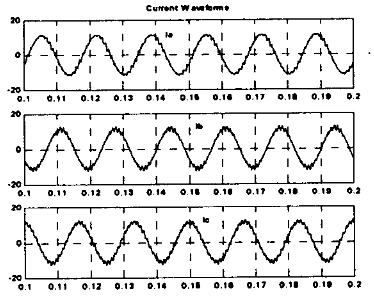


Fig. 8. 60° phase shifted PWM strategy for the four-switch inverter.

Based on the PWM ac to dc converters and PWM dc to ac inverters, which are presented in Figs. 2 and 6, entire cascade type PWM ac-dc-ac converter topologies can be composed as shown in Fig. 11. Among them, the combination of the voltage-doubler and the four-switch inverter can significantly reduce the number of switches as shown in Fig. 11(c) [17]. However, it should be noted that this configuration has the inherent problems of the voltage-doubler and the four-switch inverter, so that advanced PWM control strategies should be developed for wide utilization in industrial applications. Applying the component minimization concept of the four-switch inverter to the conventional three-phase to three-phase PWM converter system, we can reduce the number of switches from the conventional configuration and come up with the eight-switch based configuration as shown in Fig. 12 [18].

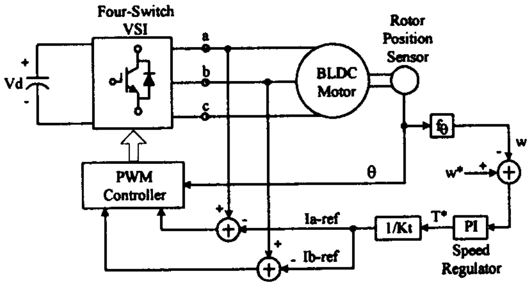


(a) PWM strategy and line-to-line voltages

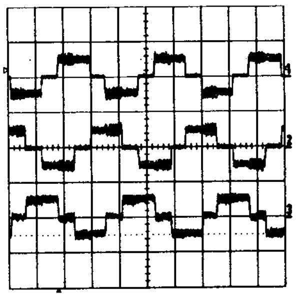


(b) Phase currents

Fig. 9 Voltage and current waveforms of the four-switch inverter for ac motor drives.



(a) Configuration and control block diagram



(b) Experimental phase current profiles (50ms/div., 2A/div.)

Fig. 10. Implementation of the four-switch BLDC drive.

Unified Type PWM Converter

A new technology in the static power converter topology has been introduced by Fujita in 2000 [19] and a more advanced family of converters has been developed and utilized by our team at Texas A&M [20], which is called unified type PWM converter, as shown in Figs. 13 and 14. The main idea is to use zero-sequence current for power factor correction and to replace the input inductor by motor leakage inductor.

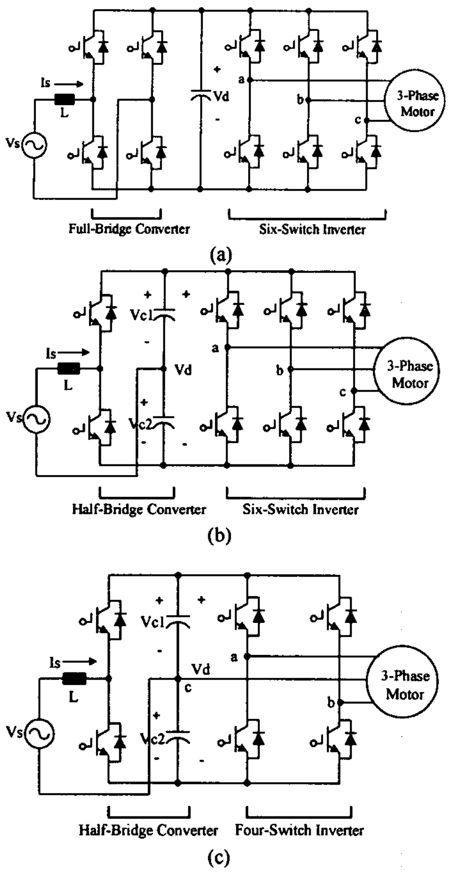
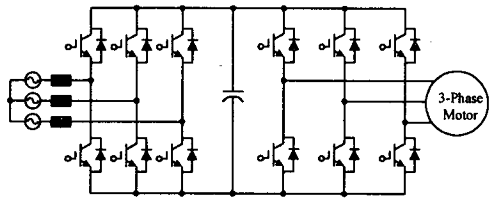
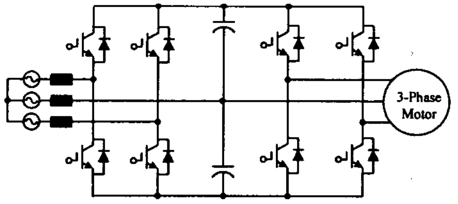


Fig. 11. Cascade PWM ac-dc-ac converters.



(a) Conventional six-switch based configuration



(b) Four-switch based configuration

Fig. 12. Three-phase to three-phase PWM ac-dc-ac converters.

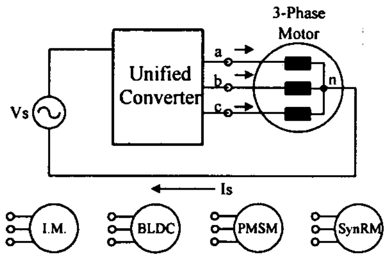
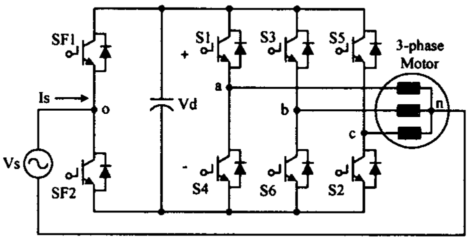
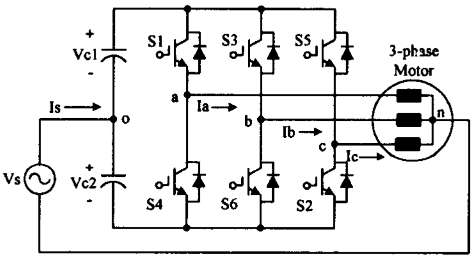


Fig. 13. Unified type PWM converter for power factor and speed controls.

As a result, it can achieve lower number of parts as compared with the conventional cascade type. Even though zero-sequence current flows through motor, it cannot generate any torque component and only positive-sequence component produce torque in motor. Therefore, the equivalent circuits of Fig. 14(b) can be obtained as shown in Figs. 15. The PWM control strategy is based on the superposition theory. It means that two control signals, such as power factor control signal (V_c) and speed control signal (V_{cm}), are added and compared with the triangular signal (V_{tri}) as shown in Fig. 16. The operational voltage and current waveforms of the six-switch unified converter are presented in Fig. 17. From the results, it is noted that it generates 30Hz positive-sequence current for speed control and at same time, outputs 60Hz input ac current (zero-sequence component) for unity power factor. However, in the unified type PWM converters, the zero-sequence current can generate the additional motor loss, such as iron loss and copper loss, and cause motor saturation problem. Also, to achieve the unity power factor, the required DC-Link voltage might be higher than the cascade type converters. Therefore, those problems should be analyzed and the compensating methods should be developed.

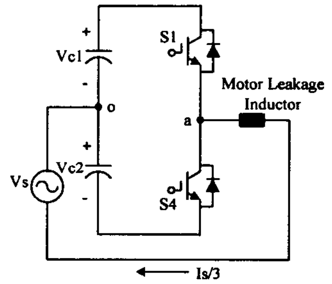


(a) Eight-switch topology by Fujita

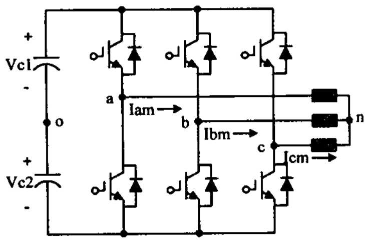


(b) Six-switch topology by Texas A&M

Fig. 14. Unified type PWM converter topologies.



(a) Power factor correction mode per phase



(b) Inverter operation mode for speed control

Fig. 15. Equivalent circuits of the six-switch unified converter.

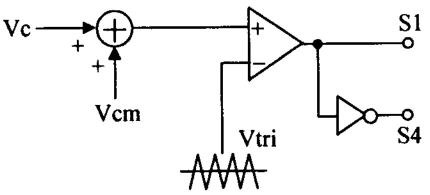
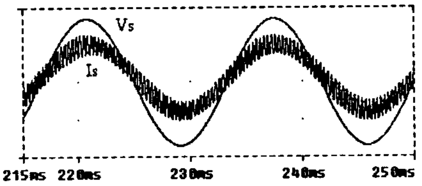
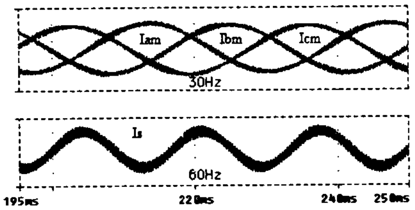


Fig. 16. Implementation of PWM control strategy for the sixswitch unified converter.



(a) Input ac source voltage and current



(b) Positive-sequence motor currents (I_{am}, I_{bm}, I_{cm}) and input ac current (zero-sequence current)

Fig. 17. Simulation voltage and current waveforms of the six-switch unified converter.

Conclusion

With our study on all old and new concepts of the reduced parts converter topologies and their control strategies, we have developed several types of low cost power converter system. Furthermore, we are developing a better concept at the present for induction motor, permanent magnet synchronous motor, synchronous reluctance motor, and brushless dc motor. Therefore, we can develop these for any manufacture or adapt a variation of our drives to their particular needs.

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