Single Phase Induction Motor Drives - A Literature Survey

Ali S. Ba-thunya   Rahul Khopkar   Kexin Wei   Hamid A. Toliyat

Electric Machines & Power Electronics Laboratory
Department of Electrical Engineering
Texas A&M University
College Station, TX 77843-3128
Ph: (979) 862-3034
Fax: (979) 845-6259
E-mail: toliyat@ee.tamu.edu

Abstract -- This paper deals with literature survey of various existing converter topologies, which have been proposed for adjustable speed single phase induction motor drives (SPIMD). Included in the paper are several newly proposed converter topologies. A study of the merit and demerit of different converter topologies have been carried out. Various converter topologies have been compared in this paper. Among these converter topologies, the adjustable frequency PWM inverter is the best choice for single-phase induction motor drives. However, adjustable-frequency drives have not been widely used with single-phase induction motors. The open-loop constant V/f control law cannot be used with the single-phase induction motor drives as it is used with three phase motors. The variation of the operating frequency at lower speed range with constant load torque causes variation in the motor's slip. A constant V/f control is suitable only over the upper speed range. However, improvements in the low frequency performance require the use of constant power dissipation in the motor. Simulation studies for some of the existing topologies as well as for the proposed ones have been carried out.

I. INTRODUCTION

In home appliances, single-phase induction motors (SPIMs) are commonly used. These motors include permanent split capacitor (PSC) motors, split phase motors, permanent magnet synchronous motors, and shaded pole motors. They are single speed motors and are used in dishwashers, clothes washers, clothes dryers, hermetic compressors, fans, pumps, draft inducers, etc. A truly variable speed operation from this motor with a wide range of speed and load would help application designers to incorporate many new features in their products. It would also mean operation with higher efficiency and better motor utilization. In industrial applications three phase induction motors have been used. However, in residential appliances, SPIMs are preferred due to the greater availability of single-phase power.

Recently remarkable efforts have been made in adjustable speed single phase induction motor drives (SPIMDs). Different types of PWM strategies have been used for SPIMD. Among them the most widely used are sinusoidal PWM and Space Vector PWM techniques. Various converter topologies have been proposed for a low-cost high performance SPIMDs [1-29].

II. VARIOUS CONVERTER TOPOLOGIES

1. Single-phase ac/ac chopper:

Variable speed operation of a single phase induction motor has been obtained through voltage control using triacs or back to back thyristors, however these suffer from large harmonic injection into the supply and low power factor, in addition to a limited speed range. To minimize the harmonic injection, topologies presented in Figs. 1 and 2 have been proposed [1,2]. This solution uses only four IGBTs to control the PSC motor. However, PWM controlled ac controllers are plagued with difficulties to commutate inductive load current from one bi-directional switch to another due to finite switch on/off times. Therefore, the four switches need to operate properly such as "four-step switching strategy" in order to prevent voltage spikes. In this circuit there is no need for costly dc bus capacitors. A small ac capacitor across the ac source might be needed in special cases to suppress the spikes on the utility line. Also, snubbers for the devices might be needed too. The motor performance as well as input power factor can be improved by implementing various PWM strategies. However, the speed variation will be over a limited range.
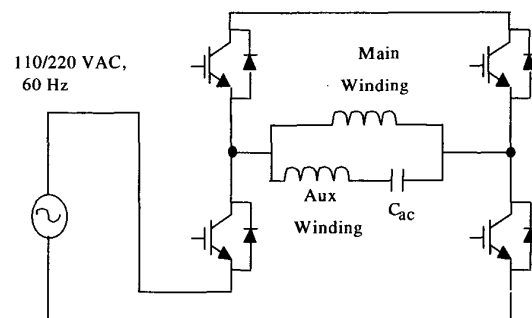

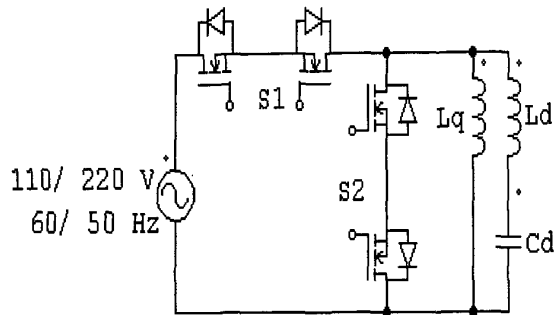*Fig. 1   AC/AC buck converter for PSC motor control.*

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Fig. 2   AC/AC converter.

2. Single-phase ac/ac cycloconverter [3-6]

The configuration presented in Fig. 3 is an extension of the previous topology. Again, ac signal is directly converted to a controlled voltage and frequency ac signal. There is no need for a dc bus capacitor. In this case, the motor torque and current can be controlled in a much better manner than the previous case and a wide range of speed variation can be obtained. However, 12 more diodes are used with respect to the previous solution. Also the efficiency suffers in the lower speed ranges. At lower speeds, the THD is quite significant and the motor current has a significant discontinuity [5]. The motor cannot operate above the rated speed. A DC chopper fed drive has been reported in [6] and is shown in Fig.4.

3. Single-phase full-bridge PWM inverter drive

In the circuit shown in Fig. 5, a full bridge diode rectifier plus a full bridge IGBT based inverter is used. A dc link capacitor is required to supply the reactive power needed by the motor. In this topology, the motor voltage can be controlled without much difficulty.

4. Half-bridge rectifier with full-bridge PWM inverter

The circuit topology in Fig. 6 is similar to that given in Fig. 5, however a half bridge rectifier is used. Two less diodes are used at the expense of using a divided dc bus, which needs a higher value of the DC filter capacitor to achieve the same dc voltage bus ripple. In this configuration there are two possibilities of operation, the first one as full bridge inverter with the maximum motor voltage equal to that of the rectified input ac voltage. In the second topology it works as a half bridge inverter where the two switches in one of the legs work at 50% duty ratio to form a mid-point of the dc bus. In this case, the maximum motor voltage will be half that of the rectified input supply. It is possible to achieve reduced torque and speed pulsations, lower vibrations and lower noise with this topology.
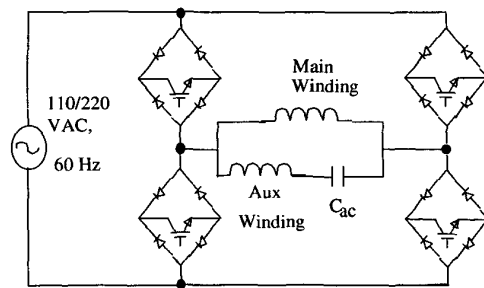

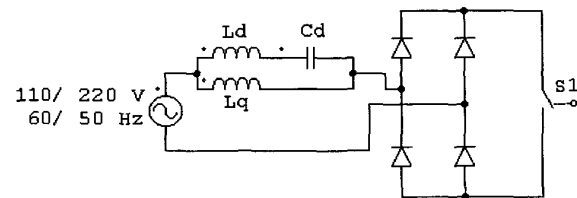*Fig. 3   Single-phase ac/ac cycloconverter.*

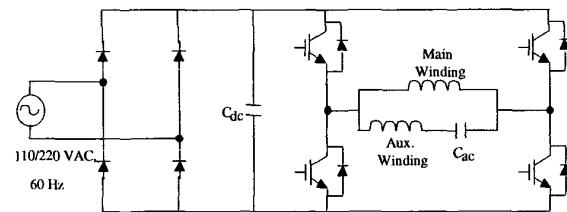*Fig. 4 DC chopper-fed single phase induction motor*

Fig. 5   Single- phase PWM inverter with full-bridge rectifier.
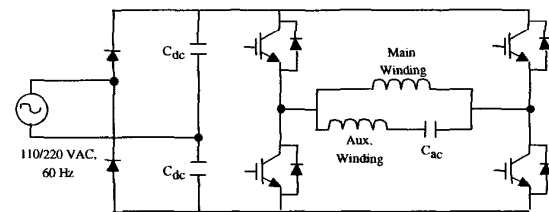

Fig. 6   Single-phase PWM inverter with half-bridge rectifier configuration.

5. Controlled rectifier with full bridge PWM inverter

The circuit topology in Fig. 7 is an extension of that given in Fig. 6. This topology while maintaining the advantages of the previous circuit has an extra advantage. Two extra IGBTs (used as an active rectifier) are used to control the utility supply current. In this case, the front-end controlled rectifier can be used to limit the total harmonic distortion (THD) and also increase the utility side power factor. This drive system has a wide speed range in the forward and reverse directions and operates with near unity power factor and also regenerative capability.

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6. Half-bridge rectifier with half-bridge PWM inverter

In the topology shown in Fig. 8, a half-bridge rectifier can be used. However, care should be taken in maintaining the dc bus mid-point balanced. In this case, only two IGBTs and two diodes are used.

7. Controlled Half-Bridge rectifier with half-bridge inverter

This topology, shown in Fig. 9 is an extension of the previous case with a controlled half-bridge rectifier. The half-bridge controlled rectifier in conjunction with the right hand side switches is needed to regulate the voltage across the motor terminals. The problem associated with this topology is same as that of the previous half bridge topologies, which is in maintaining the dc bus mid-point balanced.
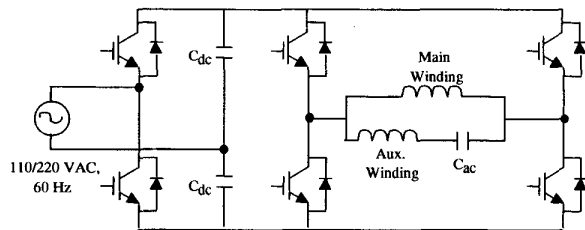

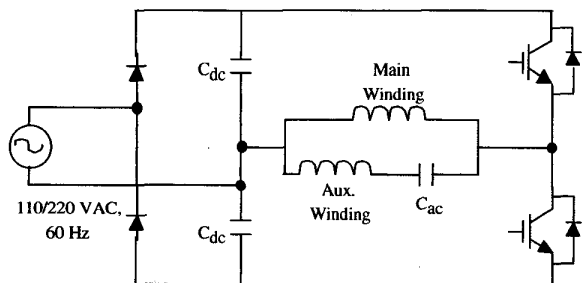*Fig. 7   Single-phase PWM inverter with a controlled half-bridge rectifier.*

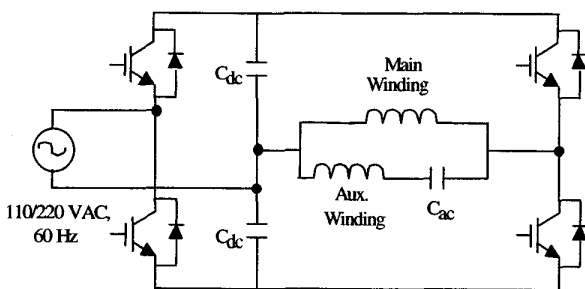*Fig. 8   Single-phase PWM inverter with half-bridge rectifier.*

Fig. 9 Single-phase PWM inverter with controlled half-bridge rectifier.

8. Two-phase full-bridge PWM inverter

In this configuration (as shown in Fig. 10 [14]) a two-phase PWM inverter motor drive is presented. An H-bridge is used to supply each winding. The two winding voltages and currents can be controlled independent of each other. Therefore, accurate control of torque and speed is possible. It is possible to implement the field-oriented control with this topology. Notice that 8 switches are used. However, there is no need for an ac capacitor in the single-phase induction motor. The main and auxiliary windings are supplied separately.

9. Two-phase half-bridge PWM inverter

This is a half bridge version of the previous drive. In this case as shown in Fig. 11, only four switches are used. However, the voltage across the motor windings would be half of the dc bus voltage, which means the motor will operate under half of the rated voltage. Also, it is crucial to keep the voltage across the dc bus capacitors balanced.

10. Two-phase semi full-bridge PWM inverter

This topology uses a six pack IGBT module as shown in Fig. 12 to control a two-phase induction motor. There is no need for a divided dc bus. However, it has the same problems as that of the previous topology, namely the motor voltage would be half the rectified input voltage. A special PWM topology needs to be implemented to achieve the maximum possible converter utilization for a two-phase output voltage (balanced or unbalanced) [15]. Eight space vectors are used for implementing a SVPWM as shown in Fig. 15. Two of the vectors are zero vectors, four vectors are equal and two of the vectors are unequal. A current controlled hysteresis technique can also be used successfully as shown in Fig. 17.
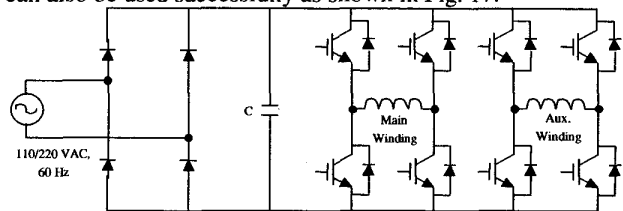

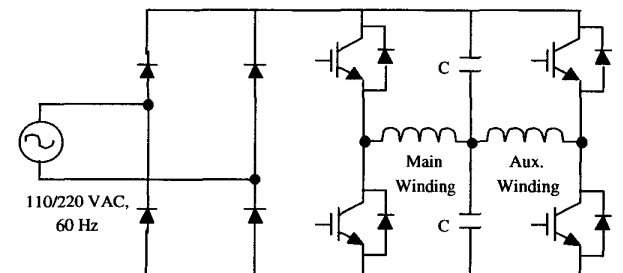*Fig. 10 Two-phase full bridge PWM inverter.*

Fig. 11 Two-phase half bridge PWM inverter.

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11. Two-phase PWM inverter with controlled rectifier

The source current and therefore the supply power factor and THD can be controlled by using IGBTs instead of diodes as can be seen in Fig. 13 [10, 11, 12, 30]. It is possible to implement a space vector PWM (SVPWM) in this case. There are four voltage space vectors and no zero voltage vectors in this two-phase inverter. In this case, the full rated voltage would be applied to the motor windings. However, it is crucial to keep the voltage across the dc bus capacitors balanced.

III. SIMULATION RESULTS

The simulation results of the motor terminal voltages for ac/ac converter shown in Fig. 1 is shown in Fig. 14. The simulation results for Fig. 12 are shown in Figs. 16 & 17. For the circuit in Fig. 13 [30], the winding currents and the supply current (in phase with the supply voltage) are shown in Fig. 18 (using current control). For this circuit, a PI regulator was used. Back emfs were not considered. It is seen that the output currents closely follow the reference currents.
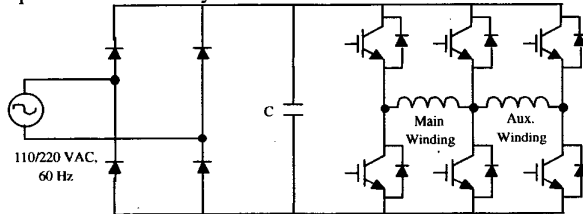

Fig. 12 Two-phase semi full bridge PWM inverter.

Fig. 13 Two-phase PWM inverter with controlled rectifier.

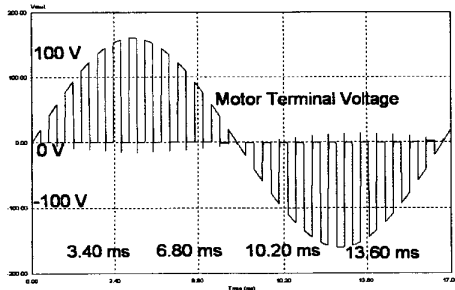
Fig. 14 Single-phase induction motor terminal voltage.
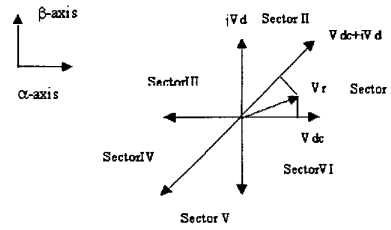

Fig. 15 Unequal basis vectors (six non-zero and two zero) vectors to generate a reference space vector (for Fig. 12).
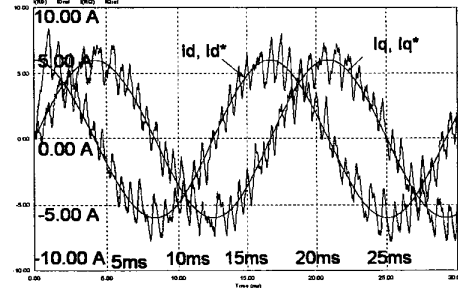

Fig. 16 d- and q-winding currents and reference currents.
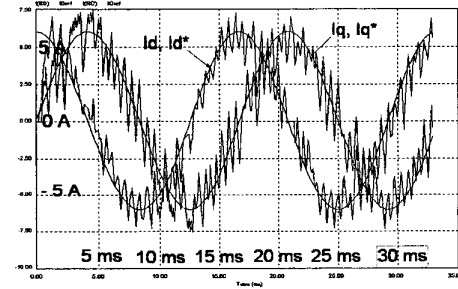

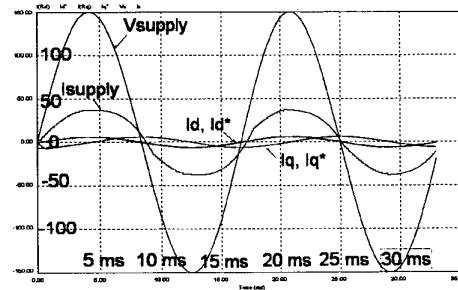Fig. 17 d- and q-winding currents using Hysteresis Control.

Fig. 18 Winding currents (and reference currents) and in-phase supply voltage and current.

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IV. COMPARISON

In the table below, various topologies are compared based on the number of devices, the size of the dc link capacitor, power factor, speed range, performance, cost, control complexity and efficiency. It is seen that the topology in which the two currents are independently controlled is the best in terms of performance, but it requires the largest number of components.

V. CONCLUSIONS

The single-phase induction motor can successfully be driven from a variable frequency power supply. Hence, the motor speed can be easily adjusted. Other methods for speed control, such as voltage amplitude control do not allow for the range of speed, which is possible with the use of a variable frequency supply. The torque performance of the capacitor-connected motors can be enhanced at low frequency range by altering the V/f control law such that the internal power dissipation in the motor is held constant [19]. High performance control strategies can be used for adjustable speed single-phase induction motor drives in combination with high performance converter topologies. Also, low-cost high-performance converter topologies have been proposed. Advantages and disadvantages of different converter topologies have been discussed. Simulation results for a few of the existing topologies and the proposed topologies have been carried out. For the figure of Fig. 12, in order to have maximum converter utilization, special PWM techniques have to be used. These include the current hysteresis and Space Vector PWM technique in which the basis vectors are unequal.

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Comparison Table for Various Topologies

Characteristics	AC/AC Chopper	Cycloconverter		Single Phase PWM inv.						Two Phase PWM inv.			
		Conventional	Non-conventional	Half Bridge inverter		Full Bridge inverter				Balanced		Unbalanced	
						Double DC-link voltage		Rated DC-link voltage					
Number of devices	4S + 4Ds	4S + 16Ds	1S + 4Ds	2S + 4Ds	4S + 4Ds	4S + 6D	6S + 6D	4S + 8Ds	6S + 8Ds	6S + 10D	8S + 10D	4S+ 8Ds	6S+ 8Ds
DC-Link Capacitor	Not used	Not used	Not used	Very large	Very large	Very large	Very large	Large	Large	Large	Large	Very large	Very large
Power factor	Good	Good	Good	Good	Best	Good	Best	Good	Best	Good	Best	Good	Best
Speed variation	Very small	Inter.* range	Inter. Range	wide range	wide range	wide range	Wide range	wide range	wide range	wide range	Wide range	wide range	wide range
Performance	Good	Good	Poor	Better	Better	Better	Better	Better	Better	Best	Best	Best	Best
Cost	Low	Low	Lowest	Med.	High	Med.	High	Med.	High	High	Highest	High	Highest
Control Compl*	Simple	Inter.	Simplest	Inter.	Co.*	Inter.	Co.	Inter.	Co.	Co.	More Co.	Co.	More Co.
Efficiency	?	High	Low	High	High	High	High	High	High	Highest	Highest	Highest	Highest

*(Med.; medium, Inter.; intermediate, Co.; complex, Compl.; complexity)

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