Research Article Open Access

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Speed control of an induction motor by 6-switched 3-level inverter

https://doi.org/10.1515/phys-2017-0138
Received December 15, 2017; accepted December 18, 2017

Abstract: This paper presents speed control analysis of an induction motor by a 6-switched 3-level inverter. In the analysis of topology, the study used the field oriented control technique which is widely used in the literature, easy and stable for operating systems. The field weaking technique was used for speeds exceeding nominal speed to reduce magnetic saturation and thermal losses. At the end of the process, it was observed to increase motor torque and inverter efficiency. Instead of using 12 switches in conventional 3-level inverters, 6 switches are used in this topology. Reduced number of switches is the greatest contribution of this study.

Keywords: Coupled inductor, induction motor, space vector pulse width modulation (SVPWM), total harmonic distortion (THD), 6-switched 3-level inverter

PACS: 84.30.Bv, 84.30.Jc

1 Introduction

Lately, studies on conversion from DC to AC has become more widespread across the world. Particularly, an induction motor is powered by AC, while various conversion methods are applied to convert DC to AC. Usage of inverters has become quite widespread among these studies. Nevertheless, the shape of the sinusoidal signal obtained in conversion from DC to AC by classic inverters is far from desired quality. Thus, the inverter output voltage level is increased to improve the quality of the sinusoidal signal that is generated.

Increasing the voltage level is inversely proportional to the amount of harmonics and it provides directly proportionate increase in efficiency. In this conversion process, while increasing efficiency, the converter must be easily applied and it must also be economical. For this reason, the cost of switches and control systems used in inverters must be in compliance with efficiency. Developing new topologies to keep these variables under control is inevitable.

Multi-level inverters create an output voltage which is close to a sinusoidal form by combining different types of DC voltage levels applied as input [1, 2]. They are superior to classic two-level inverter topologies in terms of circuit structure. Harmonic spectrum of the output signal, power factor and efficiency may be listed among the main advantages [3]. It was seen that, as the the number of input voltage levels going into the multilevel inverter increases, the output voltage is much closer to sinusoidal form; total harmonic distortion is reduced and performance is increased [2, 4, 5].

Various pulse width modulation (PWM) techniques are used in multi-level inverters to achieve voltages with minimal harmonic distortion and desired levels of frequency and amplitude. Nowadays, one of the most common modulation techniques is the space vector pulse width modulation (SVPWM) technique for two and multilevel converter systems. With this technique, three-phase voltages may be achieved as inverter output, which provides desired levels of amplitude and frequency with minimal harmonic distortion. The SVPWM technique has some features such as optimum usage of the DC input voltage, low current ripple and a good degree of harmonic performance [2, 6].

In recent years, alternative multilevel inverter topologies have been developed. One of these is a three-level inverter that has 6 IGBT switches, where a split-wound coil is coupled into each inverter output terminal. In this topology, split-wound coils are connected in series to the upper and lower switches. A significant disadvantage of this inverter topology is that there is a need for dead-time protection for the transition current during switching. However, the negative effects of dead-time are eliminated by the SVPWM method. The PWM voltage that is obtained has a potential to improve load efficiency and power density, and reduce high frequency losses on AC coils and the loads on the machine [7–10].

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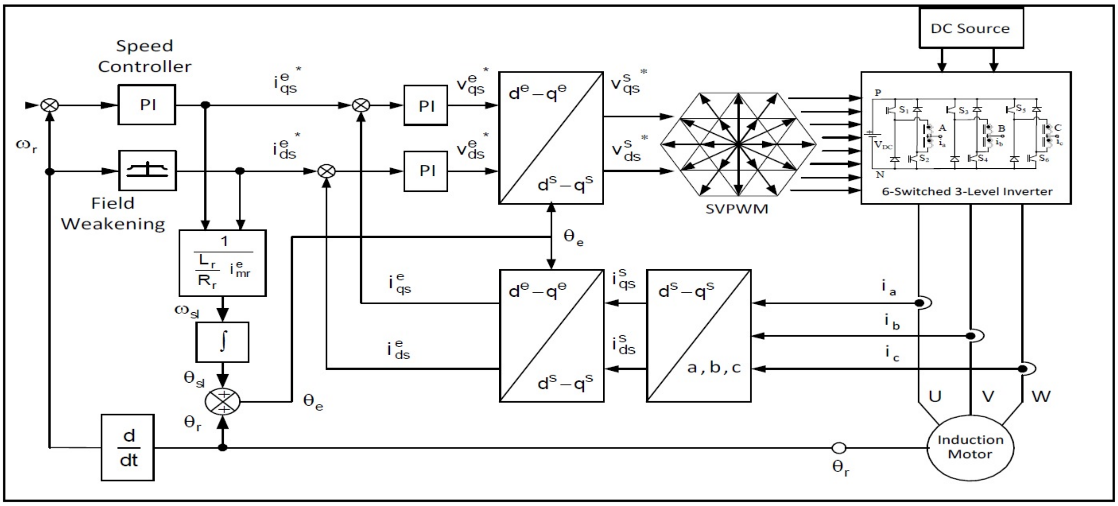

Figure 1: Block diagram of field oriented control of induction motor

In difference to others in the literature, this study contains simulation analysis of speed control of a 1 kW induction motor using a 6 switched 3-level inverter. When speed control of the induction motor was carried out, the field oriented control technique was preferred, as it is widely used in the literature, easy to use, and more stable. Increasing field weaking speeds above the rated speed reduced magnetic saturation and heat losses. At the end of this process, increases were observed in torque and efficiency. By using only 6 switches, switching losses decreased and efficiency of inverter increased.

2 Field oriented control technique

In the field oriented control technique, 3 phases of current, voltage and flux data of the motor are transferred into two planes with a 90° phase difference. Thus, the speed control of the induction was made similar to separately excited DC motors, which creates two planes independent of each other to provide speed control.

Stator and rotor voltage equations of the motor that were reduced to the two planes may be expressed in the d-q synchronous axis plane;

$$V_{qs}^e = R_s\, i_{qs}^e + p\,\lambda_{qs}^e + \omega_e\,\lambda_{ds}^e \tag{1}$$

$$V_{ds}^e = R_s\, i_{ds}^e + p\,\lambda_{ds}^e - \omega_e\,\lambda_{ds}^e \tag{2}$$

$$0 = R_r\, i_{qr}^e + p\,\lambda_{qr}^e + (\,\omega_e - \omega_r\,)\,\lambda_{dr}^e \tag{3}$$

$$0 = R_r\, i_{dr}^e + p\,\lambda_{dr}^e - (\,\omega_e - \omega_r\,)\,\lambda_{qr}^e \tag{4}$$

In the equation above, R_s: stator phase resistance, R_r: rotor phase resistance, ω_e: synchronous speed, ω_r: rotor speed and p: derivative operator. Flux and torque equation may be expressed as;

$$\lambda_{qs}^e = L_s\, i_{qs}^e + L_m\, i_{qr}^e \tag{5}$$

$$\lambda_{ds}^e = L_s\, i_{ds}^e + L_m\, i_{dr}^e \tag{6}$$

$$\lambda_{qr}^e = L_m\, i_{qs}^e + L_r\, i_{qr}^e \tag{7}$$

$$\lambda_{dr}^e = L_m\, i_{ds}^e + L_r\, i_{dr}^e \tag{8}$$

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}\,(\lambda_{dr}^e\, i_{qs}^e - \lambda_{qr}^e\, i_{ds}^e\,) \tag{9}$$

In the equation above, L_s: stator phase inductance, L_r: rotor phase inductance and L_m: common inductance. Using the electromagnetic torque equation, change of rotor speed may be expressed in terms of electrical speed as;

$$\frac{d\,\omega r}{dt} = \left(T_e - B\,\frac{2}{P}\,\omega_r - T_1 \right)\frac{P}{2j} \tag{10}$$

In the equation above, T_e: electromagnetic moments, B: coefficient of friction, T_1: load moments, j: moment of inertia, P: number of motor poles. Induction motor speed control is achieved using the equation above. Speed error may be found by calculating the difference between the actual speed and the desired speed. To compensate the speed error, it is necessary to change the conduction time and ranking of the semiconductor switches [11, 12]. Figure 1 illustrates the block diagram of field oriented control of the induction motor.

3 6-switched 3-level inverter topology

This topology produces multi-level output voltages by apllying a DC source and connecting each output to a 3 phase split-wound inductor. In this 6-switched 3-level topology, 6 switches are used as shown in Figure 2.

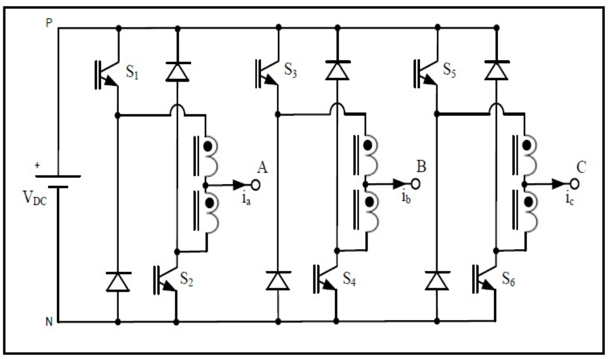

Figure 2: 6-switched 3-level inverter topology

$+0.5\ V_{DC}$, $V_{DC}$and 0 voltage values are obtained, while the inverter output terminal voltage is called V_{AN} [7–9, 12–14]. This is shown in Figure 3.

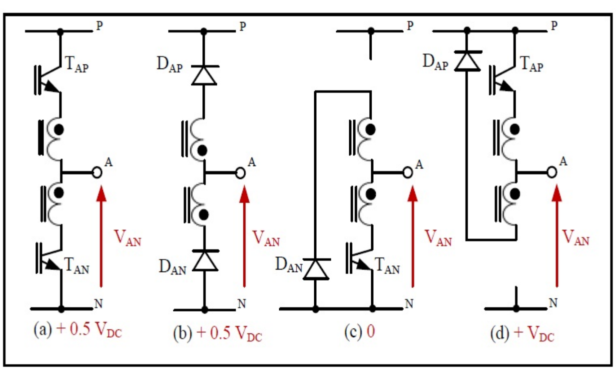

Figure 3: Switching states of one leg of the 6-switched 3-level inverter

This topology eliminates the requirement of dead-time protection and it allows upper and lower switches to pass through conduction at the same time. Dead-time effects disappear, an additional middle-point voltage is generated, and effective output switching frequency is doubled thanks to this aspect. Thus, harmonic distortion of output waves are largely resolved by ascending to the 3rd voltage level and doubling the effective switching frequency [7–9, 12, 13, 15].

Table 1: Technical data of study

Switching Frequency (KHz)	Control Technique	Source of DC input	Parameters of Induction Motor			
			Power	Volt	Pole	$\cos\phi$
10	PI	500V	1 kW	380 V	4	0.78

4 Computer aided simulation studies

Simulation studies were carried out using the Dev C++ software and the plots were performed with MATLAB. Technical data of the study are given in Table 1.

Speed, torque and current curves of 300 r/m and 1500 r/m reference speeds are shown. While the induction motor was run at the reference speed of 300 r/m, it was given 1 s to reach the desired speed and allowed to run for a total of 1.6 s. Figure 4 shows the reference-real speed curves, phase currents, d-q plane currents and torque curves. The motor was run in the opposite direction during the inital running time, and then it reached the desired speed value. The motor currents was obtained as a 3-phase current. In the d-q plane, the moment id current remained constant; however, the current iq changed based on the speed profile. When the rated speed was reached, the current iq provided a value by the motor running without a load.

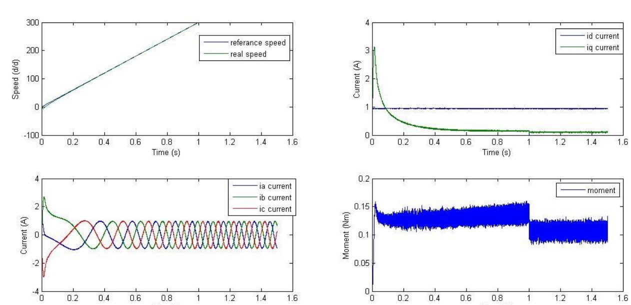

Figure 4: 300 d/d induction motor variables

The harmonic spectrum of the current i_a for 300 r/m in the induction motor is given in Figure 5.

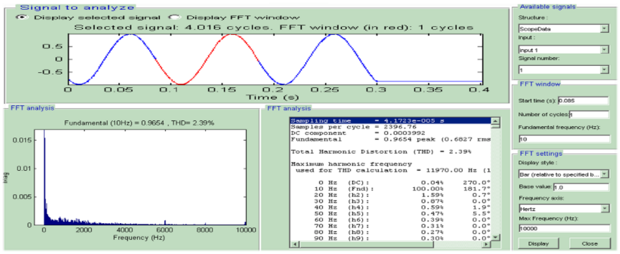

Figure 5: i_a current harmonic spectrum belongs to 300 d/d

In the study, the phase current consumed over time after reaching the nominal speed was referenced. The current ia was analysed and the THD value was observed to be 2.39%. It was an applicable value for inverters, as the THD value was desirably lower than 5%.

The reaction of the induction motor was then tested for 1500 r/m given in Figure 7. The current iq had a current value provided by the motor without a load while it reached the rated speed. The THD value for the 1500 r/m case was obtained as 3.55%, and is shown in Figure 6.

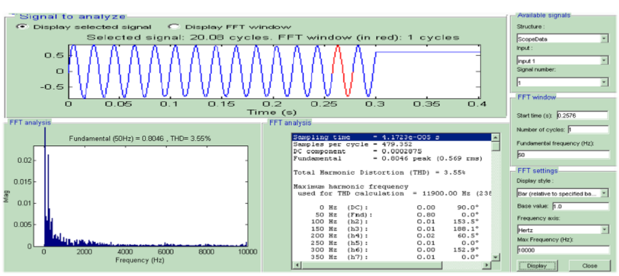

Figure 6: i_a current harmonic spectrum belongs to 1500 d/d

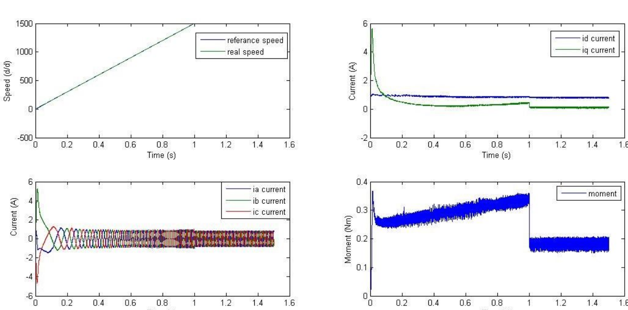

Figure 7: 1500 d/d induction motor variables

5 Conclusion

In this study, the speed of a 1kW induction motor was controlled using a 6-switched 3-level inverter and the motor's responses to different frequencie values were examined. By split-wound coils connected to each output, the inverter obtained a 3-level output voltage. Split-wound coils were connected in series to the upper and lower keys to eliminate the necessity of dead-time protection, which is usually necessary to prevent short-circuits. Thus, inverter losses were reduced substantially.

According to results of the analysis, it was seen that the amount of generated harmonics contained quite low THD values (2.39%, 3.55%), which were on acceptable levels. This demonstrates that 6-switched 3-level inverter is structurally suitable for induction motor speed control and can be used in industrial applications in the future.

In the future, the need for low power - high speed drives will increase and they will be used more widely in industrial applications. Additionally, the 6-switched 3-level inverter topology will find a significant role in high speed drive systems, as expected in the light of the results of this study.

Acknowledgement: Digest version of this paper was presented and published in 18th International Symposium on Electromagnetic Fields in Mechatronics, Electrical and Electronic Engineering (ISEF 2017) Lodz, Poland which is indexed IEEE Xplore.

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