International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 – 5161

Research Article

Designing and implementing 7.5kW three phase inverter for Electrical Vehicle

Ammar.A.Faleh[*] and Dr.Ali.H. Al-Mukhtar

University of Technology, Baghdad, Iraq

Received 15 Sept 2017, Accepted 20 Nov 2017, Available online 23 Nov 2017, **Vol.7, No.6 (Nov/Dec 2017)**

Abstract

The air pollution from petrol engine based cars that produced carbon dioxide has led the international environment agencies, car manufacturers etc. to explore opportunities in developing an environmental friendly car such as the electric vehicle. However, the drawback of such a product is the storage energy requirements and limited speed. Therefore, many initiatives by the car manufacturers were started to counter those limitations which focused on improving the car components to improve the car performance. In addition and with the advent and evolution in the electronic industry, especially in microprocessors, which enabled the production of economically (low) energy consumption, high performance, and the main energy loss in electric vehicles. There are two types of motor categories, DC and AC. However, the most commonly used motor type commercially for electric vehicles is the AC motor which due to the low power consumption. The aim of this paper is to explain the key components required and their combination interworking relationship to build an three phase inverter for electric vehicle with emphasis on the best choice of speed technique in terms of energy. The work comprised of design and build of three phase inverter for Electrical Vehicle (EV. The key design of the three phase inverter is the control with selection of the best technique for the speed control. The result was reported to find the optimum speed and maximum period of driving time.

Keywords: *Air pollution, three phase inverter etc.*

1. Introduction

The electrical motors have brought about one of the big advancements in the fields of engineering and technologies after electricity invention. The function of the electro mechanical device is to convert electrical to mechanical energies. There are different types of motors were developed to addressed different purposes. The basic function principal of the motor is to force experience in the direction perpendicular to magnetic field and the current, when field and current are made to interact with each other.

2. Speed-torque characteristics of induction motors

The typical speed-torque characteristics of an Induction Motor (IM) are shows in Figure 1. The X axis is showing the speed curve and the slip curve. The Y axis is showing the torque curve and current curve. The drawing of the characteristics are with frequency and the rated of voltage that is supplying to the stator. In start-up, it is shown that the motor typically is drawing up to seven times from the rated current. The high of the current is the result of the stator and the rotor flux, and the losses in windings of the rotor and stator, and the losses in bearings cause of the friction. This high starting current are overcoming these components and producing the force to rotate of the rotor. During the start-up, the motor is delivering 1.5 times from the rated torque of motor.

This torque of starting is called locked rotor torque when the speed is increasing, the drawn of current by the motor is reducing slightly as shown in fig.1. Significantly the Power becomes drops when the motor speed approaching to 80% of the rated speed. At rated speed of motor, the motor will be running at the rated current and reached to the rated torque. At rated motor speed, if the load on the shaft of the motor is increasing rated to the torque, the speed will be starting to drop and the slip will be increasing. At 80% of the synchronous motor speed, the load maybe increasing till 2.5 times from the rated torque. It is called breakdown torque. If the increasing of the load on the motor further, this will lead to un ability to carry any extra load. Hence, if the load increases more than the rated load and according to the characteristic the current load will be increasing by following the path of current. So due to the high current in the motor windings of the losses in the windings will increases as well.

This will lead to increasing in the temperature of motor windings. And to avoid this high temperature we

---

[*] Corresponding author's ORCID ID: 0000-0002-1791-6969

can use the suitable classes of insulation in the motor windings. When the motor is running under overloading for long time, the motor will be burned. As shown in fig.1. The Speed Torque Characteristics, it is showing that the torque is nonlinear as the varying of speed. The speed needs to be varying, that will be making the torque varies too. So the control of the speed in method of open loop is called, Variable Voltage Variable Frequency (V/f).

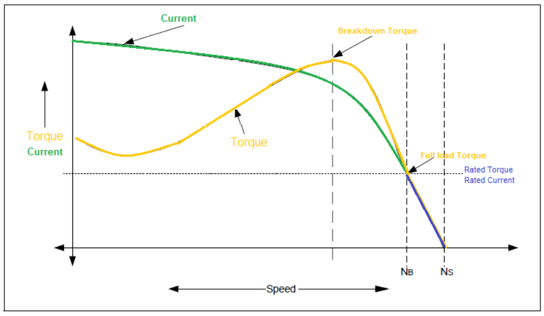

Figure 1: Torque/Speed - characteristics of induction

3. Variable Voltage Variable Frequency Control theory

The Variable Voltage Variable Frequency control is power electronics converter, the system consists of three parts DC source, boost converter and inverter. Voltage-source inverter drives are the most common drives. It is working to convert DC input to AC output. The basic inverter is configured as a three-phase, six-pulse, and full-wave diode bridge. It is consisting of capacitor which working to smoothing out the ripple to the inverter input. The filtering of the DC voltage is to converting to quasi-sinusoidal of the output AC voltage by using the active switching elements in inverter. Voltage-source inverter is providing high power factor and low harmonic distortion than the other control inverters. As we can see in Figure.1 the speed-torque characteristics, the induction motor draws the base speed at rated current and rated torque. When increasing the load to be overrated load and the speed at base speed, the speed will be dropped and the slip will be increased. The motor will be reaching approximately 2.5 times from the rated torque and the speed will be dropped approximately 20% from base speed. The torque on shaft of the motor is proportional to magnetic field of the motor stator. So, the voltage on the stator is proportional to the flux generated by stator (electromotive force (EMF)) and the angular velocity. This will be making the flux generated proportional to the ratio of the voltage and the frequency of supply. as shown in Equation (2).

$$\text{electro motive force (emf)} = 4.44 \times \emptyset \times \mathrm{F} \times \mathrm{N} \qquad (1)$$

$$\text{Synchronous Speed (Ns)} = 120 \,\mathrm{x} \frac{\mathrm{f}}{\mathrm{P}} \qquad (2)$$

Where: N: Synchronous Speed; F: rated frequency of the motor; P: number of poles in the motor and

$$\text{electro motive force (emf)} = \mathrm{V} \qquad (3)$$

So

$$\mathrm{V} = 4.44 \times \emptyset \times \mathrm{F} \qquad (4)$$

The flux magnetic $(\emptyset) =$ should be constant ; $4.44 \times \emptyset =$ constant

$$\mathrm{V} \propto \mathrm{F} \times \mathrm{N} \qquad (5)$$

$$\frac{\mathrm{V}}{F} \propto \mathrm{N} \qquad (6)$$

When changing the frequency the speed of the motor will be changed too. So, by changing the voltage and frequency at the same ratio, the torque will be staying constant through the range time of speed. we have six switches in inverter, three switches upper and the other lower switches , at least we should have three switches will be on. When the switches are on, the current flows from the DC to the winding of motor. Upper and lower switches should not be switching on at the same time. To avoid the DC supply to be shorted. Hence, there is dead time between switching off of the upper switch and lower switch and vice versa. This will be ensuring that the upper and lower switches will not conductive during the change states from off to on or vice versa.

The benefits of Variable Voltage Variable Frequency technique, energy savings, and many fixed-speed motor load applications that are supplied direct from AC line power can save energy when they are operated at variable speed by means of Variable Voltage Variable Frequency. This change gives a large power reduction compared to fixed-speed operation for control performance; AC drives are used to bring about process and quality improvements in acceleration, flow, monitoring, pressure, speed, temperature, tension, and torque. AC drives instead gradually ramp the motor up to operating speed to lessen mechanical and electrical stress, reducing maintenance and repair costs, and extending the life of the motor and the driven equipment. Variable-speed drives can also run a motor in specialized patterns to further minimize mechanical and electrical stress.

4. Inverter Stage

Power electronic switches such as Insulated-Gate Field-Effect Transistor (IGBT), power Metal–Oxide–Semiconductor Field-Effect Transistor (MOSFT), GTO or SCR switch the DC power from batteries bank on and off to produce a current or voltage waveform at the required new frequency. Presently most of the Voltage Source Inverters (VSI) use Pulse Width Modulation (PWM) because the current and voltage waveform at output in this scheme is approximately a sine wave. Power electronic switches such as IGBT, GTO etc. switch DC voltage at high speed, producing a series of short-width pulses of constant amplitude. Output voltage is varied by varying the gain of the inverter. Output frequency is adjusted by changing the number of pulses per half cycle or by varying the period for each time cycle. The resulting current in an induction motor simulates a sine wave of the desired output frequency. The high speed switching action of a PWM inverter results in less waveform distortion and hence decreases harmonic loses. As shown in fig.2 will see the three phase diagram inverter circuit.

The basic configuration of a Voltage Source Inverter (VSI) has been described to the output from this inverter is to be fed to a 3-phase balanced load. Fig.2 shows the power circuit of the three-phase inverter. This circuit may be identified as three single-phase half-bridge inverter circuits put across the same dc bus. The individual pole voltages of the 3-phase bridge circuit are identical to the square pole voltages output by full bridge circuits. The three pole voltages of the 3-phase square wave inverter are shifted in time by one third of the output time period. These pole voltages along with some other relevant waveforms have been plotted in Figure. 3. The horizontal axis of the waveforms in Figure 4 has been represented in terms of 'ωt', where 'ω' is the angular frequency (in radians per second) of the fundamental component of square pole voltage and 't' stands for time in second. In Figure 4 the phase sequence of the pole voltages is taken as V_{AO}, V_{BO} and V_{CO}. The numbering of the switches has some special significance vis-à-vis the output phase sequence.

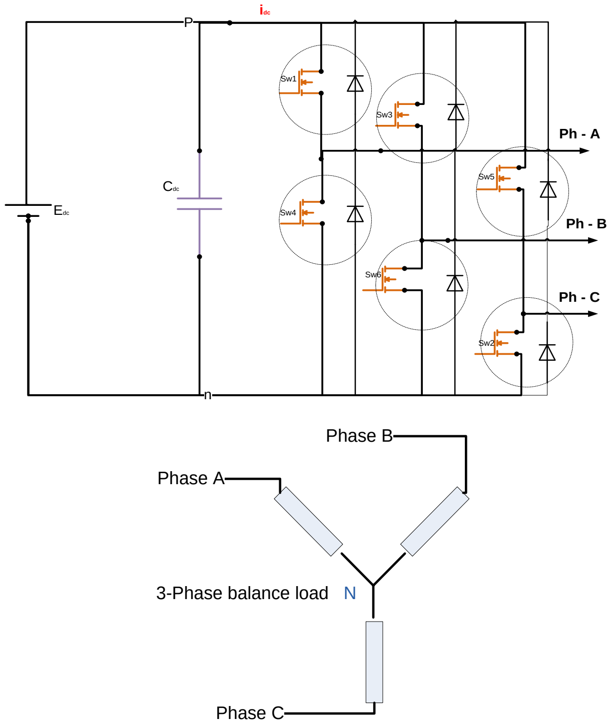

Figure 2: 3-phasevoltage source inverter (VSI) feeding a balanced load

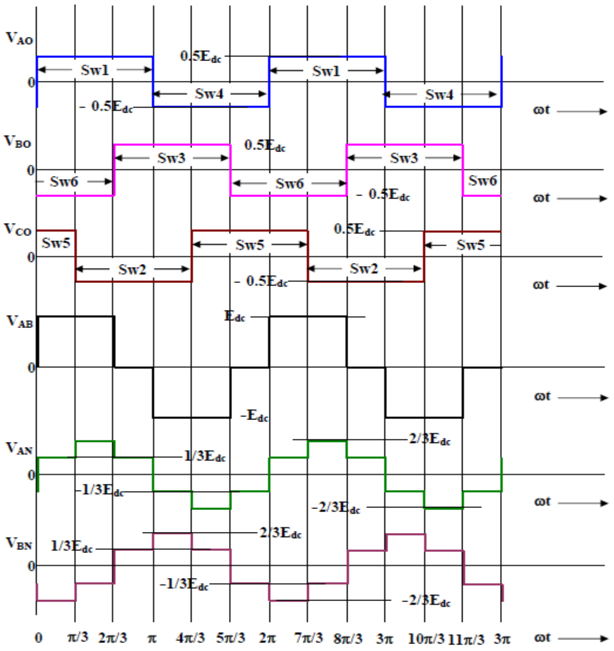

Figure 3: Some relevant voltage waveforms output by a 3-phase square wave VSI

To appreciate the particular manner in which the switches have been numbered, the conduction-pattern of the switches may be noted. It may be seen that with the chosen numbering the switches turn on in the sequence:- Sw1, Sw2, Sw3, Sw4, Sw5, Sw6, Sw1, Sw2, ….and so on. Identifying the switching cycle time as 360 degrees (2π radians), it can be seen that each switch conducts for 180^0 and the turning on of the adjacent switch is staggered by 60 degrees. The upper and lower switches of each pole (leg) of the inverter conduct in a complementary manner. To reverse the output phase sequence, the switching sequence may simply be reversed.

Considering the symmetry in the switch conduction pattern, it may be found that at any time three switches conduct. It could be two from the upper group of switches, which are connected to positive dc bus, and one from lower group or vice-versa (i.e., one from upper group and two from lower group). According to the conduction pattern indicated there are six combinations of conducting switches during an output cycle:- (Sw5, Sw6, Sw1), (Sw6, Sw1, Sw2), (Sw1, Sw2, Sw3), (Sw2, Sw3, Sw4), (Sw3, Sw4, Sw5), (Sw4, Sw5, Sw6). Each of these combinations of switches conducts for 60^0 in the sequence mentioned above to produce output phase sequence of A, B, C. As will be shown later the fundamental component of the three output line-voltages will be balanced. The load side phase voltage waveforms turn out to be somewhat different from the pole voltage waveforms and have been dealt with in the next section.

5. Implemented of three phase Inverter

The three phase inverter is responsible for converting the DC to the AC by activating the process power electronic switches as shown in fig.6. The output AC voltage of the inverter is square waveforms which require high speed of processor to produce the suitable sequence switch. The six set of IGBTs (each set including three IGBT(IRGBC40S)) is used that can tolerate 1800V with rated collector current is 60A at 150°C (20 each IGBT). Moreover, using v/f method of pulse width modulation, PWM, to control the speed of motor. The technique used to produce the PWM is the Space Vector Pulse Width Modulation (SVPWM) as informed in previous chapter. The control of the speed during the speed changing of electric vehicle including fixing of motor torque, starting with small current, the acceleration and deceleration of the electric vehicle.

The control of inverter is the main part of electric vehicle and the communication and connection of the control of inverter will be described in this section. The control speed will be performed according to the following steps:

1) Arduino will check the voltage of batteries to decide the speed limit of the vehicle as shown in fig.5. Then the relay will be activated according to the required speed given in
2) Table 1.

Table 1: The various of the voltage and frequency according to the speed

Voltage	Maximum Speed Limit	Frequency
78-74	70 Km/h	183 HZ
73-72	60 Km/h	181 HZ
72-71	50 Km/h	180 HZ
71-69	40 Km/h	179 HZ
69-67	30 Km/h	176 HZ
67	20 Km/h	172 HZ

3) For each speed given in table 1 the range of the speed is controlled by the potentiometer. The potentiometer is connected with both the relays output and the timer 555 as illustrated in fig.6 to generate the required PWM.
4) The 54175DMQB is connected to the output timer 555 and the chip will generate 3 high and 3 low pulses from the PWM as shown in fig.5 IGBT driver (IR2132) will receive the 6 pulses from the 54175DMQB to manage the IGBT groups switches as shown in fig.6 and fig.4 we used 3 set of IGBTs in each group to minimize the stress during high power required (maximum current will be 12A per phase)and in same time to be sure if there is any faulty IGBT the inverter will be working through the remaining.

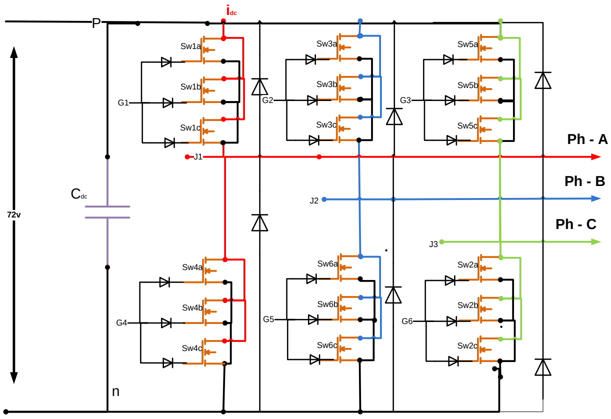

Figure 4: Circuit diagram of the three phase inverter

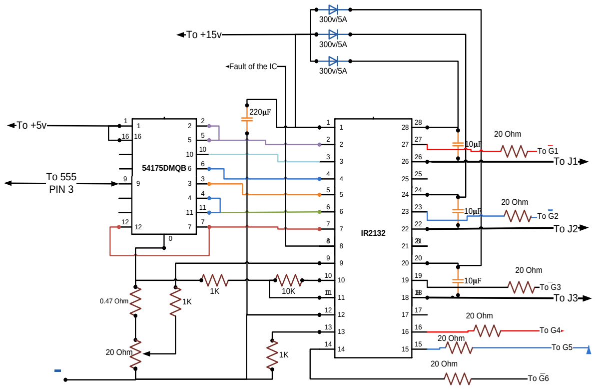

Figure 5: Circuit diagram of Control (IGBT Driver)

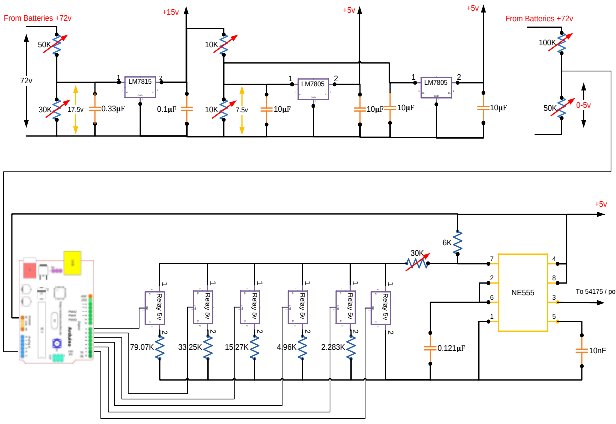

Figure 6: Power circuit (20v and 5v) for Arduino and IGBT driver

6. Prototype of the control with relevant Circuit without boost converter

As shown in Figure 8 and 9 we can see the prototype that implemented to do all the required test for the voltage, frequency and the performance of the control including the inverter and all the relevant circuit (power supplies, relays, Arduino) and it was successfully done to check all the component with the required test.

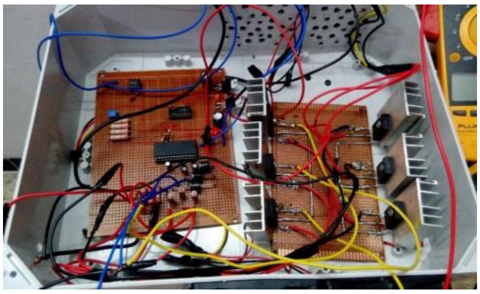

Figure 7: Prototype of the control and 3 phase inverter

Implementation of the control and three phase inverter according to the circuits in Figure 4, 5 and 6, the frequency and voltage variation without load were nearly to the theoretical calculations shown in Figure 8.

Figure 8: Pure waveform with frequency 31.2HZ and 40.36v

As shown in Figure 9 the waveform of the Y-N through star resistance and the waveform is appearing six-pules waveform as mentioned in the previous chapter.

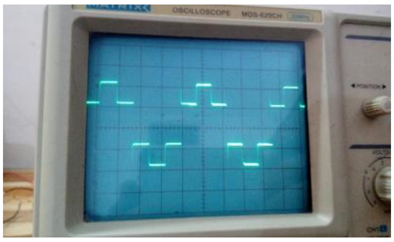

Figure 9: Output waveform Y-N

Figure 10 shows the range of the frequency according to the level of the voltage in the battery bank.

Figure10: Maximum frequency in 4 levels of the batteries to save the speed

Table 2 Test of the voltage regarding to different frequency for all the ranges of the frequency levels with high resistive load which are using for limit the speed as mentioned in previously

1st range of frequency		2nd range of frequency	
F	V (Y-G)	F	V (Y-G)
30.77	40.17	42.13	40.19
32.2	40.18	45	40.19
34.4	40.19	48.5	40.2
36.2	40.19	53.8	40.2
39.3	40.19	60.7	40.21
41.15	40.2	64.6	40.21
4.23	40.2	70.6	40.21
47.05	40.2	80.36	40.21
49.2	40.2	85.13	40.21
52.5	40.21	90.7	40.21
54.2	40.21	101.8	40.21
57.6	40.21	108.5	40.21
62.87	40.21	126.1	40.22

3rd range of frequency		4th range of frequency	
F	V (Y-G)	f	V (Y-G)
52.74	40.19	57.82	40.19
60.87	40.19	76.12	40.2
70.3	40.2	101.3	40.2
80.66	40.2	177	40.2
106.4	40.2	199.8	40.2
138.9	40.2	230.5	40.2
160.5	40.2	279.8	40.2
188.7	40.2	304.4	40.19
205.3	40.2	354.7	40.19
221.3	40.2	431.3	40.17
246.4	40.2	492.2	40.17
260.3	40.2	550	40.17
297.8	40.19	580.3	40.15

7. Performance investigation of speed vehicle with/without boost

The following are the two scenarios were investigated in order to assess the vehicle speed performance:

- Without-boost scenario
- With-boost scenario

The next two sections will provide the descriptions of the scenario with their results.

A. Without-boost scenario

Table shows the results of the vehicle with range of speed from 5km/h to 80km/h and the frequency, AC-V and AC-A was measured. It was found that the voltage of the batteries will be impacted by the maximum speed of the vehicle and this is expected. The high current produced by the invertor will generate high level of temperature. This will impact the invertor performance and it could be damaged for a long duration of driving the vehicle.

Table 3: Without boosting (72V DC input – VLL= 40V 3phase AC output)

Speed km/h	Frequency	AC	
		Phase A	
		AC- V	AC- A
5	24.54	5.8	7.98
10	35.2	9	12.9
15	42.6	14.2	17.8
20	66.9	17.3	20.7
25	71.4	17	20.6
30	90.1	23.2	24.8
35	104.5	26.4	30.4
40	123.5	33.5	40.2
45	137.6	35.5	37.9
50	157.1	36.2	45.3
55	161	37.3	47.3
60	169	38.1	49.4
65	172.5	39.2	50.1
70	179	39.6	51.2
75	180.1	39.8	51.9
80	182.3	40	52.3

B. With boost scenario

Table 4 shows the results of the vehicle with range of speed from 5km/h to 80km/h and the measured frequencies for the non-boost scenario were used. Then the AC-V and AC-A were measured. It was found that the AC-A was decreased by nearly 50% and the level of temperature is also decreased which results in inverter performance improvement. Due to the boost availability, input voltage of the inverter can be managed and the vehicle speed will not be impacted. Fig. 6 and fig. 7 illustrates the difference measurement of the non and boost scenarios.

Table 4 Results of the vehicle with range of speed from 5km/h to 80km/h and the measured frequencies for the non-boost scenario

Speed km/hr	AC with Boost_		
	Frequency	voltage	Current
5	53.988	12.76	3.63
10	77.44	19.8	5.86
15	93.72	31.24	8.1
20	147.18	38.06	9.41
25	157.08	37.4	9.36
30	198.22	51.04	11.27
35	229.9	58.08	13.82
40	271.7	73.7	18.27
45	302.72	78.1	17.23
50	345.62	79.64	20.59
55	354.2	82.06	21.5
60	371.8	83.82	22.45
65	379.5	86.24	22.77
70	393.8	87.12	23.27
75	398.2111	88	23.77
80	405.0706	88.88	24.27

Conclusions

As outlined in the paper that the following is the an important aspects in building the control of the electric vehicle and they will be discussed further in this part: during the test of the implemented circuit with high stress showing that:

- Efficacy of the circuit is approximately 98%.
- High protection of the circuit from the high stress due to using groups of the IGBTs for each switch part instead of using one IGBT or MOSFET.
- Ability to increase the supplying power more than 10kW by tuning the resistance.
- There are four range of speed to offer more driving time.
- Using boost converted will add high efficiency to the performance of the Electric Vehicle.
- Using boost converter will decrease the stress on the three phase inverter.
- v/f speed technique gives low current in startup. with high torque.
- Adding boost converter will add more stability to the system and can fix the input power to the inverter even if the batteries voltage are less than the required voltage of the operation 66%.

References

Bakshi, U.A. and V.U. Bakshi (2009), Electrical Engineering: Technical Publications.

Spivak, A., A. Kumar, and M. Franchetti (2013), Energy assessments for industrial complexes. Vol. 1: Bentham Science Publishers.

Simoes, M.G. and F.A. Farret (2011), Alternative energy systems: design and analysis with induction generators. Vol. 13: CRC press.

Lipo, T.A. (1996), Vector control and dynamics of AC drives. Vol. 41: Oxford university press.