1. Kamil PARFIANOWICZ

Rzeszow University of Technology, The Faculty of Electrical and Computer Engineering
ORCID: 1. 0000-0003-0778-308X

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Comparative analysis of multilevel voltage source inverters used to supply a five-phase Permanent Magnet Synchronous Motor

Abstract. *The paper presents the comparative analysis of the use a two-level, three-level and five-level voltage source inverter (VSI) for supplying a five-phase synchronous motor with permanent magnets (PMSM). The motor was controlled by Indirect Field Oriented Control (IFOC) with Space Vector Modulation (SVM). Simulation tests showing influence of the inverter topology on the drive system were performed in the Matlab/Simulink environment for various values of the switching frequency - from 1 to 30 kHz. The aim of the presented simulation research is analysis of the prototype five-phase PMSM machine and preliminary development of the power supply system based on multilevel inverters. As a result it will allow to correct determination of the rated parameters of the selected devices (mainly the measurement system and semiconductors). The created model can also be used as part of a larger simulation system, e.g. in an electric vehicle.*

Streszczenie*. W pracy przedstawiona została analiza porównawcza zastosowania dwupoziomowego, trójpoziomowego oraz pięciopoziomowego falownika napięcia (VSI) służącego do zasilania pięciofazowego silnika synchronicznego z magnesami trwałymi. Do sterowania układu napędowego zaimplementowano tzw. sterowanie polowo-zorientowane pośrednie (IFOC) z użyciem modulatora wektora przestrzennego SVM (Space Vector Modulation). Przeprowadzone badania symulacyjne w środowisku Matlab/Simulink zostały wykonane dla różnych wartości częstotliwości kluczowania – od 1 do 30 kHz. Celem prezentowanych badań symulacyjnych jest analiza prototypowej pięciofazowej maszyny PMSM oraz wstępne opracowanie układu zasilania opartego na falownikach wielopoziomowych. W rezultacie pozwoli to na poprawne określenie parametrów znamionowych wybranych urządzeń (głównie układu pomiarowego i półprzewodników). Stworzony model może być również wykorzystany w ramach większego systemu symulacyjnego, np. w pojeździe elektrycznym. (****Analiza porównawcza wielopoziomowych falowników napięcia stosowanych do zasilania pięciofazowego silnika synchronicznego z magnesami trwałymi PMSM****).*

Keywords: inverter, multilevel, multiphase, PMSM, Matlab
Słowa kluczowe: falownik, wielopoziomowy, wielofazowy, PMSM, Matlab

Introduction

Multiphase drive systems despite still high purchase prices are gaining more and more popularity. Compared to traditional three-phase motors, they have a lot of advantages - are characterized by smaller pulsations of the electromagnetic torque, lower current-carrying capacity of the power supply systems or greater reliability (ability to work when one or more phases will be damaged). These types of motors are used in electric drives of ships, traction vehicles, hybrid and electric cars and aviation (MEA - More Electric Aircraft). More benefits and concepts of the applications of five-phase synchronous motors with permanent magnets have been described in many scientific publications [1-4]. However, systems with more than 3 phases require a special power supply - used here are multiphase inverters with advanced control systems. It enables safe and stable operation. Currently, the most widely used is a two-level voltage inverter controlled by the Pulse Width Modulation (PWM) method. Despite simple and cheap construction it has limitations, especially when is used in high-voltage systems.

Multilevel inverters (MLI) nowadays are replacing traditional two-level inverters especially in medium and high power systems. The main principle operation of MLI allows to obtain a polar voltage with selected number of levels at the output. As the number of levels is considered the number of voltage steps that are generated by a single phase branch. According to the topology in which they are made there is several main types of multilevel inverters. These include Half-Bridge Cascade converters, Neutral Point Clamped (NPC) converters, Flying Capacitor (FC) converters and other models presented in [5-8]. The topologies of the tested inverters are shown in Figure 1.

Compared to a two-level inverter and with the same supply voltage MLI have improved power quality and higher efficiency, reduced common mode voltages, near sinusoidal waveforms and better electromagnetic compatibility. It can also reduce the derivative of the output voltage, which allows to obtain currents with more favourable parameters (it reduces the Total Harmonic Distortion THD). Despite the use of a greater number of semiconductor switches, multilevel inverters are characterized by lower power losses during the switching process [9,10].

Actual research are mainly based on the use of multiphase systems powered by classical two-level inverters. There is only a few publications describing the combination of that technologies - multiphase machines with multilevel inverters. In addition, an important issue here is the switching frequency of transistors, which affects to the obtained parameters.

Multilevel inverter technology

A single branch of the three-level converter consists of four switches (IGBT or MOSFET transistors), four reverse diodes and two levelling diodes. Power is supplied from two voltage sources with a value of 0.5 Vdc. A diagram of this solution is shown in Figure 1b. The control signal is supplied to the transistors working as a two-state switches (which determine their switching on/off). At the output of the inverter we receive pulses that are generated alternately from the positive and negative pole of the voltage DC source. The pulses are arranged to make the obtained voltage wave as close as possible to the sinusoidal one. For a three-level inverter the appropriate switching sequence of the transistors operation is presented in Table 1.

The five-level inverter consists of eight transistors for one branch, voltage source and voltage divider executed of four capacitors. The potentials of the individual divider outputs are in relation to the power source and determine the given level of the output voltage. The schematic diagram of the NPC topology is shown in Figure 1c, while the FC version is shown in Figure 1d. The switching sequences in the five-level inverter is presented in Table 2.

Table 1. Switching pattern of three-level inverter

Voltage levels	Switching sequence			
	S_{11}	S_{12}	S_{13}	S_{14}
$V_{dc}/2$	1	1	0	0
0	0	1	1	0
$-V_{dc}/2$	0	0	1	1

Table 2. Switching pattern of five-level inverter

Voltage levels	Switching sequence							
	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}	S_{18}
$V_{dc}/2$	1	1	1	1	0	0	0	0
$V_{dc}/4$	0	1	1	1	1	0	0	0
0	0	0	1	1	1	1	0	0
$-V_{dc}/4$	0	0	0	1	1	1	1	0
$-V_{dc}/2$	0	0	0	0	1	1	1	1

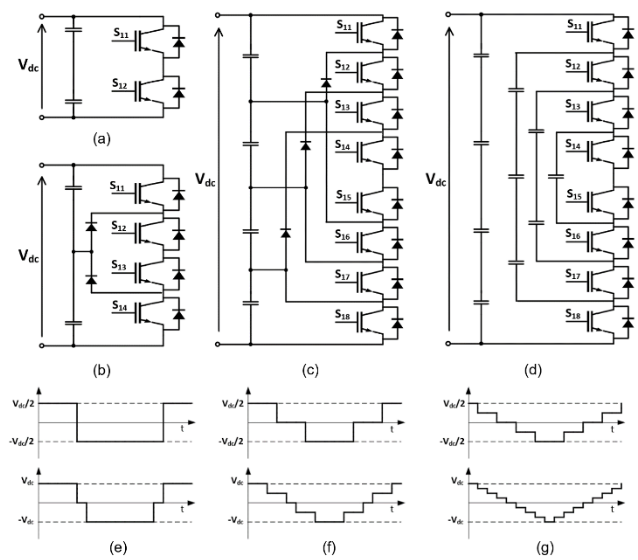

Fig. 1. One leg (phase) diagram of inverter a) two-level, b) three-level, c) five-level NPC, d) five-level FC, e) phase voltage (upper) and line-to-line voltage (lower) of two-level inverter, f) phase voltage (upper) and line-to-line voltage (lower) of three-level inverter, g) phase voltage (upper) and line-to-line voltage (lower) of five-level inverter

Five Phase PMSM Model

The practical implementation of the system will be performed by the authors on the FPGA platform using libraries of the Matlab/Simulink environment and the HDL Coder extension. It will help to generate the VHDL code containing control of multilevels inverters. To perform simulation and experimental research a prototype of five-phase PMSM motor will be created based on the existing three-phase machine. The dimensions of the stator and rotor are shown in Table 3. Basis of these parameters and assumptions in the Motor-CAD software was created a field model of a five-phase SPMSM machine in order to obtain resistance-inductive parameters used in subsequent studies in Simulink (Table 4).

Table 3. Motor dimensions to make the prototype of 5ph PMSM

Slot number	40	Magnet thickness [mm]	5
Stator diameter [mm]	221	Magnet segments	1
Stator bore [mm]	140	Airgap [mm]	1
Slot width [mm]	8	Shaft diameter [mm]	50

The use of multiphase windings in Permanent Magnet Motors (PMSM) makes it possible to increase the attractiveness of drive systems. Motors of this types are characterized by high values of electromagnetic torque in relation to their dimensions and weight, high efficiency and very good dynamics. This transfers into quick and precise adaptation to the given parameters. The stator of PMSM is similar to the stator of an induction motor. On the rotor in a special way are glued permanent magnets and due to the location of the them we can distinguish two types of machines - Interior Permanent Magnet Synchronous Motor (IPMSM) and Surface Mount Permanent Magnet Synchronous Motor (SMPMSM) [3, 11-13].

The mathematical model of a five-phase PMSM motor is based on differential equations in a dq rotating reference frame. Assume that:

- the saturation effect is ignored,
- all windings are shifted in phase 72 °,
- BEMF is sinusoidal,
- eddy currents and hysteresis losses are negligible,
- the magnetic circuit is symmetrical,
- togging torque is omitted

it can be written by the following equations [14-16]:

$$v_{d1} = R_s i_{d1} + L_d \frac{di_{d1}}{dt} - p\omega L_q i_{q1} \quad (1)$$

$$v_{q1} = R_s i_{q1} + L_q \frac{di_{q1}}{dt} - p\omega L_d i_{d1} + p\omega\psi_{PM} \quad (2)$$

$$v_{d2} = R_s i_{d2} + L_d \frac{di_{d2}}{dt} \quad (3)$$

$$v_{q2} = R_s i_{q2} + L_q \frac{di_{q2}}{dt} \quad (4)$$

where: v_{d1}, v_{q1}, v_{d2}, v_{q2} - components of the stator supply voltages; i_{d1}, i_{q1}, i_{d2}, i_{q2} - components of the stator currents; R_s - resistance of the stator windings; L_d, L_q - stator d-axis and q-axis inductance; ω - rotor mechanical rotational speed; p - number of pole pairs; ψ_{PM} - flux induced by the permanent magnets.

Equations 1-4 can also be written in the form of a state equations of stator current. After appropriate transformations, we receive:

$$\frac{di_{d1}}{dt} = \frac{v_{d1}}{L_d} - \frac{R_s i_{d1}}{L_d} + \frac{p\omega L_q i_{q1}}{L_d} \quad (5)$$

$$\frac{di_{q1}}{dt} = \frac{v_{q1}}{L_q} - \frac{R_s i_{q1}}{L_q} - \frac{p\omega L_d i_{d1}}{L_q} - \frac{p\omega\psi_{PM}}{L_q} \quad (6)$$

$$\frac{di_{d2}}{dt} = \frac{v_{d2}}{L_d} - \frac{R_s i_{d2}}{L_d} \quad (7)$$

$$\frac{di_{q2}}{dt} = \frac{v_{q2}}{L_q} - \frac{R_s i_{q2}}{L_q} \quad (8)$$

Mechanical equations of the motor:

$$J * \frac{d\omega}{dt} + D * \omega + T_L = T_e \quad (9)$$

$$\frac{d\varphi}{dt} = \omega \quad (10)$$

The electromagnetic torque expression is given by:

$$T_e = \frac{5}{2} * p * \left(\psi_{PM} i_{q1} - \left(L_{d1} - L_{q1}\right) * i_{d1} i_{q1}\right) \quad (11)$$

where: T_e - electromagnetic torque; T_L – torque load; J - inertia of rotor and load; D - viscous friction.

In order to generate an appropriate signal in the drive system to feed the inverter connectors, the selected type of PWM should be implemented. There are mainly two methods: SPWM (Sinusoidal Pulse Width Modulation) and SVM (Space Vector Modulation). Due to better properties more popular in multiphase systems is SVM (especially the possibility of obtaining a higher value of the inverter supply voltage).

Table 4. Five-phase PMSM parameters

Number of pole pairs	2	Inertia of rotor	4*10-3 kg*m^2
Stator windings resistance [R_s]	3 Ω	Flux by PM	0.2 Wb
D-axis inductances [L_d]	0.009 H	DC-link Voltage	250 V
Q-axis inductances [L_q]	0.009 H	Torque load	15 Nm

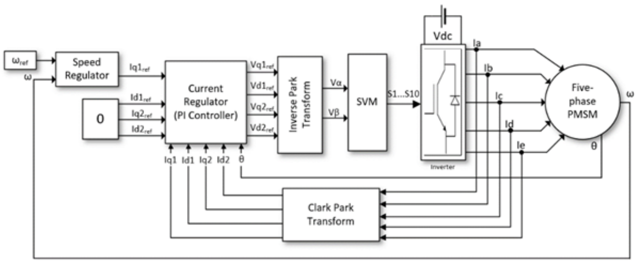

Fig. 2. Block diagram of vector control for a five-phase PMSM

In the SVM method the order and time of transistors switching in the inverter is determined by an algorithm based on the set reference values of the stator currents or torque. This algorithm takes the reference voltage generated by the
inverse Park transform and produces a modulating signal based on the appropriate sequence of vector switching at given time intervals. For a five-phase two-level inverter it is a combination of 25 (32) voltage vectors - 30 which are called active vectors and 2 passive (zero) vectors. Such an arrangement is made up of a set of three concentric decagons, each with 10 sectors. The angle of the voltage vector is controlled by switching between two adjacent fundamental vectors, whereas the magnitude of the voltage vector is controlled by switching between the fundamentals and zero vectors. There are two methods of principle operations. The first method uses only the large and zero control vectors to control electronic switches. The second method uses an appropriate combination of large medium and zero vectors. This method was implemented in the tested model. The modulating signal produced by this method is compared using a comparator with a sawtooth or triangle-shaped reference (carrier) signal. As a result of this comparison, five control signals are obtained in the form of a series square pulses with a fill proportional to the value of the modulating signal. Furthermore is produced five signals negated to them. These pulses are sent to particular connectors in the inverter [17-19].

The output voltages for multilevel inverters can be shaped in the same way as for two-level inverters - using the same pulse width modulation methods. For a three-level inverter two carrier waves are used to create 20 control signals. The possible number of space vector positions is 35 (243). The five-level inverter obtains 40 control signals by comparing the modulating signal with the four periodic signals, and the space vector may have 55 (3125) positions. A detailed description of the SVM method in relation to multiphase multilevel systems can be found in [20-21].

Results

In order to verify the presented assumptions the model of the drive system from Figure 2 was implemented in the Matlab/Simulink environment. The analysis included a five-phase PMSM motor controlled by the Space Vector Modulation with three variants of inverters - 2, 3 and 5-level. The parameters of the tested system can be found in table 4.

Figure 3 shows the line-to-line voltage, where for a two-level inverter three voltage levels can be clearly seen : + Vdc, 0, -Vdc. The three-level inverter has five levels of line voltage, the five-level inverter has nine. Figure 4 shows the phase voltages where, respectively, for each of the tested inverters there are two, three or five voltage levels. It can be seen that both the five-level NPC inverter and the FC inverter have the voltage that most closely resembles a sine wave.

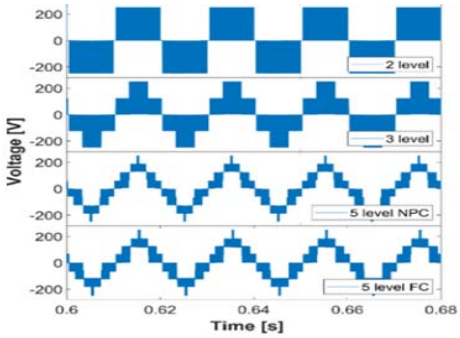

Fig. 3. Line-to-line voltage comparison for different types of multilevel inverters

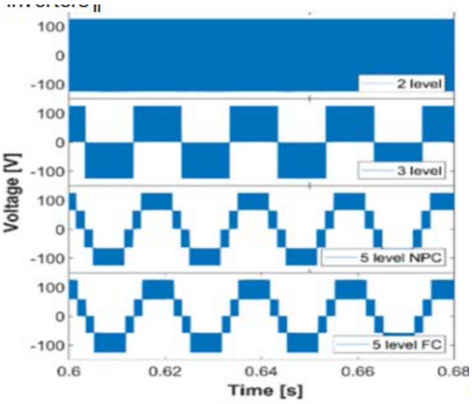

Fig. 4. Phase voltage comparison for different types of multilevel inverters

Table 5. Min and max torque with ripples for different switching frequencies

Switching frequency	Torque min/max [Nm]	Torque ripples [%]	Torque min/max [Nm]	Torque ripples [%]	Torque min/max [Nm]	Torque ripples [%]
	5 kHz		10 kHz		5 kHz	
2 – level	14.75/15.29	3.6	14.87/15.1	1.53	14.87/15.09	1.46
3 – level	14.81/15.19	2.34	14.91/15.08	1.13	14.97/15.08	0.8
5 – level NPC	14.95/15.06	0.73	14.96/15.03	0.46	14.98/15.01	0.2
5 – level FC	14.94/15.07	0.89	14.97/15.08	0.73	14.95/15.04	0.58

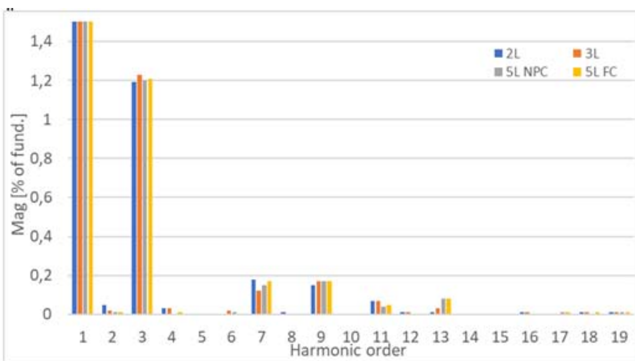

Fig. 5. FFT analysis of current harmonics

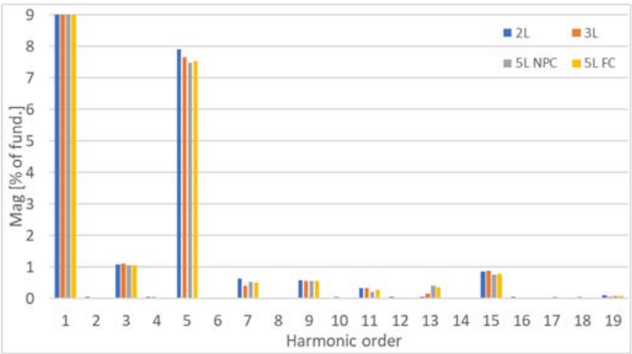

Fig. 6. FFT analysis of phase voltage harmonics

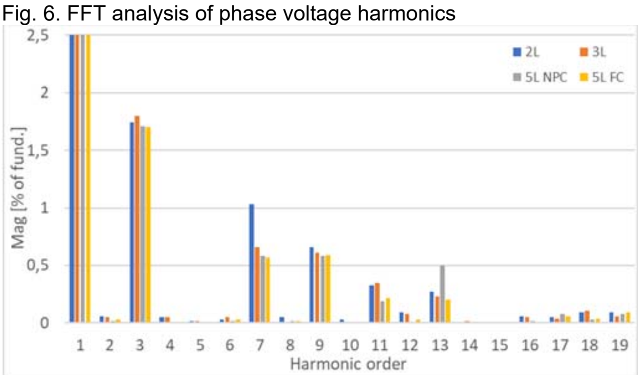

Fig. 7. FFT analysis of line-to-line voltage harmonics

Figure 8 shows a comparison of the rated electromagnetic torque for the tested five-phase machine in various configurations of the multi-level inverter and the switching frequency. A detailed comparison of the data for a better presentation of the efficiency improvement is shown in Table 5, where the measured minimum and maximum torque values were collected. Based on these measurements was calculated torque ripples. It can be noticed that with an increase of the number of transistors and with an increase of the switching frequency the torque ripple clearly decreases.

By analysing Figures 5 - 7 and Tables 6 and 7, it is also possible to find a positive impact of multilevel inverters on the operation of drive systems. The harmonics of current and voltage decrease, but at higher switching frequencies (above 20 kHz) it does not have much influence on the THD coefficient.

Table 6. Total Harmonic Distortion of the Current

Switching frequen-cy	Total Harmonic Distortion of Current [%]							
	1 kHz	2 kHz	5 kHz	10 kHz	15 kHz	20 kHz	25 kHz	30 kHz
2 – level	6.23	3.17	1.62	1.36	1.24	1.18	1.47	1.13
3 – level	3.18	1.86	1.33	1.30	1.23	1.16	1.49	1.25
5 – level NPC	2.59	1.70	1.43	1.23	1.19	1.15	1.48	1.21
5 – level FC	2.83	1.76	1.39	1.28	1.21	1.16	1.49	1.22

Table 7. Total Harmonic Distortion of Voltage

Switching frequency		Total Harmonic Distortion of Voltage [%]							
		1 kHz	2 kHz	5 kHz	10 kHz	15 kHz	20 kHz	25 kHz	30 kHz
Line to line	2 level	99.84	100.01	100.1	99.99	99.94	99.86	99.93	99.75
	3 level	43.41	43.43	43.36	43.37	43.38	43.39	43.31	43.33
	5 level NPC	28.47	26.66	26.38	26.33	26.21	26.25	26.28	26.26
	5 level FC	28.98	27.32	27.21	27.15	27.12	27.16	27.17	27.11
Phase voltage	2 level	85.38	85.32	85.30	85.35	85.25	85.24	85.24	85.39
	3 level	41.75	40.89	40.92	40.93	40.89	40.87	40.91	40.85
	5 level NPC	22.12	21.94	21.86	21.78	21.64	21.61	21.73	21.74
	5 level FC	24.01	23.86	23.52	23.41	23.39	23.36	23.42	23.27

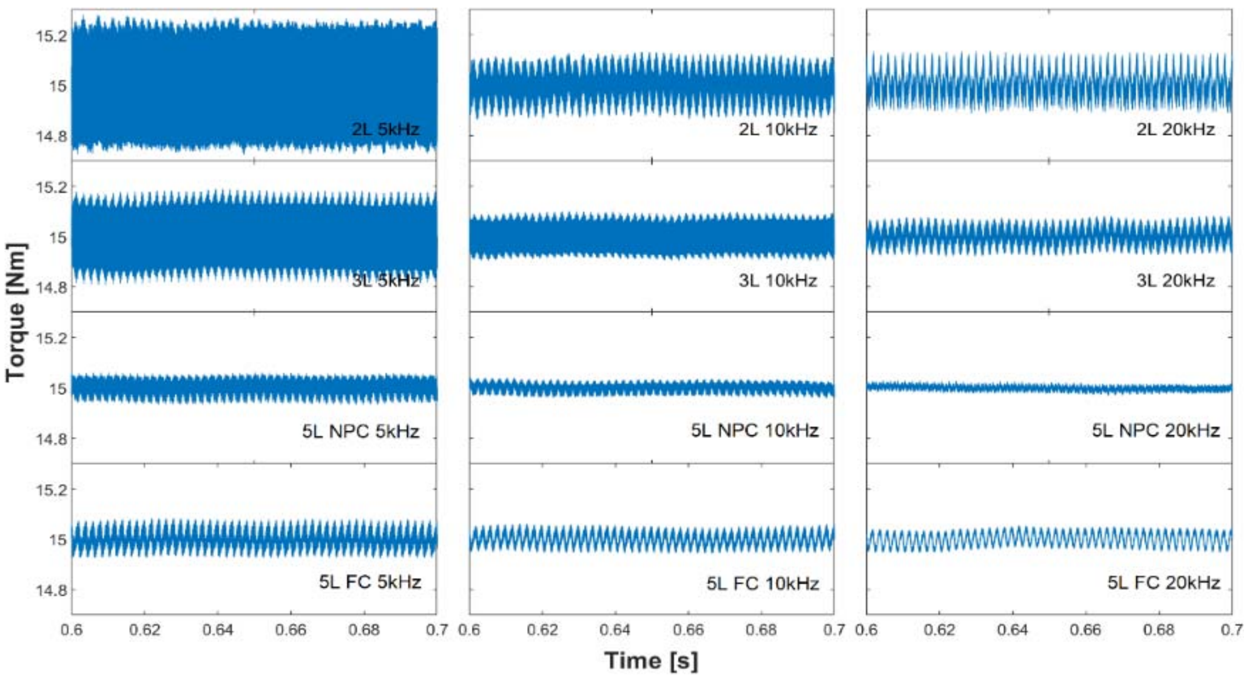

Fig. 8. Torque comparison for different types of multilevel inverters and switching frequencies

Conclusion

A different types of multilevel inverters based on Field Oriented Control fed multi-phase Permanent Magnet Synchronous Motor drive using Space Vector Modulation is presented in this paper. Created model can be used for prototyping drive systems, especially in terms of power and control modules. By modifying the relevant parameters of the regulators, it is possible to check the behaviour of the motor under steady state and different load operating conditions. Theoretical concepts related to five-phase multilevel inverters describing higher efficiency and better power quality have been confirmed by simulation tests. As the number of inverter levels increase it reduces the switching power loss, electromagnetic torque ripple, current ripple and the total harmonic distortion. Use of a multilevel inverter allows to generate voltages similar to sinusoidal waveform simultaneously keeping low common-mode voltage and decreased voltage change (dV/dt). Increasing the switching frequency allows to reduce the ripples of torque and current THD, but it can be noted that frequencies higher than 20 kHz introduce only a slight improvement in the parameters of the system.

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***Autorzy**: mgr inż. Kamil Parfianowicz, Katedra Energoelektroniki i Elektroenergetyki, E-mail: kparfianowicz@prz.edu.pl; Politechnika Rzeszowska, Wydział Elektrotechniki i Informatyki, ul. Wincentego Pola 2, 35-959 Rzeszów*

REFERENCES

[1] Wilczyński F., Strankowski P., Guziński J., Morawiec M., Lewicki A., Kostro G., Five-Phase Induction Motor Drive Operation During Stator Phase Fault, *Automatyka - Elektryka – Zakłócenia*, vol. 8 (2017) no. 4(30), 28-37

[2] Hezzi A., Elghali S., Salem Y., Abdelkrim M. N., Control of five-phase PMSM for electric vehicle application, *Proceedings of 18th International Conference on Sciences and Techniques of Automatic Control and Computer Engineering (STA), Monastir, Tunisia,* 21-23 Dec (2017), 205-211, DOI: 10.1109/STA.2017.8314959

[3] Hosseyni A., Trabelsi R., Mimouni M., Iqbal A., Vector Controlled Five-Phase Permanent Magnet Synchronous Motor Drive, *Proceedings of 2014 IEEE 23rd International Symposium on Industrial Electronics (ISIE), Istanbul, Turkey*, 1-4 June (2014), 2122-2127, DOI: 10.1109/ISIE. 2014.6864945.

[4] Umoh G., Ogbuka C., Obe E., Modelling and analysis of five-phase permanent magnet synchronous motor in machine variables, *Przegląd Elektrotechniczny*, 96 (2020), no. 1, 123-126, 10.15199/48.2020.01.21

[5] Michalak J., Zygmanowski M., Hybrid Asymmetric Multilevel Converter – Selected Aspects, *Prace Naukowe Politechniki Śląskiej "Elektryka",* vol. 4 (2014), no. 232, 31-40

[6] Gandomi A. A., Saeidabadi S., Parsa L., A Fault Tolerant T-type Inverter for Five-phase PMSM Drives, *Proceedings of IECON 2019 - 45th Annual Conference of the IEEE Industrial Electronics Society, Lisbon, Portugal*, 14-17 Oct. (2019), 834-839, DOI: 10.1109/IECON.2019.8927164.

[7] Poorfakhraei A., Narimani M., Emadi A., A Review of Multilevel Inverter Topologies in Electric Vehicles: Current Status and Future Trends, *IEEE Open Journal of Power Electronics*, vol. 2 (2021), 155-170, DOI: 10.1109/OJPEL.2021.3063550.

[8] Bughneda A., Salem M., Richelli A., Ishak D., Alatai S., Review of Multilevel Inverters for PV Energy System Applications, *Energies*, vol. 14 (2021), no. 6, DOI: https://doi.org/10.3390/en14061585.

[9] Muc A., Iwaszkiewicz J., Mysiak P., Piechowski L., The power supply system for multi-level inverters using multi-pulse rectifiers with coupled reactors, *Przegląd Elektrotechniczny*, 97 (2021), no. 2, 72-76, DOI: 10.15199/48.2021.02.18

[10] Sekhar O. C., Lakhimsetty S., Direct torque control scheme for a five-level multipoint clamped inverter fed induction motor drive using fractional-order PI controller, *International Transactions on Electrical Energy Systems*, vol. 30 (2020), no. 9, DOI: https://doi.org/10.1002/2050-7038.12474

[11] Listwan J., Pieńkowski K., Field-oriented control of multiphase induction motor with space vector modulation methods, *Prace Naukowe Instytutu Maszyn, Napędów i Pomiarów Elektrycznych Politechniki Wrocławskiej*, vol. 70 (2014), no. 34, 167-182

[12] Gołębiowski L., Gołębiowski M., Mazur D., Smoleń A., Analysis of axial flux permanent magnet generator, *COMPEL - The international journal for computation and mathematics in electrical and electronic engineering*, vol. 38 (2019), no. 4, pp. 1177-1189, https://doi.org/10.1108/COMPEL-10-2018-0415

[13] Smoleń A, Gołębiowski L, Gołębiowski M, Mazur D., Computationally Efficient Method of Co-Energy Calculation for Transverse Flux Machine Based on Poisson Equation in 2D, *Energies*, vol. 12(22):4340 (2019), https://doi.org/10.3390/en12224340

[14] Gołębiowski M., Smoleń A., Gołębiowski L., Mazur D., Functional simulation model of the axial flux permanent magnet generator, *Archives of Electrical Engineering*, vol. 67 (2018), no. 4, 857–868, DOI: 10.24425/aee.2018.124745

[15] Kamel T., Abdelkader D., Said B., Vector control of five-phase permanent magnet synchronous motor drive, *Proceedings of 2015 4th International Conference on Electrical Engineering (ICEE), Boumerdes, Algeria*, 13-15 Dec., (2015) DOI: 10.1109/INTEE.2015.7416853.

[16] Ramana N., Sastry V. L. N., A Novel Speed Control Strategy for Five Phases Permanent Magnet Synchronous Motor with Linear Quadratic Regulator, *International Journal of Computer and Electrical Engineering*, vol. 7, no. 6, pp. 408-416 (2015).

[17] Gołębiowski M., Gołębiowski L., Mazur D., Humer M., The gearless, grid-connected, 6-phase asymmetric wind turbine generator system, *Archives of Electrical Engineering*, vol. 64 (2015), no. 3, 391-403, DOI: 10.2478/aee-2015-0031

[18] Suresh Kumar A., Sri Gowri K., Nagaraja Rao S., Manjunatha B.M., Sesi Kiran P., Niteesh Kumar K., Integer factor based SVPWM approach for multilevel inverters with continuous and discontinuous switching sequences, *Archives of Electrical Engineering*, vol. 70 (2021), no. 4, pp. 859 – 872, DOI: 10.24425/aee.2021.138266

[19] Panda A. K., Pandey R., A simplified carrier based PWM method for five-level inverter fed five-phase induction motor, *Proceedings of 2018 IEEMA Engineer Infinite Conference (eTechNxT), New Delhi, India*, 13-14 March (2018), 1-6, DOI: 10.1109/ETECHNXT.2018.8385307

[20] Lavanya M, Jyothi B., Performance Analysis of 5-Phase Multi-level Inverter Using Carrier Based PWM Technique, *International Journal of Applied Power Engineering (IJAPE)*, vol. 5 (2016), no. 3, 151-158, DOI: http://doi.org/10.11591/ijape.v5.i3.pp151-158

[21] Rangari S.C., Suryawanshi H.M., Shah B., Implementation of Large and Medium Vectors for SVPWM technique in five phase Voltage Source Inverter, *Proceedings of 2017 International Conference on Intelligent Computing and Control Systems*, 15-16 June (2017), Madurai, India, 751-756, DOI: 10.1109/ICCONS.2017.8250