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Optimal Phase Number of Induction Motor with the Integrated Frequency Converter

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Introduction

Lasting practice has proved an optimality of three-phase transmission lines of the electric power. Electric power industry used three-phase system. However, recently more often induction motors are connected to independent frequency converters. Sometimes such converters have a big number of phases and affirm that power parameters are then above [1]. The five-phase control diagramme by the induction motor and the features of its work are investigated [2]. The authors of this work have not specified, why the five-phase alternative is chosen, and why it is more preferable than others. Therefore, also efforts are made to define optimum number of phases of the induction motor which is working from the independent frequency converter. Transistors in the frequency converter work in a key regime therefore jumps occur with the change of voltage of an exit of the converter. The converter creates non sinusoidal voltage system.

Such voltage system by means of Fourier series can be presented as the sum system of the sinusoidal voltages, the frequency of which is aliquot to a switching frequency of keys of the frequency converter. If voltages of an exit of the converter are odd functions, we have Fourier series in the form of the sum of the odd harmonics starting phases of which are equal to zero

$$u(t) = \sum_{k=2n-1} U_{km} \sin(k\omega t), \qquad (1)$$

where U_{km} – the maximum value of the k-th voltage harmonic; n=1,2,3….

If the m-phase voltage system is symmetric, the voltage for r-th phase, using transformation of the beginning of time co-ordinate on a certain period can be written as:

$$u_r(t) = \sum_{k=2n-1} U_{km} \sin\left(k\omega t - kr\frac{2\pi}{m}\right), \qquad (2)$$

where r – the number of a phase which is chosen by the first ($r < m$); m – the phase number.

For all the higher harmonics in phases, except the first, there is the various initial phase lag depending on a serial number of a harmonic.

In frequency converters sinus pulse width modulation is more often applied. It allows reducing some level of higher harmonics in an output voltage, but it remains high enough. For example, if the period breaks into 24 parts, the width of a pulse, which varies under the sine law, the ratio of the general effective value of voltage of all higher harmonics to a effective value of voltage of a fundamental frequency, in percentage, is more than 50 %.

It is considered, that the large number of phases promotes level decrease of higher harmonics but any arguments about it are not presented. It is to be supposed that it goes without saying. After all in case of a two-phase winding there are all odd harmonics: the magnetic field of the third harmonic is rotated in a direction opposite to a direction of rotation of the first, the direction of rotation of magnetic field of the fifth harmonic coincides with rotation direction of the first, the seventh harmonic is rotated opposite to the direction of rotation of the first, and so on. In case of a three-phase winding there is no third harmonic and all harmonics, serial number is aliquot to three. The harmonic factor of a three-phase winding is less than of two-phase winding at the same conditions. It is natural to ask a question: whether the results would be better when the phase number will be increased? In some works where the influence of phase number on motor parameters is considered, it is suggested to decrease the undesirable higher harmonics by filters [3].

The goal of this work is to answer the following question: what number of phases is optimum when the induction motor is connected to non sinusoidal voltage system and there are no preliminary restrictions on the number of phases.

A technique and criteria of the analysis

The qualitative differences between the magnetic fields, created by windings are investigated, the number of phases in which varies from two to eight. The sampling of such range is caused by following reasons. Two phases is the minimum possible number. For big numbers of phases in the converter the big number of expensive powerful switching transistors is necessary [4,5]. Therefore, if the number of phases is above eight its use becomes economically unprofitable. The amplitude of the magnetic field created by each phase winding, is accepted equal to one. The total magnetic field, created by all phase windings for each harmonic, has been calculated using the special programme. Under this programme magnetic field components for each phase on *x* and *y*-axes for the various moments of a time have been calculated. Corresponding components of harmonics algebraically are summed up for the equal moments of the time the number of which is equal to 48 for the period. Calculating results are presented by tables and figures of a trajectories of a vector. The calculating is carried out to 49 harmonics inclusive. The analysis of magnetic field components for two-phase and three-phase systems is widely considered in the literature. A comprehensive analysis of already known and newly created tree-phase windings, which permits to evaluate and compare them from electromagnetic point of view is presented in [6].

Results of the analysis

Two-phase winding. There are circular magnetic fields of higher harmonics with serially varying direction of rotation. The amplitude of magnetic field of each of harmonics is directly proportional to a maximal voltage of a corresponding harmonic and inversely proportional to its serial number.

Three-phase winding. There are no harmonics which serial number is equal or aliquot to three. Magnetic fields of the other harmonics are circular with serially varying direction of rotation. The amplitude of magnetic field of each of harmonics is directly proportional to a maximal voltage of a corresponding harmonic and inversely proportional to its serial number.

Four-phase winding. There are circular magnetic fields of higher harmonics with serially varying direction of rotation. The amplitude of magnetic field of each of harmonics is directly proportional to a maximal voltage of a corresponding harmonic and inversely proportional to its serial number. Actually, four-phase winding represents two two-phase windings connected in the corresponding way the magnetic fields of which are summed up. Taking into account that the number of switching transistors in the four-phase inverter are twice as much than in two-phase, it is possible to define inexpediency of application of four-phase converters.

Five-phase winding. Magnetic fields of higher harmonics qualitatively differ from magnetic fields of higher harmonics of the windings before-mentioned. They are not circular. It means that for the higher harmonics a winding is partially bifilar. It is so, because for higher harmonics, except those the serial number of which is equal or aliquot for five, the sequence of voltages makes the symmetric five-pointed star of voltages, but with the changed phase sequence. An initial phase angle for a harmonic on a serial number of a harmonic is larger than an initial phase angle for a first harmonic. Apparently in fig. 2, the phase sequence varies. And it is equivalent to winding diagramme change when the order of phase zone arrangement varies. It is different for each following harmonic and all possible combinations of a mutual bracing of phases are gradually settled.

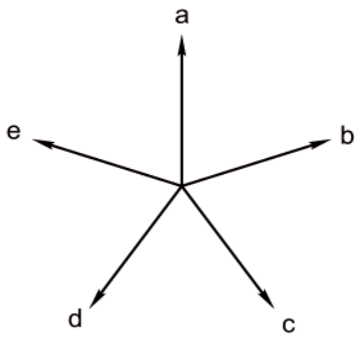

Fig. 1. Five-phase voltage system for the first harmonic

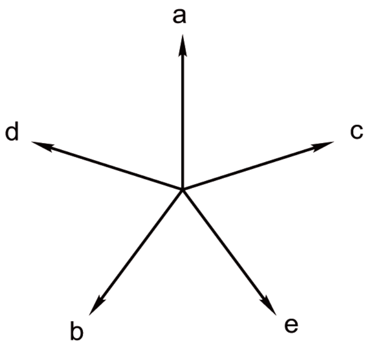

Fig. 2. Five-phase voltage system for the third harmonic

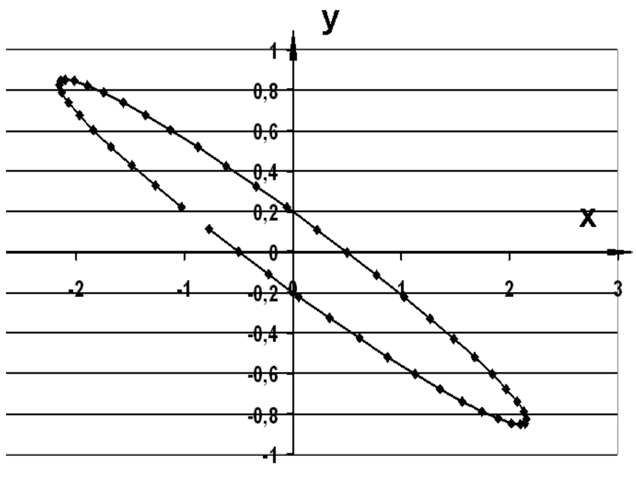

Fig. 3. A trajectory of the magnetic field vector for the five-phase winding of the third harmonic

Six-phase winding. Actually the six-phase winding represents two three-phase windings connected in the corresponding way the magnetic fields of which are summed up. There are no harmonics the serial number to which is equal or aliquot to three. The magnetic fields of other harmonics are circular with serially varying direction of rotation.

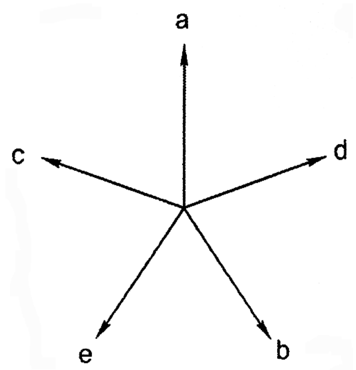

Fig. 4. Five-phase voltage system for the seventh harmonic

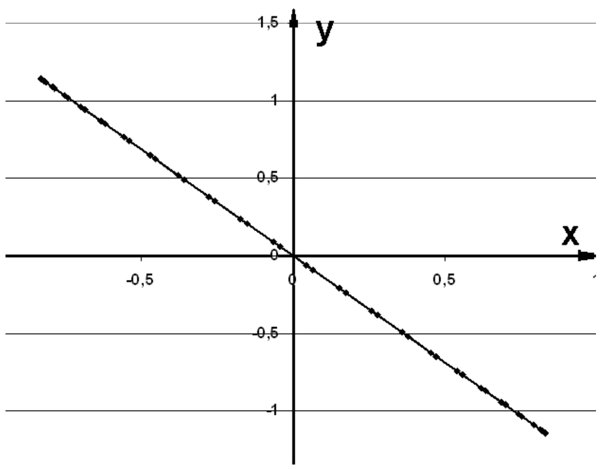

Fig. 5. A trajectory of the magnetic field vector for the five-phase winding of the seventh harmonic

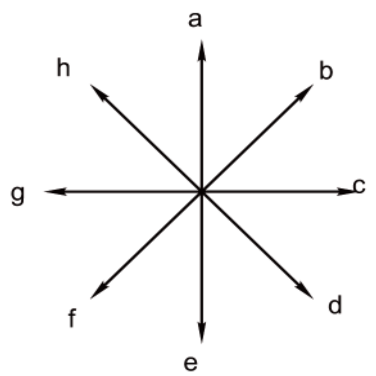

Fig. 6. Eight-phase voltage system for the first harmonic

The amplitude of magnetic field of each of harmonics is directly proportional to a maximal voltage of a corresponding harmonic and inversely proportional to its serial number. Taking into account that the number of switching transistors in the six-phase inverter twice as much than in three-phase, it is possible to define inexpediency of application of six-phase converters.

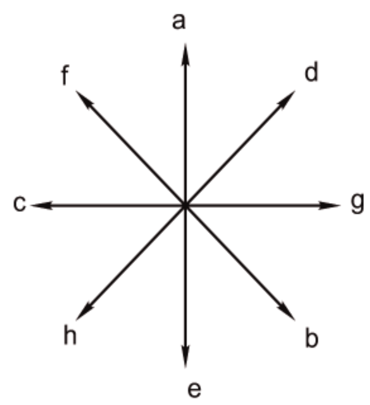

Fig. 7. Eight-phase voltage system for the third harmonic

Seven-phase winding. There are no basic differences, in comparison to a five-phase winding. The magnetic fields of higher harmonics are also not circular. For higher harmonics, except those the serial number of which is equal or aliquot to seven, the sequence voltages make the symmetric seven-pointed star of voltages, but with varying of the order of phase-sequence.

Eight-phase winding. Some harmonics of voltage do not create corresponding magnetic fields, for example, the third and the fifth harmonics, but not because corresponding currents do not proceed. They will be rather considerable, as the main inductive reactance for these harmonics is equal to zero. A winding as though is a bifilar for these harmonics.

Windings of separate phases create magnetic fields of the mentioned harmonics but they compensate each other.

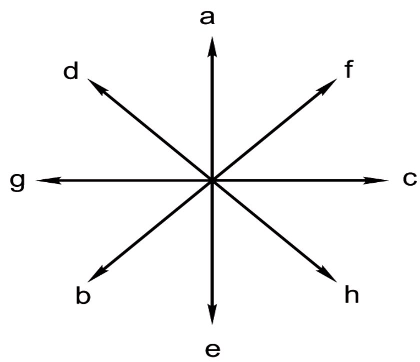

Fig. 8. Eight-phase voltage system for the fifth harmonic

Conclusions

1. The level and features of developing process of the higher time harmonics in the magnetic field of induction motors with four-phase and six-phase windings are precisely the same as in the magnetic field with two-phase and three-phase windings. Considering the difference in the use of wanted number of powerful key transistors, such number of phases is not expedient.
2. The features of developing process of the higher time harmonics in the magnetic field of induction motors with five-, seven-, and eight-phase windings allow to

make the conclusion, that one part of a winding fully or partly make the time harmonics of the magnetic field, created by the other parts of a winding, weaker. It would be the advantage of a winding to space harmonics. But for time harmonics it is a deficiency.

3. The voltage converter is a potential source of different frequencies, including of these which does not create a magnetic flux in a motor air gap. The magnetic fluxes of the corresponding harmonics are direcly proportional to its voltages and inversely proportional to the frequencies. Therefore if the separate winding parts demagnetize each other the corresponding magnetizing currents and losses increase.
4. The optimum number of phases recommended in the induction motor with the integrated frequency converter is three.

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The analysis of the magnetic field created by a winding connected to the system of non sinusoidal voltages is presented. Windings with number of phases from two to eight are taken into consideration. It is shown, that four-phase and six-phase windings in comparison to the higher harmonics in magnetic field of the induction motor are identical accordingly to two-and three-phase windings. For five-phase and seven-phase windings in some directions the amplitude of the higher harmonic components of magnetic field reduced for the reason that the directions of the magnetic fields created by separate phase windings, are opposite. The corresponding magnetic fields created by them are elliptical or pulsating. Therefore each of them consists of positive and negative sequence components. An exception is only those harmonics, the number of which is aliquot to five for five-phase and to seven for a seven-phase winding. They do not create magnetic fields for the same reason to which magnetic fields do not create the third and aliquot harmonics in a three-phase winding. Therefore, optimum number of phases is three. Ill. 8, bibl. 6 (in English; summaries in English, Russian and Lithuanian).

С. Й. Бугянис, Й. Ванагас, С. Гячис. Оптимальное число фаз в асинхронном двигателе с интегрированным преобразователем частоты // Электроника и электротехника. – Каунас: Технология, 2008. – № 8(88). – С. 67–70.

Представлен анализ магнитного поля, создаваемого обмоткой, подключенной к системе несинусоидальных напряжений. Рассматриваются обмотки с числом фаз от двух до восьми. Показано, что четырехфазная и шестифазная обмотки по составу высших гармоник в магнитном поле двигателя идентичны соответственно двух- и трехфазной обмоткам. Для пятифазной и семифазной обмоток в некоторых направлениях амплитуды высших гармонических составляющих магнитного поля уменьшены из-за того, что направления магнитных полей, создаваемых отдельными фазовыми обмотками, противоположны по направлению. Ими созданные соответствующие магнитные поля эллиптические или пульсирующие. Поэтому каждая из них состоит из двух – прямой и обратной последовательности. Исключением являются только те гармоники, номер которых кратный пяти для пятифазной и семи для семифазной обмотки. Они не создают магнитных полей по той же причине, по которой магнитных полей не создают третья и кратные трем гармоники в трехфазной обмотке. Поэтому оптимальное число фаз – три. Ил. 8, библ.6 (на английском языке; рефераты на английском, русском и литовском яз.).

S. J. Bugenis, J. Vanagas, S. Gečys. Optimalus asinchroninio variklio su integruotu dažnio keitikliu fazių skaičius // Kaunas: Technologija, 2008. – Nr. 8(88). – P. 67–70.

Pateikta apvijų, prijungtų prie nesinusinės įtampų sistemos, kuriamo magnetinio lauko analizė. Nagrinėjamos apvijos, kurių fazių skaičius yra nuo dviejų iki aštuonių. Parodyta, kad keturfazė ir šešiafazė apvijos pagal variklio magnetinio lauko aukštesniųjų harmonikų sudėtį yra identiškos atitinkamai dvifazei ir trifazei apvijoms. Penkiafazės ir septynfazės apvijų tam tikra kryptimi magnetinio lauko aukštesniųjų harmonikų amplitudės sumažėja dėl to, kad magnetinio lauko, sukurto atskirų fazinių apvijų, kryptys yra priešingos. Jų sukurti atitinkami magnetiniai laukai yra elipsiniai arba pulsuojamieji, todėl jie susideda iš dviejų dedamųjų – tiesioginės ir atvirkštinės sekų. Išimtis yra tiktai aukštesniosioms harmonikoms, kurių eilės numeriai yra penkiu kartotiniai, esant penkiafazei apvijai, ir septynių kartotiniai, esant septynfazei apvijai. Jos nesukuria atitinkamų magnetinių laukų dėl tos pačios priežasties, dėl kurios nesukuria trečiosios ir jų kartotinės trifazėje apvijoje. Dėl viso to optimalus fazių skaičius yra trys. Il. 8, bibl. 6 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).