Energy Efficiency Invariance Laws Acting in the Field of Multiphase Inverter-Fed AC Linear Motors

A.V. Brazhnikov, I.R. Belozyorov & S.A. Molokitin
Siberian Federal University, P.O. Box 16142, Krasnoyarsk, 660001, Russia
multypha@mail.ru

ABSTRACT: The study of AC inverter liner and non-linear drives in the case when the number of their phases is more then four allows finding out some basic laws of these systems which does not manifest themselves when the phase number is equal to three or four. Two previously unknown laws of energy efficiency invariance are established in the field of multiphase (i.e. having the number of phases more than four) AC inverter drives. The ignoring these laws lead necessarily to the decrease of the multiphase drive system energy efficiency.

1 INTRODUCTION

The study of AC inverter liner and non-linear drives (ACID) in the case when the number m of ACID phases is more than four allows finding out some basic laws of these systems which do not manifest themselves when m is equal to three or four. A knowledge of these peculiar laws is of not only scientific (i.e. cognitive), but also great practical importance because these laws ignoring leads necessarily to the decrease of the ACID energy efficiency when $m \geq 5$.

By present time two previously unknown laws of space-temporal spectral relations have been established by the authors of this paper as a result of the corresponding investigations. These laws are true for the case when the motor winding set is symmetric and electromagnetic processes in ACID are steady-state. They are essentially the laws of energy efficiency invariance for the field of multiphase (i.e. having the number of phases more than four) AC inverter drives.

2 LAW OF M-INVARIANCE

The first of these two laws links the ACID efficiency η, phase number $m \geq 5$ and relative spectra $U^*(c)$ and $B^*(n)$, where $U^*(c)$ is the relative spectrum of the output (phase) voltage u(t) of inverter that is also the AC liner (or non-linear) motor stator phase voltage, c is the number of the voltage u(t) harmonic (i.e. the number of a time harmonic), $B^*(n)$ is the relative spectrum of the function b(y) which describes the space distribution of the magnetic induction created by each phase winding of the AC liner (or non-linear) motor stator in the machine air gap within the limits of the motor pole pitch, n is the number of the function b(y) harmonic (i.e. the number of a space harmonic), t is a time, and y is the space coordinate, which is plotting on the space coordinate curved axis Oy, that runs along entire length of the AC liner or non-linear motor air gap ($y \in [0; 2\pi]$).

The above-mentioned relative spectra differ from the corresponding absolute (real) spectra in that the amplitude $A^*(x)$ of some relative spectrum harmonic is equal to $A^*(x) = A(x) / A(1)$, where A(x) is the amplitude of the corresponding (i.e. of the same name) harmonic of the appropriate absolute (real) spectrum and x is the number of a harmonic ($x \equiv c$ for $U^*(c)$ and $x \equiv n$ for $B^*(n)$).

The values $U^*(c)$ and $B^*(n)$ for all c and n are dimensionless. Therefore both their envelope lines may be constructed on the common two-dimensional subspace (plane) kOd (Fig. 1), where the axis Ok is horizontal, the axis Od is vertical, $k \equiv c$ for $U^*(c)$, and $k \equiv n$ for $B^*(n)$. The values $U^*(c)$ and $B^*(n)$ are plotting on the axis Od.

The above-mentioned law is given the title “law of ACID efficiency η invariance to the ACID phase number m" (or more simply, "law of m-invariance"). It is stated as follows: if b(y) = const when m = var, then the envelope line of spectrum $U^*(k)$ must lie not above the envelope line of spectrum $B^*(k)$ on the plane kOd to ensure the invariability of the ACID efficiency η when the ACID phase number m is changing (see Figure 1, where I is the area, where the law of m-invariance is fulfilled, and II is the area, where the law of m-invariance is not fulfilled). Besides, the frequency composition of the function b(y) must be identical (at least) to the frequency composition of the voltage u(t) or be wider than it.

The identity $U^*(k) \equiv B^*(k)$ is a particular (the limiting) case of the law of m-invariance.

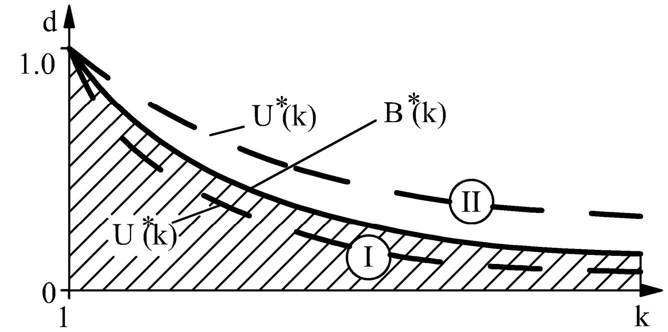

Figure 1. Illustration of the law of m-invariance.

This law is in some contrast with widely known notion of ACID which was obtained as a result of researches only in the field of 3- and 4-phase AC liner and non-linear drives. In particular, according to this notion the sinusoidal version of the function b(y) is always considered the optimal version.

3 LAW OF *H*-INVARIANCE

The second law concerns the phase-pole controlled multiphase ACID, i.e. when the phase-pole control method (PPM) is used in ACID (Brazhnikov 1993, Brazhnikov & Dovzhenko 1994, Brazhnikov et al. 1995, Brazhnikov et al. 1996, Brazhnikov & Dovzhenko 1997, Brazhnikov & Dovzhenko 1998, Brazhnikov & Belozyorov 2011a, b). This law links the ACID efficiency η, relative spectrum $U^*(c)$, relative spectrum $B^*(n)$ and integer-valued parameter H of PPM, where $H \geq 1$ (the value H = 1 corresponds to a traditional control mode, and the value H > 1 corresponds to PPM).

The essence of the control according to PPM is that in this case the electrical angles between the voltages (or currents) of the nearest phases of inverter increase by a factor of some whole number H without any change of the inverter voltage (or current) amplitude and frequency. During PPM application process, when the parameter H changes, the effect adequate to the synchronous change of the ACID phase number and number of motor poles appears.

The above-mentioned second law is given the title "law of ACID efficiency η invariance to the parameter H PPM" (or more simply, "law of H-invariance"). It is stated as follows: the identity $B^*(n) \equiv B^*(H \cdot n)$ must be provided to ensure the invariability of the ACID efficiency η when the parameter H is changing during PPM application process. Besides, for the mentioned purpose the law of m-invariance must also be fulfilled as to spectra $U^*(c)$ and $B^*(n)$ for all values of parameter H (see Figure 2, where the line 1 is the n-dependence of $B^*(n)$ for H = 1, the line 2 is the n-dependence of $B^*(H \cdot n)$ for H = 2, and the line 3 is the c-dependence of $U^*(c)$).

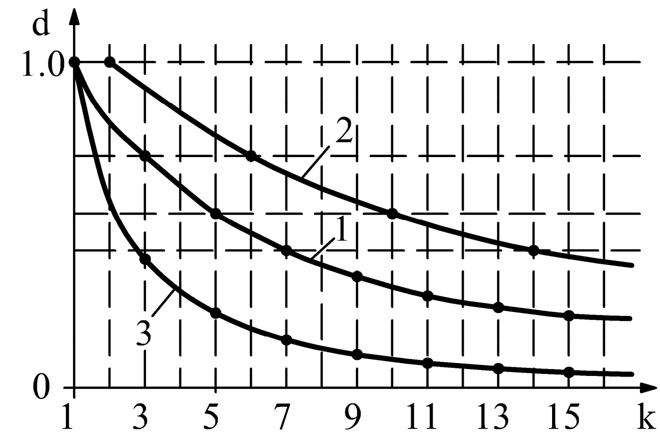

Figure 2. Illustration of the law of H-invariance.

It is necessary to use some peculiar designs of multiphase AC liner and non-linear motors to ensure fulfillment of the H-invariance law (Brazhnikov & Dovzhenko 1998, Brazhnikov & Belozyorov 2010, Brazhnikov et al. 2011).

According to one of such design versions the stator consists of the individual rods located in stator slots and insulated from stator magnetic circuit. The rods can be made from copper, aluminum, etc. Every rod is connected to an individual phase of a frequency converter by one of its ends (Fig. 3). Other rods ends are connected in star having or not having a neutral conductor. The rods of the stator winding are connected to the frequency converter via a m-phase transformer stepping down voltage. In this case m is the number of the rods (i.e. the number of real phases of the drive system). Such winding design is simpler than the traditional ones, but in this case it is necessary to use transformer stepping down voltage, which has large mass-and-overall dimensions. This design version may be used for both linear and non-linear AC motors.

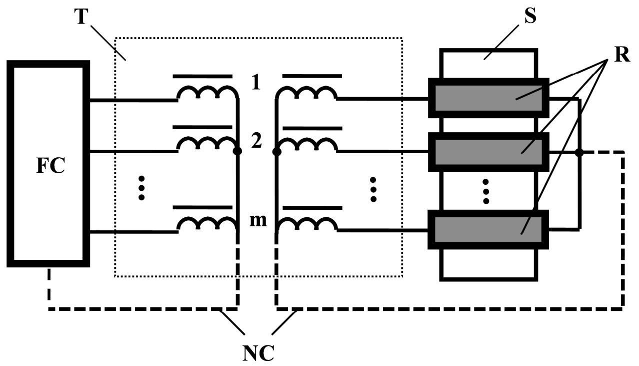

Figure 3. Connection of m-rod stator winding to a m-phase frequency converter, where FC is the frequency converter, T is m-phase transformer stepping down voltage, S is stator of an induction motor, R are the rods of stator winding, and NC are neutral conductors.

Another design version of the stator of a 6-phase flat type AC linear motor is presented in Figure 4. In this case the diamagnetic shield DS divides the magnetic field created by the stator winding into two subfields separated in space. The change of magnetic field pole number on intervals between borders of everyone above mentioned subfield is observed during PPM application process.

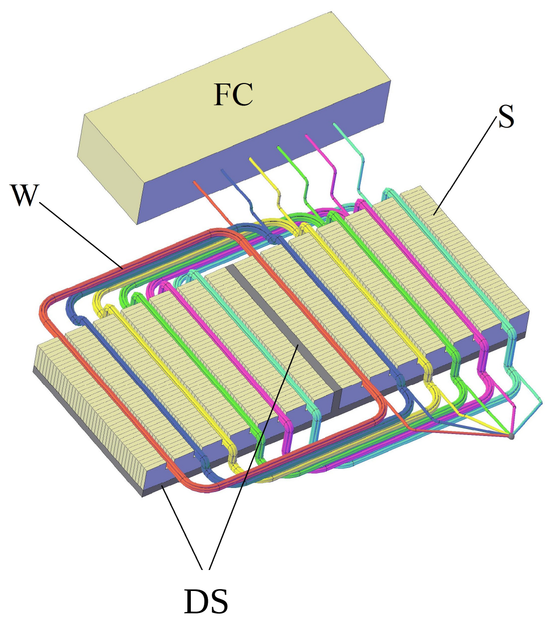

Figure 4. Design version of the stator of a 6-phase flat type AC linear motor and winding connections, where FC is a 6-phase frequency converter, S is the motor stator, W is phase multiple-turn winding of the motor stator, and DS is diamagnetic shield.

4 IGNORING LAWS OF ENERGY EFFICIENCY INVARIANCE

If the above-mentioned laws of ACID efficiency invariance are not fulfilled, then the ACID efficiency η decreases and when the ACID phase number m increases more than four and when the going from some traditional control mode to PPM is being attained. For example, m-dependence of the ACID efficiency η is presented in Figure 5 for the case when the function b(y) is sinusoidal and t-dependence of the voltage u(t) has form of right-angled meander (in this case the law of m-invariance is not fulfilled).

Figure 5. m-dependence of the ACID efficiency η for the case when the function b(y) is sinusoidal and t-dependence of the voltage u(t) has form of right-angled meander.

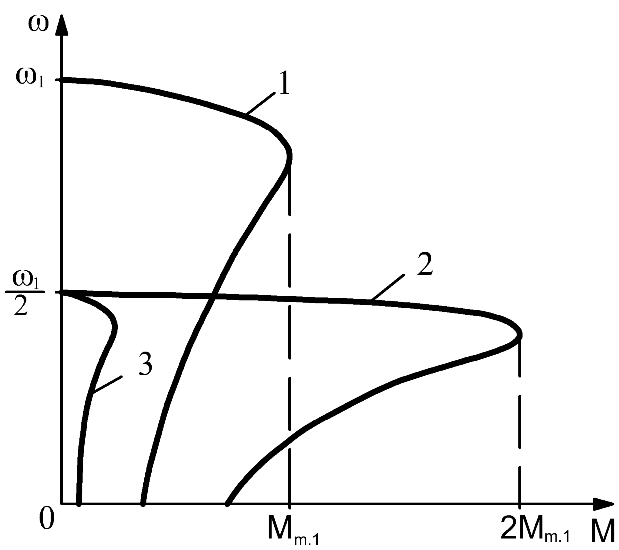

Figure 6. Mechanical characteristics of some multiphase phase-pole controlled induction motor with $m \geq 6$ for the cases when H = 1 (line 1) and H = 2 (lines 2 and 3).

In support of the H-invariance law the mechanical characteristics (i.e. ω – M characteristics) of some multiphase phase-pole controlled induction motor with m ≥ 6 are presented in Figure 6 for the cases when H = 1 (see line 1) and H = 2 (see lines 2 and 3), where the line 2 is the mechanical characteristic if the law of H-invariance is fulfilled, line 3 the mechanical characteristic if the law of H-invariance is not fulfilled, ω is the speed of rotation, and M is the linear force created by the motor (or torque, when the motor stator is bow-shaped).

5 CONCLUSION

The above-mentioned laws of ACID efficiency invariance are particular cases of the fundamental law (or principle), which prevails in the field of multiphase AC liner and non-linear drives and may be stated as follows: for the ensuring of maximal energy efficiency of multiphase ACID the laws of space-temporal spectral relations, which acts in the field of these systems, must be necessarily fulfilling during the process of both ACID structural elements design and motor control mode elaboration.

6 REFERENCES

Brazhnikov, A.V. 1993. Additional resources of control of multiphase inverter drives. *Electrical machines and drives*; *Proc. 7th intern. conf. ELMA‘93, Varna, Bulgaria, October 7-9, 1993*: 325-332.

Brazhnikov, A.V. & Dovzhenko, N.N. 1994. Beyond routine control of multiphase inverter drives. *Power electronics, motion control and associated applications*; *Proc. intern. conf. PEMC‘94, Warsaw, Poland, September 20-22, 1994*: 99-104.

Brazhnikov, A.V., Dovzhenko, N.N. & Izmaylov, E.B. 1995. Prospects for the use of multiphase electric drives in field of mining machines. *Mine mechanization and automation*; *Proc. 3rd intern. symp. MMA‘95, Golden, CO, USA, June 12-14, 1995*: 13-13 – 13-23.

Brazhnikov, A.V., Dovzhenko, N.N., Gilyov, A.V. & Butkin, V.D. 1996. Improvement of technical-and-economic characteristics of drilling rigs owing to the use of multiphase electric drives. *Proc. ISDT 16th annual technical conf., Las Vegas, NV, USA, May 1-3, 1996*: 8 p.

Brazhnikov, A.V. & Dovzhenko, N.N. 1997. Advantages of multiphase electric drives – application in drilling rigs. *Mine mechanization and automation*; *Proc. 4th intern. symp. MMA’97, Brisbane, Queensland, Australia, July 6-9, 1997*: B4-37 – B4-42.

Brazhnikov, A.V. & Dovzhenko, N.N. 1998. Control potentials and advantages of multiphase ac drives. *Proc. 29th annual IEEE power electronics specialists conference PESC‘98, Fukuoka, Japan, May 17-22, 1998*: 2108-2114.

Brazhnikov, A.V. & Belozyorov, I.R. 2010. Inverter multiphase induction motor drive with phase-pole control. *Russian patent № 100863 dated 27.12.2010* (in Russian).

Brazhnikov, A.V. & Belozyorov, I.R. 2011a. Prospects for the use of multiphase phase-pole-controlled AC inverter drives in traction systems. *European Journal of Natural History* (2): 63-66.

Brazhnikov, A.V. & Belozyorov, I.R. 2011b. Over-phase control of inverter multiphase AC linear drives. *Llinear drives for industry application*; *Proc. 8th intern. symp. LDIA‘2011, Eindhoven, the Netherlands, July 3-6, 2011* (in press).

Brazhnikov, A.V., Belozyorov, I.R. & Molokitin, S.A. 2011. Solid ferromagnetic rotor for phase-pole-controlled induction motor. *Resolution of FS “Rospatent” (Moscow, Russia) dated 02.06.2011 about granting a patent according to the patent pending № 2011114280* (in Russian).