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Experimental investigation on modified vector control algorithm for induction motor asymmetry compensation

***Abstract**. This paper deals with experimental verification of vector-control algorithm for induction motor operation under asymmetry. Proposed algorithm allows one compensate negative influence of motor asymmetry on electric drive energy consumption parameters. Thus, it helps to ensure more effective energy consumption mode of induction motor under asymmetry. In this paper, it is described theoretical principles of asymmetry compensation algorithm, developed software and discussion of derived experimental results.*

***Streszczenie.** Artykuł dotyczy eksperymentalnej weryfikacji algorytmu sterowania wektorowego w asymetrycznej pracy silnika indukcyjnego. Proponowany algorytm pozwala skompensować negatywny wpływ asymetrii parametry zużycia energii napędu elektrycznego. Jest tom pomocne w zapewnieniu efektywniejszego zużycia energii przy pracy asymetrycznej. W artykule opisano podstawy teoretyczne algorytmu kompensowania asymetrii. Opracowano algorytm, przedyskutowano wyniki badań eksperymentalnych. (**Badania doświadczalne nad zmodyfikowanym algorytmem sterowania wektorowego w kompensacji asymetrii silnika indukcyjnego**)*

Keywords: induction motor, vector control, asymmetry compensation.
Słowa kluczowe: silnik indukcyjny, sterowanie wektorowe, kompensacja asymetrii

Introduction

Induction motors often operates under presence of different kinds of faults or damages. Significant amount of them operates under certain degree of different kinds of asymmetry, particularly, stator windings asymmetry, caused by motor production process or its failure during operation. These asymmetries lead to deterioration of entire production process as well as to increased losses, which leads to increased power consumption [1]. To avoid unnecessary losses, it was proposed to compensate asymmetry influence using modified vector control algorithm in power inverter software. These methods were theoretically well-grounded and verified using mathematical simulation software, and results were presented in [2–4]. However, the main objective is practical implementation of developed solutions in order to obtain very economically effective results. In order to implement developed methods and control algorithms practically, it was considered to create experimental set-up basing on Microchip dsPICDEM MCHV-3 Development Board. This board allows one modify power inverter control algorithm in order to implement induction motor asymmetry compensation methods both for scalar and vector control algorithms.

Theoretical theses

In order to develop physical sample of induction motor control system for implementation asymmetry compensation algorithm, first of all we should determine signals which we should use for calculations. In [4–6] it was grounded, that electrical signals, such as currents, voltages and power consumption signals, are the most proper choice for analysis for creating induction motor diagnostic and condition-based control systems. Thus, developed experimental setup is based on the analysis of these signals during motor operation.

In [3, 4] it was grounded the use of vector control system to implement for induction motor asymmetry compensation. Typical induction motor vector control algorithm use currents and voltages signals and it is based on Park and Clark's transformation, which represents connection between *dq* and *αβ* coordinate systems [3]:

$$\begin{bmatrix} I_{sd} \\ I_{sq} \end{bmatrix} = \frac{1}{\sqrt{U_{s\alpha}^2 + U_{s\beta}^2}} \begin{bmatrix} U_{s\alpha} & U_{s\beta} \\ -U_{s\beta} & U_{s\alpha} \end{bmatrix} \begin{bmatrix} I_{s\alpha} \\ I_{s\beta} \end{bmatrix}, \tag{1}$$

where $U_{s\alpha}$, $U_{s\beta}$, $I_{s\alpha}$, $I_{s\beta}$ are projection of voltage and current vectors in a fixed coordinate system; I_{sd}, I_{sq} are projection of current vector in an orthogonal rotating coordinate system.

The obtained I_{sd}, and I_{sq} values can be written down as a sum of a fixed and variable component [3]:

$$I_{sd} = I_{sd0} + I_{d\,\mathrm{var}}; \qquad I_{sq} = I_{sq0} + I_{q\,\mathrm{var}}.$$

In this case, we can introduce and calculate compensation currents as follows:

$$\begin{bmatrix} I_{c\alpha} \\ I_{c\beta} \end{bmatrix} = \frac{1}{\sqrt{U_{s\alpha}^2 + U_{s\beta}^2}} \begin{bmatrix} U_{s\alpha} & -U_{s\beta} \\ U_{s\beta} & U_{s\alpha} \end{bmatrix} \begin{bmatrix} -I_{d\,\mathrm{var}} \\ -I_{q\,\mathrm{var}} \end{bmatrix}. \tag{2}$$

Finally, after transforming the obtained signal into rotating coordinate system by direct Clark transformation we can add the output signal to the referential currents for each current coordinate:

$$I'_{sd} = I_{sd\,(\mathrm{ref})} + I_{cdr}; \qquad I'_{sq} = I_{sq\,(\mathrm{ref})} + I_{cq}.$$

Thus, while developing experimental setup, we have to take into consideration necessity of having online access to currents and voltages, as well as possibility to modify output currents and voltages, which take part in formation, supply for asymmetrical induction motor.

Experimental results

In order to create experimental setup, we used Microchip dsPICDEM MCHV-3 Development Board (High Voltage). This development board aimed to control variable-speed alternate and direct current motors, and grants access to its basic control algorithms. Thus, this solution provides possibility to implement developed algorithm to control induction motor, which operates under asymmetry.

To implement our solutions, we used basic alternate current induction motor (ACIM) control algorithm for sensorless vector control mode, which is provided by dsPICDEM MCHV-3 software developers. This algorithm operates with measured three phase currents, voltages, and their transformations into two-phase coordinate systems (*dq* and *αβ*) using Clark and Park transforms. Thus, we have access to all necessary process variables described in (1, 2), and we are able to compute compensation currents for chosen damage type. In fig. 1 it is shown modified control algorithm for ACIM, where in red colour it is shown "Compensator" block (block 9), where compensating currents are being computed. After computing, compensating current are being added to output *q* and *d* axis current projections, and takes part in formation supply voltages taking into account asymmetry compensation.

In fig. 1 it was adopted following legend. Hardware blocks: 1 – alternate current induction motor; 2 – three-phase bridge – rectifier, inverter and acquisition and protection circuitry. Software blocks: 3 – Clarke forward transform block; 4 – Park forward transform block; 5 – angle and speed estimator block; 6 – PI controller block; 7 – field weakening block; 8 – SVM block; 9 – compensation currents computation block.

In order to verify implemented control algorithm with asymmetry compensation, it was conducted series of experiments, using tested AC induction motors type AIR80V4U2, 1.5 kW. To simulate stator windings asymmetry caused by stator windings short-turns, it was made taps in one of the stator windings, which aimed to simulate different degree of short-circuited turns.

Basing on developed hardware equipment and dsPICDEM MCHV-3 development board, we were able to provide series of experiment to verify effectiveness of proposed solutions. In this paper, we will discuss results obtained basing on the analysis of data derived from the following experiments:

- healthy motor, with and without introduction of compensation current.
- motor with 14,2 % of asymmetry in one of stator windings phase, with and without introduction of compensation current.
- loaded healthy motor, with and without introduction of compensation current.
- loaded motor with 14,2% of asymmetry in one of stator windings phase, with and without introduction of compensation current.

The last case of asymmetry is the expositoriest, as the biggest asymmetry degree clearly shows the effect of compensation algorithm. Thus, following in the paper, this case will be analysed more deeply.

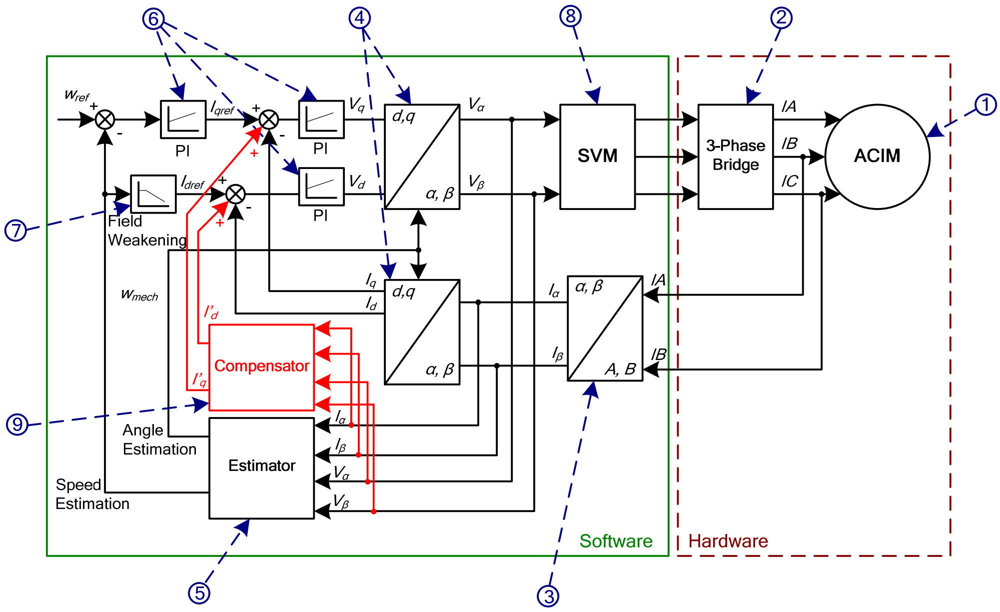

Fig. 1 Block diagram of modified alternate current induction motor vector control algorithm

While conducting experiments, additionally we collected currents and voltages, using previously developed measuring system [7, 8], and afterwards analysed data using mathematical software.

One of the most informative among the analysed parameters, which could help us make conclusion about effectiveness of compensation algorithm, is motor's power consumption signal. Thus, having instant values for currents and voltages for each experiment, we can calculate instant values for power consumption signal.

However, in order to evaluate energy saving effect, additionally we had to calculate electrical losses for all case studies as

$$L(t) = R \times i(t)^2, \quad (3)$$

where motor resistance R was equal to 5.0 Ohm.

Fig. 2 shows total three-phase motor power collected for loaded motor with 14.2% of asymmetry in one of the stator phases for the case of operation without (1) and with (2) introduction of compensation current. Basing on these timeseries, it is hard to make clear conclusions about effectiveness of implemented algorithm. Fig. 3 shows electrical losses of all motor phases for operation without (1) and with (2) introduction of compensation currents, for the same experimental case.

From fig. 3 it is quite clear visible, that the stator winding losses decrease significantly with the introduction of compensation current.

To confirm derived results numerically we also calculated losses mean value and losses variable component for each motor phase both for operation without and with introduction of compensation current in relation to rated losses for healthy motor:

$$L_{comp}\,(\%) = \frac{L - L_h}{L_h}, \quad (4)$$

where L_{comp} are the losses compare with healthy motor; L are losses in damaged motor; L_h are losses in healthy motor.

It is clearly visible from derived charts (fig. 4, 5) that the use of compensation currents allows one decrease losses in each stator phase. The most significant decrease we can observe in damaged phase. This experiment results confirmed results derived using mathematical simulation software and described in [3, 4].

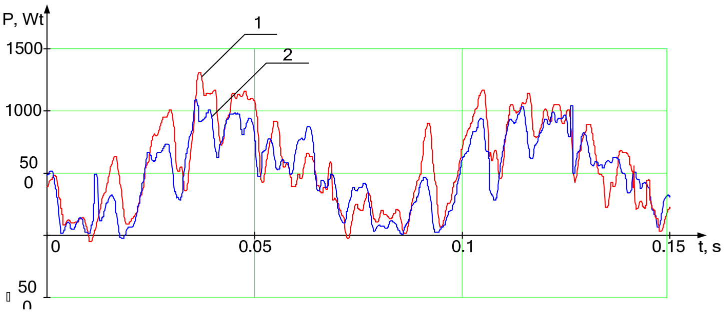

Fig. 2. Total three-phase power (1 – no compensation, 2 – with the compensation)

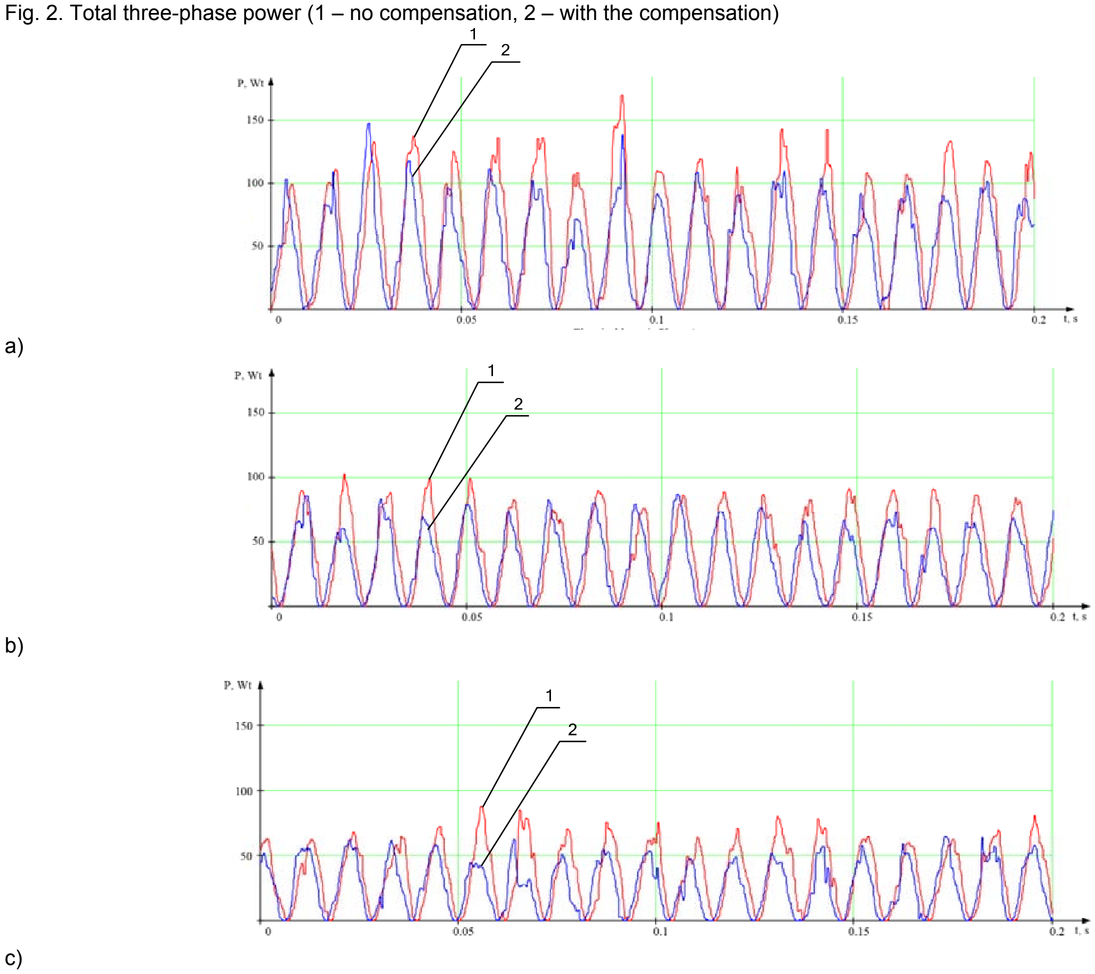

Fig. 3. Electrical loses in Phase C (1 – no compensation, 2 – with the compensation)

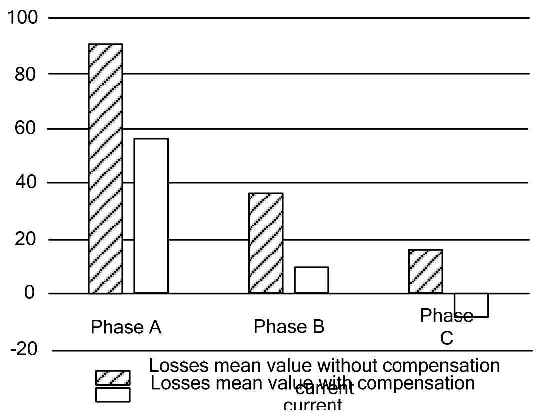

Fig.4. Mean value of losses, %

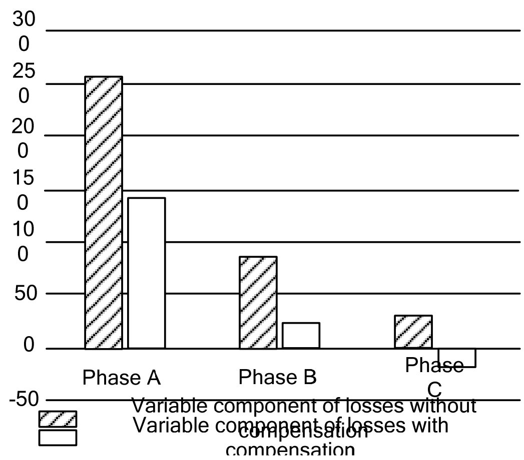

Fig.5. Variable component of losses, %

Thus, developed control algorithm allows one to decrease losses of the motor, which operates under asymmetry caused by short turns in one of the motor phases, which, in its turn, testifies about more effective power consumption. Therefore, we can conclude, that developed solutions helps to provide energy effective operation modes for motors under damages.

Conclusions

A motor controlled by our algorithm, using the "compensation for variable component of consumed active power" method, shown a net decrease of the losses compare to a motor without compensation, by 25–34% for the mean values losses and by 49–113% for the variable components of losses in different phases. Thus, this algorithm allows one to reduce power consumption of a damaged induction motor and, as sequence, could also extend its operating lifetime.

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