Mohamed Z. QAWAQZEH[1], Andrii KALINOV[2], Volodimir LOYOUS[2], Mykhaylo ZAGIRNYAK[2]

Al-Balqa' Applied University, Jordan (1), Kremenchuk Mykhailo Ostrohradskyi National University(2)

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Experimental research of the loading system for an induction motor with the use of a double-fed machine

Abstract. *The performed analysis of different systems for testing induction motors under load with the use of a frequency converter enables choosing the most rational variant taking into consideration the specific conditions of the production. The specific character of use of a double-fed machine in generator mode for testing induction motors with different number of ports in loading operating modes was investigated. Conducted experimental research confirms a possibility of creation of a loading mode for induction motors with different number of ports using double-fed machines with recuperation of both active and reactive power into supply mains.*

Streszczenie. *Przedstawiono analizę różnych systemów testowania silników indukcyjnych pod obciążeniem z wykorzystaniem przetwornika częstotliwości, który umożliwia wybranie najbardziej racjonalnego wariantu z punktu widzenia specyficznych warunków produkcyjnych. Przebadany został specyficzny charakter wykorzystania podwójnie zasilanej maszyny w modzie generatorowym do testowania silników indukcyjnych. Przeprowadzone badania eksperymentalne potwierdziły możliwość utworzenia modu obciążenia silnika indukcyjnego z różną liczbą wejść w sytuacji kiedy liczba wejść jest różna przy użyciu podwójnie zasilanych maszyn z odzyskiwaniem zarówno energii biernej jak i czynnej do zasilających jednostek.* ***(Badanie eksperymentalne system obciążenia silnika indukcyjnego z użyciem podwójnie zasilanej maszyny)***

Key words: induction motors, frequency converter, double-fed machines, load test
Słowa kluczowe: silniki indukcyjne, przetworniki częstotliwości, podwójnie zasilana maszyna, test obciążenia

Introduction

Besides modern diagnostic methods by parameters of electric instantaneous [1] and vibration [2] powers the one of the ways to test induction motors (IM) is to test them under loading conditions [3, 4]. In spite of indirect methods of determination the energy characteristics [5] and load-carrying capacity of the IM, testing under load is the closest to real operating modes of IM [4]. In some technological mechanisms, the replacement of induction motor is quite a hard task according to technical requirements. Thus, it is important to provide testing of correspondence of IM parameters and characteristics to rated values as well as provide IM reliability testing before its installation, which will ensure a certain period of failure-free operation.

The use of frequency converter (FC) for tasks of IM testing significantly extends possibilities for creation of different types of testing excitations as well as testing modes. The development of specific and unique equipment is not always reasonable for small enterprises. Along with this, the use of industrial FC in modern testing systems significantly simplifies the process of implementation and decreases time needed for implementation of modern testing equipment. Examples of systems for testing IM under loading conditions are shown in (fig. 1-4).

The use of a direct current generator (DCG) as a loading machine allows recuperating energy into a direct current link of FC that feeds the tested IM (fig. 1). When the proposed system is used (fig. 1), only energy of losses in IM, DCG and FC autonomous voltage invertor (AVI) is consumed from the mains during the load test. The load is controlled through action on DCG excitation winding (EW) current. Variation of excitation current results in change of EMF and, correspondingly, of DCG current and IM torque load. Energy generated by DCG is recuperated into a FC direct current link and is again consumed by IM. Essentially higher cost is a disadvantage of the use of DCG in comparison with alternating current machines, so, it is more expedient to use alternating current machines as a loading machine.

It is possible to perform loading with the use of an alternating current machine with recuperation of energy into the mains when the IM1 tested machine operates in a generator mode (fig. 2). Increase of IM2 supply voltage frequency is provided by means of FC, which results in IM1 operation under recuperation mode with output of energy into the supply mains. The advantage of the considered system consists in the fact that energy is recuperated into the supply mains without intermediate members. The disadvantage is that IM1 rotation frequency will exceed the rated one and that operation of the tested IM1 in generator mode is not regulated by any normative documents [3, 4].

Creation of loading condition with the use of FC is possible using frequency modulation method (fig. 3) [3]. In this case assigning of IM supply frequency containing a low-frequency variable component will allow creation of IM indirect loading with equivalent current and torque due to alternate transition from the motion to recuperation mode. This method is more suitable for IM with a big inertia moment as the higher inertia is the lower the required amplitude and frequency (usually 1-2 Hz) of modulation is. Analysis of the operation modes under such load test is conveniently carried out in the frequency domain by using the mathematical tool of series discrete convolution [6].

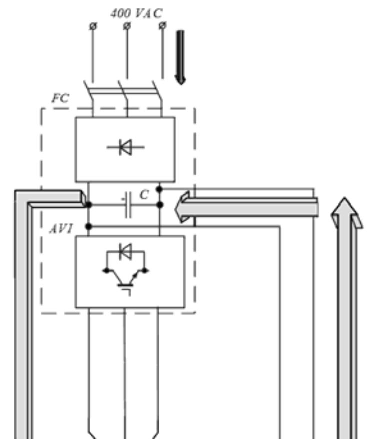

Fig. 1. IM loading system with DC generator with energy recuperation into FC direct current circuit

Absence of a loading machine is an advantage of the system of load test with the use of the frequency modulation method, creation of load by an indirect method is its disadvantage.

IM loading is possible with the use of a loading machine with a squirrel-cage rotor and two FCs (fig. 4). In this case FC1 and FC2 are interconnected along direct current circuits. Due to creation of difference between IM1 and IM2 frequencies, the IM1 machine operates in a motion mode and IM2 – in a generator mode. Electric energy generated by IM2 is transferred from FC2 AVI to IM1 by FC1 direct current circuit. The described system has the following advantages: use of IM with a squirrel-case rotor as a loading machine and simplicity of control of loading modes. Increase of capital expenditures on creation of the system at the expense of the use of two FCs of practically the same power may be considered its drawback.

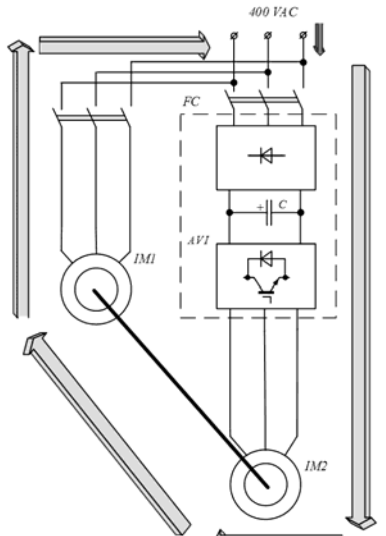

Fig. 2. IM loading circuit with energy recuperation into alternate current network

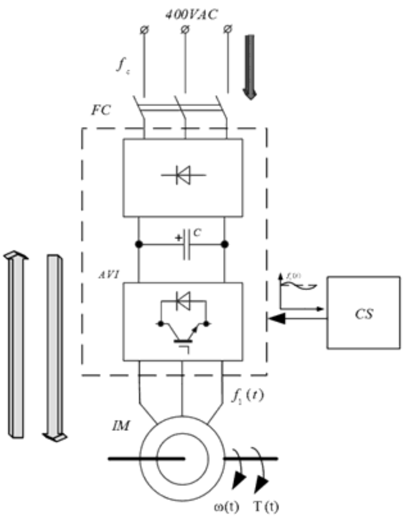

Fig. 3. IM loading circuit using frequency modulation method

The performed analysis of different test systems for induction motors under load with the use of FC makes it possible to choose the most rational variant taking into account the particular production conditions. However, a common disadvantage of the considered systems is caused by the fact that in real conditions of application of test systems one has to load IMs with different number of ports. It results in the necessity for choice of a loading machine with maximum rotation frequency and its overmotoring, which causes increase of FC power and growth of capital expenditure.

In modern electric generators double-fed machines (DFM) based on IM with phase-wound rotors and frequency converters (FC) in rotor circuit took certain place in wind-generator systems. Under varying shaft rotation frequency the use of DFM allows one to reach high energy characteristics [7, 8].

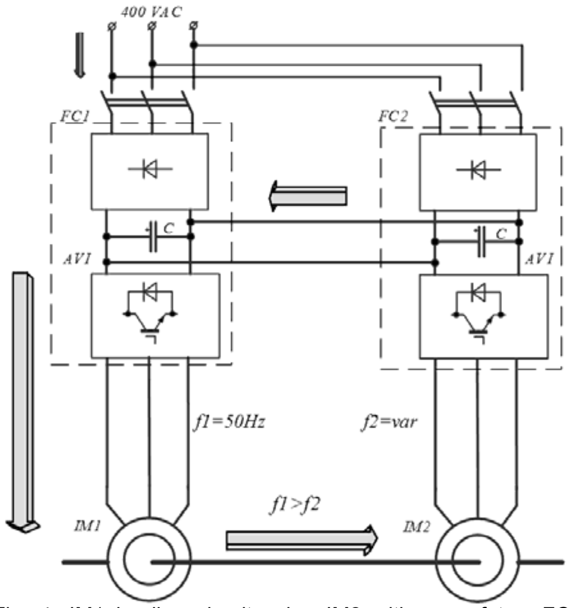

Fig. 4. IM1 loading circuit using IM2 with use of two FCs and energy recuperation into direct current circuit of FC1

Problem statement

Investigate specifics of use the DFM operating in generator mode for testing IM with different number of ports under loading conditions.

Material and results of the research

The IM testing using DFM allows one to load tested motor and to recuperate generated energy directly to supply mains from the stator circuit of IM with phase-wound rotor without using intermediate converters. The regulation of loading level of the tested IM is provided via regulation of the frequency and amplitude of the supply voltage in rotor circuit. The advantages of loading system with the use of DFM are the use of unidirectional industrial FC, which simplifies the system and decreases its cost; and high quality of energy which is recuperated to supply mains.

The specificity of testing the IM under loading conditions using one double-fed motor is the possibility to test induction motors with different rated power values and different number of ports. The DFM operation in braking mode with energy recuperation into supply mains under different number of ports of loading and tested motor is possible because of the regulation of supply frequency in rotor circuits of IM with phase-wound rotor. Herewith the loading level of the tested motor is determined by its slip:

(1) $$s\left(f_{r\,IM2}\right)=1-\frac{p_{IM1}}{p_{IM2}}\frac{f_{s\,IM2}+f_{r\,IM2}}{f_{s\,IM1}},$$

where s is the slip of the tested motor IM1; p_{IM1}, p_{IM2} are number of ports in tested (IM1) and loading (IM2) motor, respectively; $f_{s\,IM1}, f_{s\,IM2}$ are stator supply frequencies of IM1 and IM2, respectively; $f_{r\,IM2}$ is the rotor supply frequency of the IM2.

Thus, according to (1), with the possibility to regulate frequency of IM1 and ports numbers $p_{IM1} = 2,\, p_{IM2} = 3$ the dependence of the IM1 slip on rotor supply frequency of IM2 ($f_{r\,IM2}$) is shown in fig.5. Without the possibility to regulate frequency of IM1 ($f_{s\,IM1} = f_{s\,IM2} = 50\ Hz$) the rotor voltage supply frequency of IM2 should be in the following range: $0 < f_{r\,IM2} < 25\ Hz$.

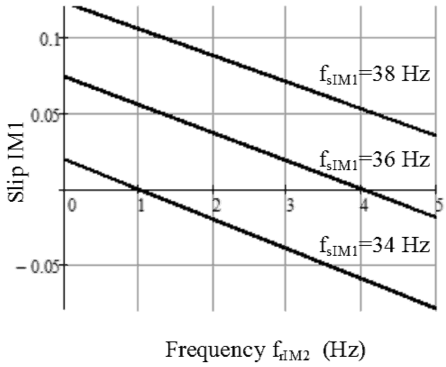

Fig.5 Dependence of IM1 slip on rotor voltage frequency of IM2 ($f_{s\,IM2} = 50\ Hz$)

Experimental research

To research the specificity of the use of DFM in generator mode for the task of testing IM with different number of ports under the loading, experimental research based on the circuit shown in fig. 6 was carried out.

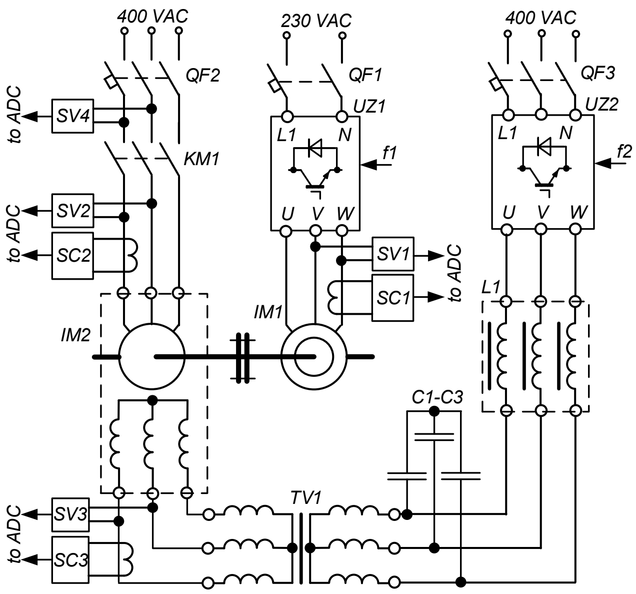

Fig.6. Circuit of experimental installation for investigation of the IM under loading conditions using double-fed motor

Motor IM1 fed by FC UZ1 and rotor circuit of loading motor IM2 fed by FC UZ2 were tested. The LC-filter is used to filter UZ2 output voltage (L1, C1-C3). Using step-down transformer TV1 decrease of voltage level in rotor circuit of IM2 is provided. Currents and voltages in circuits of IM1 and IM2 are controlled via current sensors SC1-SC3 and voltage sensors SV1-SV4, respectively. Signals from current and voltage sensors are collected by analog-digital converter (ADC) to digitize and transfer them to personal computer (PC).

In accordance with (1) and (fig. 5) certain initial value $f_{r\,IM2}$ is to be set, which ensures operation of IM1 with minimal load. With further decrease of IM2 rotor current frequency $f_{r\,IM2}$ the desired loading level of IM1 is to be set. Thus, during testing operations special attention should be paid to voltage synchronization during plugging the stator of IM2 to the supply mains.

Experimentally measured phase current $i_{sc1}(t)$ and interphase voltage $u_{sv1}(t)$ of tested motor IM1 (fig. 7), phase current $i_{sc2}(t)$ and interphase voltage $u_{sv2}(t)$ of the stator of loading motor IM2 (fig. 8), interphase voltage $u_{sv2}(t)$ of the stator of loading motor IM2 and $u_{sv4}(t)$ of supply mains (fig. 9) confirm the possibility to create the loading mode with recuperation of both active and reactive power into supply mains.

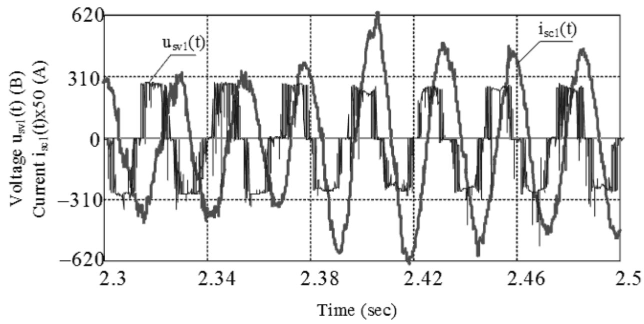

Fig. 7. Phase current $i_{sc1}(t)$ and interphase voltage $u_{sv1}(t)$ of tested motor IM1

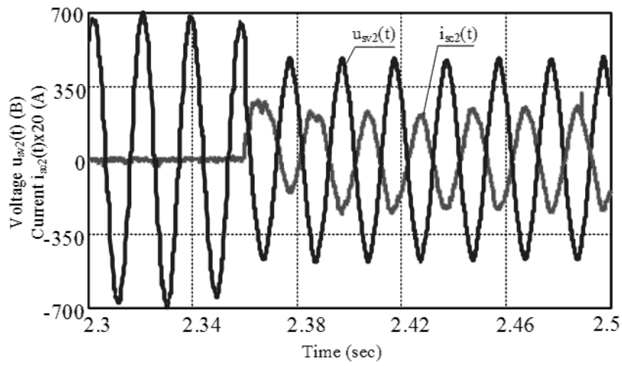

Fig. 8. Phase current $i_{sc2}(t)$ and interphase voltage $u_{sv2}(t)$ of the stator of loading motor IM2

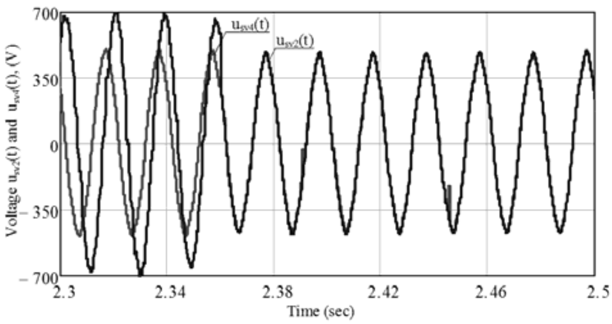

Fig. 9. Interphase voltage $u_{sv2}(t)$ of the stator of loading motor IM2 and $u_{sv4}(t)$ of supply mains

Conclusions

The specific character of the use of a double-fed motor in generator mode for testing induction motors with different number of ports in loading operating modes was researched. Conducted experimental research confirms the possibility of creation of loading mode for induction motors with different number of ports using double-fed motors with recuperation of both active and reactive power into supply mains.

Authors: *Assistant Professor of Faculty of Engineering, Al-Balqa' Applied University (Jordan) Mohamed Zaidan Qawaqzeh, e-mail: qawaqzeh@hotmail.com; Associate Professor of Electric Drive and Control Systems Department of Kremenchuk Mykhaylo Ostrohradskyi National University Andrii Kalinov, Pershotravneva str. 20, Kremenchuk, Ukraine, 39600, e-mail: andrii.kalinov@gmail.com; PhD student of Electric Machines Department of Kremenchuk Mykhaylo Ostrohradskyi National University Volodimir Lotous; Rector of Kremenchuk Mykhailo Ostrohradskyi National University and the Chairman and the Professor of Electric Machines Department Mykhaylo Zagirnyak, Pershotravneva str. 20, Kremenchuk, Ukraine, 39600, e-mail: mzagirn@gmail.com*

REFERENCES

[1] M. Zagirnyak, D. Mamchur, A. Kalinov (2010) Elimination of the Influence of Supply Mains Low-Quality Parameters on the Results of Induction Motor Diagnostics, XIX International Conference on Electrical Machines, ICEM 2010, Rome. IEEE Catalog Number: CFP1090B-CDR. ISBN: 978-1-4244-4175-4. Library of Congress: 2009901651. RF-009474, 6 p.

[2] M. Zagirnyak, A. Kalinov, O. Bratash (2014) Estimation of the efficiency of vibration power application for induction motor diagnostics, Przegląd Elektrotechniczny (Electrical Review), R. 90 Nr. 12. pp. 176–179.

[3] IEC 60034-2-1:2007 Rotating electrical machines - Part 2-1: Standard methods for determining losses and efficiency from tests (excluding machines for traction vehicles).

[4] IEEE Standard Test Procedure for Polyphase Induction Motors and Generators. IEEE Std 112™-2004 (Revision of IEEE Std 112-1996). 3 Park Avenue, New York, NY 10016-5997, USA.

[5] M. Zagirnyak, V. Ogar, V. Chenchevoi (2014) Analysis of induction motors features taking into account change of iron properties, Acta Technica. – Iss. 59/2014 (1). – PP. 25–47. – ISSN 0001–7043.

[6] M. Zagirnyak, A. Kalinov, M. Maliakova (2011) An algorithm for electric circuits calculation based on instantaneous power component balance, Przegląd Elektrotechniczny (Electrical Review), R. 87, Nr. 12b, pp. 212–215.

[7] Cardenas, R., Pena, R., Alepuz, S., Asher, G. (2013) “Overview of Control Systems for the Operation of DFIGs in Wind Energy Applications”, IEEE Trans. on Industrial Electron., Vol. 60, no. 7, pp. 2776–2798.

[8] Peresada, S., Tilli, A., Tonielli, A. (2003) “Indirect Stator Flux-Oriented Output Feedback Control of the Doubly-Fed Induction Machine”, IEEE Trans. on Control Systems Technol., Vol. 11, no. 6, pp. 875–888.