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An analysis on induction motor reliability and lifetime estimation methods

Abstract*. The aim of this paper is to research induction motor's most common failures, analyze reasons and find a way to predict it. Reliability is a parameter that cannot be calculated based on induction motor parameters only. Power supply quality, detail's defects, abnormal operation mode and other cause untimely breakings that could lead to significant losses. That is why induction motor condition monitoring is an important engineering problem that demands deep research and supervision. Due to these conditions were researched methods that allows to defining induction motor parameters and evaluate its condition.*

Streszczenie. *Celem artykułu jest przebadanie najczęściej spotykanych awarii silników indukcyjnych, przeanalizowanie przyczyn ich występowania oraz wypracowanie metod ich predykcji. . Niezawodność tych urządzeń nie może opierać się wyłącznie na ich parametrach. Jakość zasilania, defekty elementów, nietypowy sposób działania i inne czynniki powodują bezterminowe awarie co prowadzi do znaczących kosztów. Z tego powodu warunki monitorowania silników indukcyjnych stanowią wyzwanie dla inżynierów i wymagają poważnych badań i nadzoru. IW artykule przebadano metody, pozwalające na zdefiniowanie parametrów silnika indukcyjnego i ocenę ich odpowiedniości (**Analiza niezawodności silnika indukcyjnego i metody oceny jego żywotności**)*

Keywords: induction motor, fuzzy logic, artificial neural network.
Słowa kluczowe: silnik indukcyjny, logika rozmyta, sieci neuronowe

Introduction

It is well known that induction motors (IM) dominate over other motor types due to their reliability, efficiency and construction simplicity. These reasons made this type of motors so popular in different industrial branches. Over past decades, the number of induction motors increased so much that according to some researches they consume up to 70% of total produced electric power. Under these circumstances, any deviations in operation modes lead to significant expenses. IM components' deterioration leads to their untimely replacement. Deviations in supply conditions cause additional losses that also damage parts sensitive for temperature changes, such as insulation. Thus, there is important task to detect these deviations and take them into account during estimation IM reliability as well as its lifetime.

Theoretical theses

The most common breakings [1–11] are depicted in fig. 1.

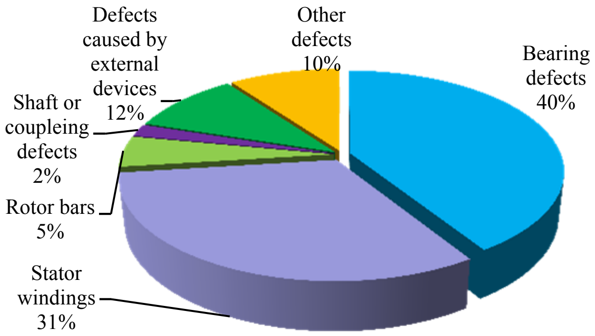

Fig.1. Most frequent IM faults

Induction motor diagnostics and reliability evaluation methods were revised in this paper. Evaluating motor's components condition and tracking factors that have influence on them is a way for creating analysis system. Scheduled maintenance is usually performed after definite number of hours and lead to replacing parts that are supposed to break soon. This kind of periodic maintenance is inefficient and may cause unneeded costs that do not guarantee absence of faults. To achieve better effect, it was developed different on-line IM diagnostic systems and methods.

Automatic tracking system is the most effective solution. Timely completed maintenance may prevent serious breakings, production stoppage and overspending.

Fuzzy logic and artificial neural network systems in this case are very effective choice.

Methods that are mostly used for induction motor condition diagnosis are:

- MPSA/MCSA;
- temperature deviation tracking;
- vibration analysis;
- current spectral analysis etc.

Induction motors malfunctioning and its components breakings are also informative ways to evaluate conduction and maintenance necessity.

Methods that does not demand production stoppage and allow performing online diagnosis has higher priority.

Research results

Statistic of mechanisms' breakings declare that risks are much higher at its early life occurred by details or constructive defects or after a wear-out period. (fig. 2).

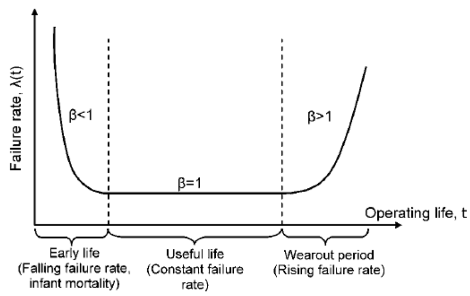

Fig. 2. Components failure rate.

Induction motors failures can be separated to groups due to their location, reasons, consequences for the electric drive and duration. Rapid breakings are highly difficult to predict, at the same time tracking induction motor condition modes and operating condition gives information that can help to prevent more common and spreader breakings [12–14].

Power supply deviation tracking is an efficient way to evaluate risks and possibilities of different IM failures. In addition, this kind of analysis can be performed online and it needs only voltage sensors and data processing equipment. Fluctuations that occur during the day happen due to specifics of local power supply system, changes in electric consumption during the day and other factors [12–16].

Rotation frequency depends directly on changes in supply voltage and are reflected by the following equation:

(1) $$n = n_c\left(1 - k_3 \frac{U_n^2}{U^2} s_n\right),$$

where n_c – synchronous speed, k – load coefficient, U_n, s_n – rated values of voltage and sleep, respectively, U – actual voltage value.

Deviations in a power supply mode also increase risk of product defects. Increasing voltage according to the equation leads to growth of rotation frequency, reactive and active power consumption.

Induction motor lifetime can be evaluated as [14]:

(2) $$T = \frac{T_n}{R}$$

where T_n – rated IM lifetime, R – coefficient that depend on voltage deviations and load:

(3) $$R = (47\delta U^2 - 7.55\delta U + 1)\, k_l^2$$

where $-0,2 < \delta U < 0$ – voltage deviation; kl – load coefficient.

Negative voltage deviation decline induction motor's lifetime as shown in fig. 3.

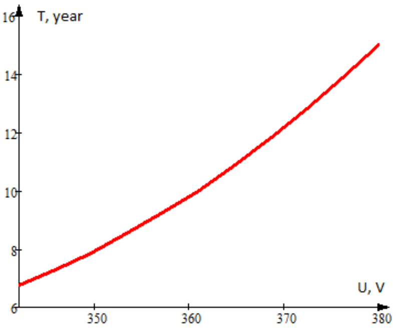

Fig. 3. Negative voltage deviation influence

3-axes surface that combines changes in main parameters of the equation was created using MatLab (fig. 4). It shows dependency of voltage, load and expected lifetime. According to these calculations negative influence of lower voltage meanings can be compensate with load reduction.

Induction motors are highly influenced by low voltage meanings. As it was calculated basing on induction motor simulation models and using empiric formulas (fig. 4) 10 % voltage drop (from 380 V to 342 V) shortens operation time for 54 % (from 15 to 6.9 years).

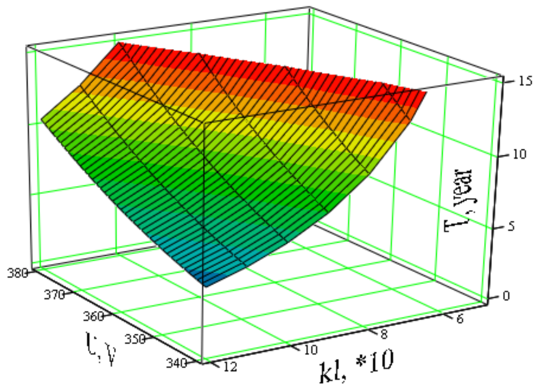

Fig. 4. 3-axes model

Insulation reliability is another factor that has crucial impact for induction motor exploitation time. Insulation overheating has significantly influence on induction motor condition even if it is limited in time. Approximate remained lifetime may be calculated using next equation [14]:

(4) $$T = \Delta t \cdot \sum_{k=1}^{M} e^{-\beta \cdot \Delta\tau_k}$$

where $\beta = \frac{ln2}{\Delta\theta}$; $M = \frac{T_n}{\Delta t}$, T and T_n – insulation lifetime with set and acceptable temperatures; $\Delta\tau k$ – overheating in k-period of time; $\Delta\Theta$ – coefficient that depends on insulation class. This equation is universal and may be applied for different insulation types. Dependency of lifetime to temperature deviation is presented in fig. 5.

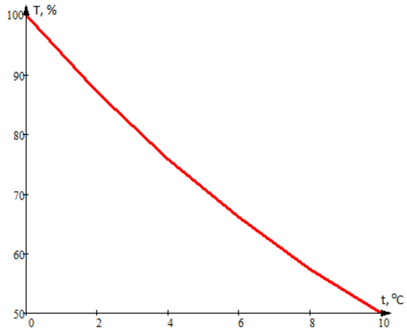

Fig. 5. Induction motor's relative remained lifetime

Bearings condition monitoring must be considered as one of the most important factors due to the frequency of such breakings. It is especially important for low power and high frequency motors. Depending on bearing type, the failure happens due to alien particles, overloads, grease aging and cracks. Operation time can be significantly shortened by load increasing. For example, twice load increase for polling bearings reduces its lifetime for almost ten times. One of the most important factors that determine quality of bearing exploitation is installation accuracy. Rated lifetime for rolling bearing in proper conditions is up to 20 000 hours.

Equation for metal fatigue:

(5) $$\sigma_z = \frac{A}{\sqrt[m]{N_c}},$$

where σ_z – strain that match fatigue limit, A – wear resistance coefficient, N – number of strain cycles, m – experimental coefficient.

Accurate bearings reliability calculation must consider changes in grease. Rainolds number is used for this purpose:

(6) $$R_e = \frac{\rho \cdot n \cdot d_0^2}{\mu},$$

where n – inner bearing ring velocity, ρ – grease density, d_0 – average bearing diameter, μ – dynamic grease viscosity.

There are different equations depend on used grease type:

- oil grease:

(7) $$\frac{T^*}{T_e} = a_0 \cdot \lambda^{a_\lambda} \cdot R_e^{aRe},$$

where λ – grease parameter, T_e – estimated bearing lifetime, T^* – experimental value.

- any liquid grease:

(8) $$\frac{T^*}{T_e} \approx 0{,}41 \cdot \lambda^{0.78} \cdot R_e^{0.56},$$

- plastic grease:

(9) $$\frac{T^*}{T_e} = a_0 \cdot \lambda^{a_\lambda} \cdot R_e^{aRe} \cdot \Delta^{a_\Delta},$$

where $\Delta = 2\delta a/\delta 0$ – average radial gap.

All the methods that have been revised covers up to 85% of total induction motor breakings. The next task is to create system that combines all of them (fig. 6).

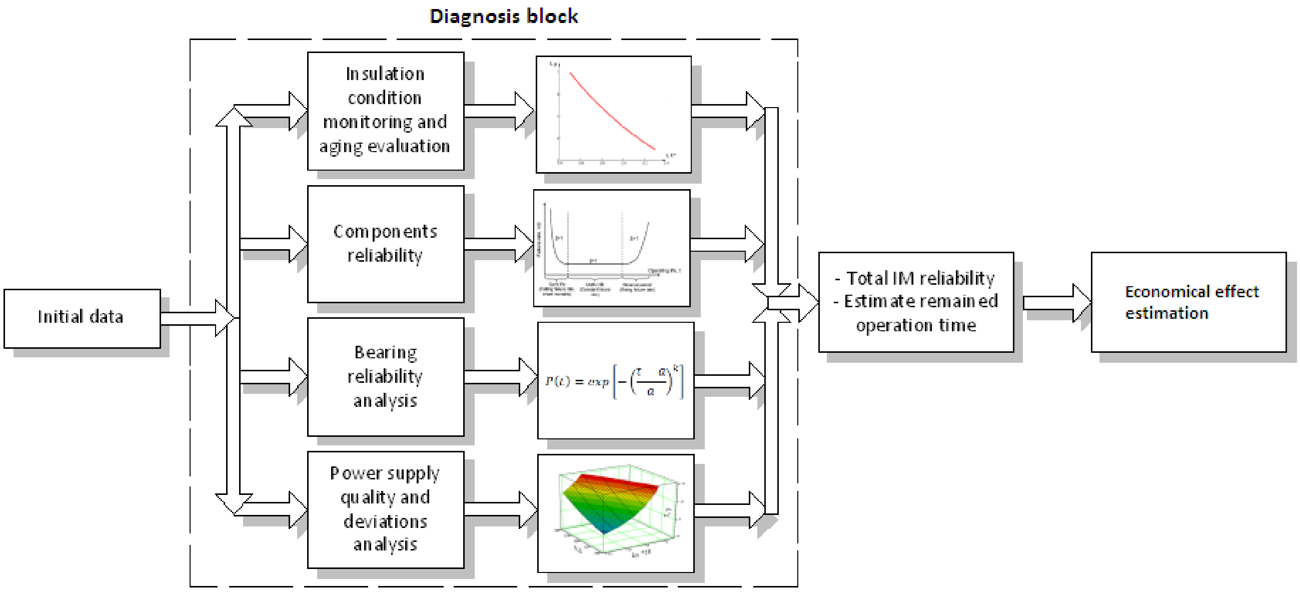

Fig. 6. A diagram of induction motor diagnostics and its lifetime and reliability estimation system

Initial data received form sensors must be processed in diagnosis block. Conclusion about induction motor reliability and necessity of maintenance must be calculated according to processed data and breakings rate.

One of the ways to accomplish data evaluation is to employ fuzzy logic system for this task. It is one of the most efficient instruments to analyze incoming data from electric drive. In case of fuzzy logic, the meaning of variables must not be exact to identify some fault, which allow to the system to indicate about any deviation in IM work before serious damage happen.

Scheme of fuzzy-logic-based diagnosis system is illustrated in fig. 7.

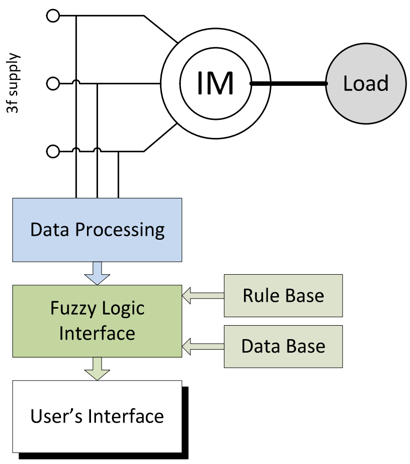

Fig. 7. Automated diagnosis system based on fuzzy logic

Fuzzy logic system must have a set of rules that would define system's output and indicate about any deviations (fig. 8).

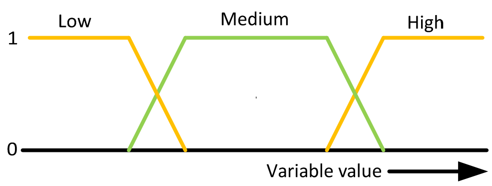

Fig.8. Fuzzy logic rule example for coefficient or variable

Computed coefficients and variables should be compared with the values that are set in system's base. Appearance of higher or lower harmonics level, increasing or reducing of any coefficient change the system's output according to the definite rule. It makes possible to identify faults before any serious breakings.

Table 1. Fuzzy logic rules

Rule	I	B	V	Lifetime
1	Low	Low	Low	Normal
2	Low	Low	Medium	Normal
3	Low	Medium	Low	Normal
4	Medium	Low	Low	Normal
5	Low	Medium	Medium	Reduced
6	Medium	Medium	Medium	Reduced
7	Medium	Medium	High	Reduced
8	Medium	High	Medium	Reduced
9	High	Medium	Medium	Critical
10	Medium	High	High	Critical
11	High	High	High	Critical

where I – insulation condition, B – breakings condition, V – power supply quality.

New induction motor starts operation with normal parameters and rated lifetime. After some period of time its reliability reduces and parameters deviations can be detected. Timely qualified maintenance increase mechanisms reliability and prolong time till next repair. Absence of necessary or skipping planned repair lead to serious breakings.

Example of induction motor lifetime is presented in fig. 9.

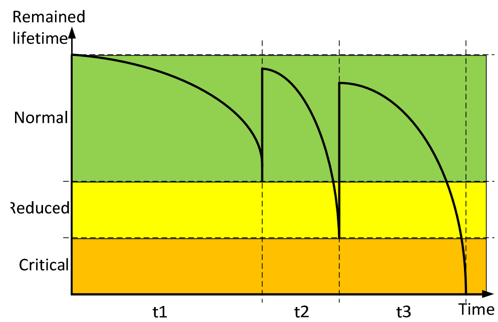

Fig. 9. Induction motor condition degradation curve

In past years, significant steps were made in developing artificial intelligence and technologies in this sphere.

Neural networks have many advantages. It is a nonlinear system that increases its flexibility. The main difficult in using such systems is the initial setting.

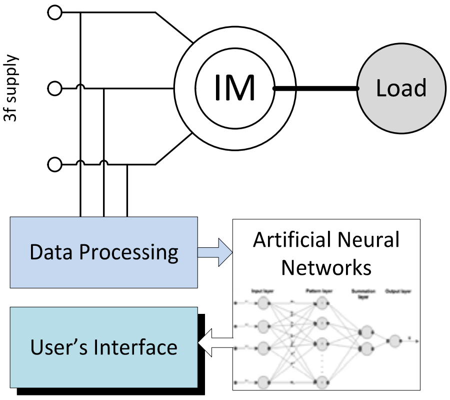

Fig.10. Automated diagnosis system based on artificial neural network

Properly tuned ANN can warn about deviations in induction motor and operating mode that might cause faults. Service stuff in this case has options and information about possible breakings.

The final step is to calculate economical effect. It may be evaluated based on electric drive cost, exploitation and repair expenses. There is a limit for every motor when actual or potential cost of a new one is less and will be reasonable.

Total induction motor expenses equation:

(10) $$C = C_1 + C_2 + C_3,$$

where $C1 = A$ – IM cost, $C2 = B\cdot t$ – current exploitation expenses that include planned maintenance, electrical energy, etc., $C3 = D\cdot t^n$ – repair expenses.

(11) $$C = A + B\cdot t + D\cdot t^n,$$

Expenses $\frac{C}{t} = \frac{A}{t} + B + D\cdot t^{n-1}$ will be minimum when

(12) $$t = \sqrt{\frac{A}{(n-1)D}}.$$

Higher motor cost and less repair expenses increase optimal lifetime for induction motor.

Conclusion

This paper dealt with induction motor reliability evaluation and its remaining lifetime estimation. Timely fault recognizing and serious damage prevention is an important factor for effective equipment exploitation. Based on components reliability calculations could be made decision if maintenance is required. Current signal gives all the necessary information about main detail's condition. Fuzzy logic and artificial neural network are effective instruments for data processing. Combination of presented diagnosis methods allows us to predict most common problems that occur due to condition modes, different deviations or defects. Based on results of research, it was proposed an algorithm for analytic system that provides recommendations for possibility of motor operation under current conditions. Automation of monitoring process reduces requirements to operating stuff and allows reducing chance of human fault. According to investigated researches, monitoring of induction motor can be performed in automated mode with high speed and accuracy. Increasing induction motor reliability due to its timely maintenance and condition monitoring lead to its proper operation and economic effectiveness.

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