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Bacterial foraging algorithm application for induction motor field efficiency estimation under unbalanced voltages

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ABSTRACT

In electric supply systems of industry and other entities, it is very common to find problems of power quality. Among these problems, unbalance and voltage deviation is one of the most common. They primarily affect the operation of electric motors. This paper proposes the use of a bacterial foraging algorithm as an economic, accurate and low-invasive tool, to obtain in field conditions, the output power, losses and efficiency of induction motors feed with unbalanced voltages. The algorithm is based on estimating the motor parameters of positive and negative equivalent circuits. The tool was tested on a 7.5 kW motor for different load conditions and high levels of voltage unbalance, yielding to accurate results, and demonstrating its effectiveness for performing energy audits in situ on unbalanced voltages conditions. This application of bacterial foraging technique has not been reported in the literature.

1. Introduction

The analysis of efficiency in the operation of asynchronous machines is an important potential source of savings, since these machines consumes over the 60% of the electricity end use worldwide. They are also the majority of the installed load in industrial systems [1].

The problems associated with energy quality, constitute an everyday phenomena. Voltage unbalance, which in most cases occurs associated with voltage deviations, is one of the most common in terms of energy quality and has a direct influence on the increase of losses in electric motors and systems [2].

Under field conditions, the output power is very difficult to measure. For that reason, several methods for determining the efficiency of motors working in such conditions have long been proposed. IEEE-112 and IEC 60034-2-1 standards, which offer the most accurate results, are not applicable in industrial conditions [3].

The nameplate, slip and currents methods are some of the most used, giving a low cost in necessary equipment and a low level of intrusion implied. However, their use in presence of power quality problems, imply unacceptable levels of errors. The same happens with softwares based on statistical and empirical methods that are recognized internationally, as the Motormaster and Ormel 96. The latter may introduce errors of 4% [4].

The equivalent circuit method has also been one of the most used for determining the efficiency of induction motors under field conditions. In recent years, the scientific literature has reported numerous studies related to the use of heuristic techniques for implementing this approach, allowing the estimation of the parameters of the motor circuit and its efficiency.

Among the most commonly used heuristic techniques, the genetic algorithm (GA) has been successfully employed to solve complex non-linear optimization problems. However, recent research has identified some deficiencies in the GA performance [5]. Errors in efficiency are apparent when the parameters being optimized are highly correlated, and the premature convergence of the GA degrades its performance in terms of reducing the search capability.

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Nomenclature

BF	bacterial foraging
GA	genetic algorithm
PSO	particle swarm optimization
$\overline{V_s}$	stator phase voltage (V)
$\overline{I_s}$	stator phase current (A)
$\overline{I_r}$	rotor current (A)
r_s	stator resistance (Ω)
x_s	stator leakage reactance (Ω)
r_{LL}	stray loss resistance (Ω)
r_{corefw}	core and mechanical loss resistance (Ω)
x_m	magnetizing reactance (Ω)
r_r	rotor resistance (Ω)
x_r	rotor leakage reactance (Ω)
S	slip
$\overline{I_m}$	magnetizing current (A)
$\overline{ZM}$	calculated motor equivalent impedance (Ω)
$\overline{RM}$	calculated motor equivalent resistance (Ω)
P_n	nominal motor power (W)
P_{in}	input power (W)
P_{cus}	stator copper losses (W)
P_{cur}	rotor copper losses (W)
P_{corefw}	core and mechanical loss (W)
P_{LL}	stray load loss (W)
P_{tot}	total losses (W)
P_{out}	output power (W)
$MinJ$	global objective function
P	dimension of the optimization problem
s	population of the *Escherichia coli* bacteria
N_c	maximum number of chemotactic steps
N_S	maximum number of swims
N_{re}	maximum number of reproduction steps
N_{ed}	number of elimination-dispersal events
S_r	number of bacteria reproductions per generation
P_{ed}	probability of occurrence of elimination-dispersal events

Subscripts

i	$i = 1$ (positive sequence), $i = 2$ (negative sequence)
e, m, c	estimated, measured and calculated data

A new evolutionary algorithm known as bacterial foraging (BF) has been proposed [6] to mitigate the above mentioned deficiencies. This algorithm is based on the methods for locating, handling and ingesting food, used by Escherichia coli bacteria present in the human intestine and it is known as foraging.

It has been shown that the BF algorithm offers a superior performance in terms of solution quality and convergence speed, in comparison to the particle swarm optimization (PSO) and the GA [7]. BF has been used to solve various types of engineering problems [8–10] such as the efficiency calculation of motors in field conditions by solving the equivalent circuit. However, it only considers positive sequence circuit, which limits its use to cases where there are no voltage unbalance problems [11].

The contribution of this work is the use of bacterial foraging technique to determine in field conditions and with a low invasiveness, the total losses, the output power and efficiency of induction motors working in networks with voltage unbalance and deviations.

The application of the proposed method requires the nameplate data, as well as measurements of voltages and line currents, input power, stator resistance and speed of the rotor shaft. The proposed model was tested on a 7.5 kW motor.

2. Problem formulation

The proposed method for assessing energy performance of induction motors working in situ, and feed by unbalanced and deviated voltages, consists in determining the parameters of the circuit shown in Fig. 1. This circuit is based on the Fortescue transformation theory that decomposes an unbalanced system, into two balanced systems of positive and negative sequence. For the final results, the principle of superposition [12,13] was applied. In the circuit, the resistance representing the stray load loss r_{LL} is placed on the stator as in [14], but in this case, it is calculated using the IEC 60034-2-1 standard.

2.1. Equivalent circuit parameters

In order to obtain the parameters of the equivalent circuits within allowable limits values, the stator resistance r_s is measured and corrected for operational temperature. The stator and magnetizing branch parameters are considered constant for positive and negative sequence. The rotor parameters vary by skin effect. The rotor leakage reactance is related to the stator according to the motor design through the factor $k_{re} = (x_s/x_r)$ [15], being $k_{re} = 1$ for design A and D; $k_{re} = 0.67$ for design B; and $k_{re} = 0.43$ for design C. The representative resistances of stray load loss are located in the stator and are calculated according to IEC 60034-2-1 as follows.

For motors between 1 kW and 10,000 kW, the standard proposes the following relationship between the additional losses and the input power [16]:

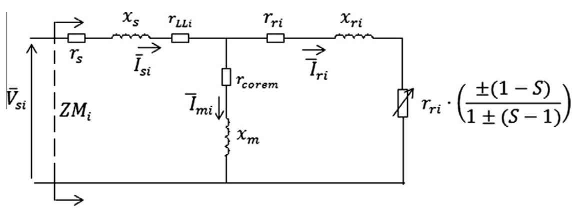

Fig. 1. Equivalent circuit of an induction motor feed with unbalanced voltages ($i = 1$: positive sequence; $i = 2$: negative sequence).