Electric Power Systems Research 125 (2015) 211–219

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Comparative performance analysis of a standard three-phase induction motor and an asymmetric three-phase induction motor fed from a single-phase network

Prado Wellington [a,*], Gonçalves de Mendonça Roberlam [a], Martins Neto Luciano [b,1]

[a] IFG, Coordenação de Eletrotécnica, Itumbiara, GO, Brazil
[b] Laboratório de Máquinas Elétricas, Faculdade de Eng. Elétrica, Universidade Federal de Uberlândia, Campus Santa Mônica, Uberlândia, MG, Brazil

ARTICLE INFO

Article history:
Received 7 November 2014
Received in revised form 20 February 2015
Accepted 21 February 2015
Available online 4 May 2015

Keywords:
Three phase induction motor
Asymmetrical motor
Performance
Power factor
Inrush current

ABSTRACT

This paper aims at conducting a comparative study between a traditional three-phase squirrel cage induction motor and asymmetrical three-phase induction motor fed by single-phase voltage. For the purpose of this study, two engines with the same power were employed. During the research herein, the authors investigated the behaviour of various magnitudes for each machine. It was found that the asymmetric motor features a number of advantages over traditional motors, which makes it an excellent choice when the application requires the drive loads of high power and do not have an available three-phase supply.

1. Introduction

The present-day characteristics of the energy consumer aligned with financial resource limitations for investment in rural electrification programs, have pushed electricity providers towards the use of single-phase or single-wired energy distribution systems. Characteristics of this type of system are exemplified by; low monthly kW h consumption; few consumers per m of installed network; low simultaneous maximum demands.

At present, the development of new techniques for irrigated plantations as well as the improvement of agricultural products within the local of production imposes upon rural producers the need to increase electrical energy consumption, mainly where maximum demand is concerned. However, with the current available system being of single-phase means those rural producers are restricted to the specifications and characteristics of this system.

The downside to this type of energy distribution used in electrification of rural properties can be given as; single-phase electric motors are more expensive, physically bigger and consequently heavier, and more likely to suffer failures. In addition, their production in Brazil is limited to 9193.734 W (12.5 hp)-pumps for drawing water from deep wells are in their greater part driven by three-phase motors, which are lighter, cheaper, easier to find on the market and found in a wider power range.

Therefore, the use of typical three-phase loads, as for example induction motors with a power range above 9193.734 W (12.5 hp), is limited only to those rural consumers, where the substitution of the single-phase network for three-phase has taken place, which in most cases is financially unfeasible. In this case, an alternative is to make use of static, rotary or electronic single to three-phase converters [3–5]. On the other hand, one can look at a more contemporary solution based on a three-phase asymmetric induction motor with single-phase feed [1,2,6–10]. These motors show themselves as extremely advantageous when it comes to cost, especially when these have their cost estimated from the pool of three-phase and single-phase motors, where the value tends to be closer to that of the three-phase of powers greater than 9193.734 W (12.5 hp). Besides this fact, its yield is practically equal to that of a three-phase motor of the same power, with the additional advantage that its power factor is practically unitary.

In this work the authors propose a more economical and efficient solution for the employment of electric motors on rural properties. This proposal corresponds in essence to the use of asymmetric three-phase induction motors, fed by a single-phase system.

* Corresponding author. Tel.: +55 064 8134 0812..
E-mail addresses: wellington.prado@ifg.edu.br (P. Wellington), roberlammendonca@yahoo.com.br (G.d.M. Roberlam), lmn@ufu.br (M.N. Luciano).
1 Tel.: +55 034 3239 4764.

http://dx.doi.org/10.1016/j.epsr.2015.02.016
0378-7796/

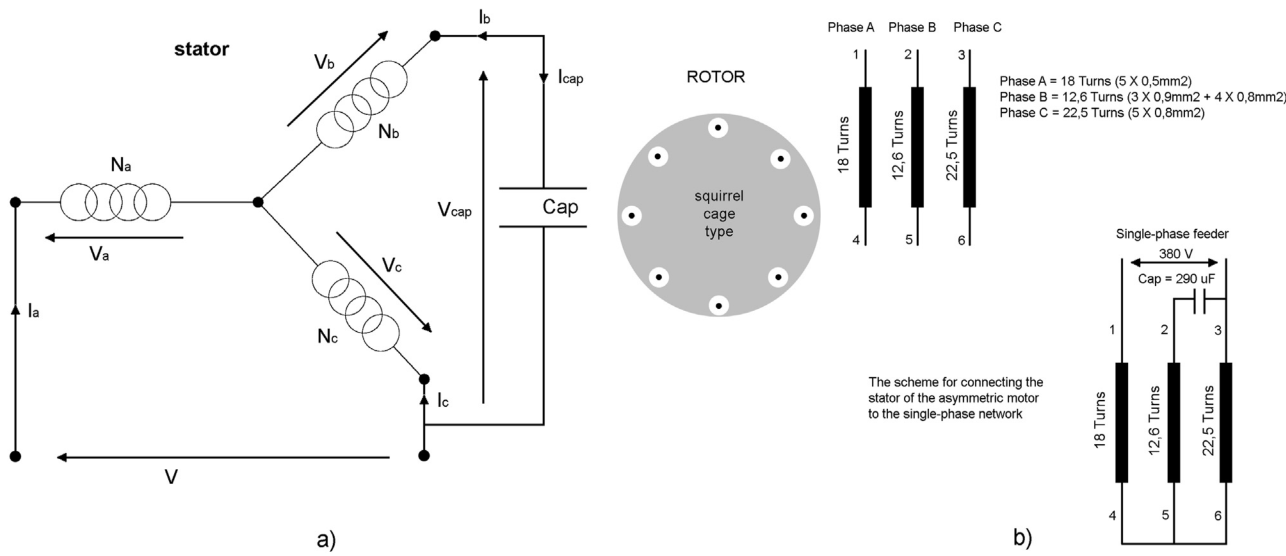

Fig. 1. Asymmetric three-phase induction motor and stator winding data and the connection design.

Working within this framework, the authors of this study have as their objective to present an essentially scientific–technical study, comparing the performance of a traditional asymmetric three-phase induction motor with single-phase feed. The studies were directed in an evaluation of operational performance scenario of both motors, with emphasis being placed upon yield; start up time, maximum start up current value and power factor.

2. Asymmetric three-phase induction motor

The asymmetric three-phase induction motor project is established from the conventional three-phase induction motor, with only the stator winding being substituted and preserving the stator's magnetic structure and rotor in a squirrel cage. Initially, trials are carried out on a commercial three-phase induction motor, to obtain the equivalent circuit parameters, since the equivalent circuits of the phases for this motor are equal.

Through an initial application of the equivalent circuit parameter values it is possible to vary b, c and C_{ap}, where the factors b and c represent the relationship of the number of turns on phase a of the stator by the number of turns on phases b and c of the stator, respectively. Thereby, obtaining the respective values for T, and maintaining the slippage value to that of the nominal rotation of the original symmetrical motor. The varied sets of values for b, c and C_{ap}, which result in T very close or equal to that of the nominal, are those results which allow one to design the asymmetric motor, such that in nominal rotation it supplies approximately or exactly the nominal torque and therefore the nominal power. For every one of these value sets of b, c and C_{ap} that result in nominal power to the asymmetric motor, through modelling in the time domain, one obtains the curves for the torque and rotation in the time function. Hereby, aimed at adding in steady state the average rotation of the motor into the nominal rotation value of the original symmetric motor. Through an analysis of the obtained results, it is possible to choose from the sets b, c and C_{ap} that which best represents the performance of the motor and as such, one has sufficient elements to design and construct the asymmetric three-phase induction motor.

The asymmetric three-phase induction motor is based upon the traditional three-phase induction motor, with a squirrel cage type rotor and ferromagnetic stator structure, both similar to the traditional three-phase induction motor. The difference between the two motors is found in the stator windings. This winding, in the asymmetric motor has a different number of turns per phase, therefore maintaining the electrical shift of 120 degrees. Fig. 1a illustrates the star connection diagram of an asymmetric three-phase induction motor on a single-phase fed network.

It is necessary here to highlight that the decision to use the asymmetric induction motor, was based upon the comparative analysis of its operational performance in relation to the traditional three-phase motor, besides the economic analysis of the cost compared to the overall cost of the traditional motor and the modifications of the network from single to three-phase. Once that through simulations in the time domain, the prototypes proposed for this design were built in accordance with the scheme in Fig. 1b.

3. Theoretical analysis

In this item, time domain equations are presented for both motors. By processing the equations computationally, one can simulate the working operation of both motors from start-up through to steady state.

3.1. Mathematical modelling in the time domain

Initially, the equations between the two generic phases i and j are established, which represent the phases for both motors. In this manner, one can write the expression. For voltage v_i for phase i [11]:

$$v_i = r_i \times i_i + \frac{d\lambda_i}{dt} \quad (1)$$

$$\lambda_i = L_{ii} \times i_i + L_{ij} \times i_j + L_{di} \times i_i \quad (2)$$

where: v_i, i_i, r_i, λ_i—are voltage, current, resistance, and the magnetic flux linkage in the phase i, respectively, L_{ii}, L_{ij}, L_{di}—are the inductances for i without mutual dispersion i and j, and with dispersion i, respectively.

Therefore, now considering j as representing every phase of the motor, including phase i, expression (2) thus becomes the following equation [11]:

$$\lambda_i = L_{di} \times i_i + \sum_j L_{ij} \times i_j \quad (3)$$

In relation to inductance L_{ij}, if one considers only the fundamental component for the spatial distribution of the magnetic density flow, which in turns is produced by the circulation of each current i_i