Engineering Science and Technology, an International Journal xxx (2018) xxx–xxx

HOSTED BY

ELSEVIER

Contents lists available at ScienceDirect

Engineering Science and Technology, an International Journal

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

Full Length Article

Modelling and analysis of dual stator-winding induction machine using complex vector approach

A.S.O. Ogunjuyigbe, T.R. Ayodele *, B.B. Adetokun

Power, Energy, Machines and Drives (PEMD) Research Group, Electrical and Electronic Engineering Department, Faculty of Technology, University of Ibadan, Nigeria

A R T I C L E I N F O

Article history:
Received 3 March 2017
Revised 14 March 2018
Accepted 24 March 2018
Available online xxxx

Keywords:
Complex vector
Modelling
Simulation
Dual stator
Induction machine
MATLAB-Simulink

A B S T R A C T

In this work, complex vector modelling technique is utilized to develop and simulate a dual stator-winding induction machine with squirrel-cage rotor. The transient and dynamic performances of the machine under two cases of input conditions are analysed and presented both at no load and when a constant load torque is applied. The modelling and simulation has been carried out in a step-wise procedure that clearly set forth for the complex vector Simulink implementation in a MATLAB-Simulink environment. The approach presented in this work can easily be applied to other types and configurations of electric machines and drives.

1. Introduction

The concept of dual-stator-winding machines and its applications has gained prominence in recent years [1–4]. Two categories of these machines have been identified [5]. The first is the split-wound dual-stator winding machine designed to increase power capabilities of large synchronous generator. The second category is the brushless doubly fed machine (BDFM), also known as self-cascaded machine, is made up of 3-phase windings embedded in a common stator structure and a special rotor structure which allow the effects of cascade connection through the nested loops on the rotor.

The dual stator machines find applications in several systems, ranging from synchronous machines with AC and DC outputs to large pumps, compressors and rolling mills driven by induction motors. A new dual-stator-winding squirrel cage induction machine was proposed in [6]. It consists of two separate symmetrical 3-phase windings embedded in the same stator structure but wound to have unequal number of poles in the ratio $1:3$. The rotor structure is a standard squirrel cage rotor with skewed rotor bars, which is intended to reduce the magnitude of harmonic torques due to the harmonic content of the magneto motive force (MMF) waves [7]. Fig. 1 shows the dual stator winding distributions of a typical induction machine [6].

This design eliminates the circulating harmonic currents and the net magnetic coupling between the two windings of the stator. It has been shown that the best configuration is $2poles - 6poles$ structure. The output torque is the algebraic sum of two independent torques developed by the independent interaction of each stator current with the rotor flux. With these two independent torques, the machine can be easily operated at high/medium speed and at low speed, when the torques are added and subtracted respectively. Such dual stator machine behaves like two independent induction machines mechanically coupled through the shaft, due to the decoupling effect produced by the dissimilar pole pairs, whereupon all the control schemes for induction machine can also be applied to the dual stator winding machine [6].

Some work have been presented on the dual stator-winding machines in the literature: Pienkowski [8] developed mathematical models of dual stator squirrel-cage induction motor, formulated in phase coordinate system. The author considered the control systems of field-oriented control and direct torque control for the induction motor. Similarly, Dehghanzadeh and Behjat [9] have developed a dynamic model of a dual-stator permanent magnet synchronous generator using a technique that could transform two stator winding sets to two winding couples on the d-q axes of the rotor reference frame. Bu et al. [10] have presented slip frequency control strategy and its experimental implementation of dual-stator-winding induction generator for variable frequency

* Corresponding author.
E-mail addresses: a.ogunjuyigbe@ui.edu.ng (A.S.O. Ogunjuyigbe), tr.ayodele@ui.edu.ng (T.R. Ayodele).

Peer review under responsibility of Karabuk University.

https://doi.org/10.1016/j.jestch.2018.03.013
2215-0986/© 2018 Karabuk University. Publishing services by Elsevier B.V.

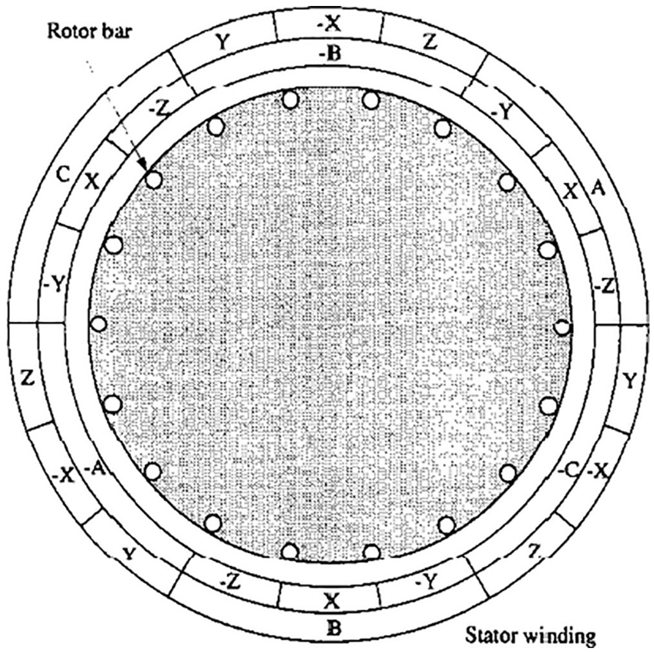

Fig. 1. Dual Stator Winding Distributions.

generating system. The generator has two sets of stator windings embedded into the stator slots. The power winding produces the variable frequency AC power to feed the loads, and the control winding was connected to the static excitation controller to control the generator for output voltage regulation with speed and load variations. Slimene et al. [11] have examined a steady state performance analysis of stand-alone double stator induction generator self-excited with two independents capacitors banks. An impedance approach based on double three-phase induction-generator model was employed to derive steady equations of the double stator self-excited Induction generator. In another work, Slimene et al. [12] modelled and analysed self-excited dual stator winding induction generator (DSWIG) using fzero algorithm. A prototype of the dual stator-winding induction generator (DWIG) and its dynamic model to verify the validity of this machine design as variable speed generator for renewable energy systems has been presented by Rodrigo et al. [13]. The authors revealed that the proposed DWIG has a better use of energy compared to a squirrel cage induction generator (SCIG) in variable speed applications. It was also revealed that the performance of DWIG with a bidirectional converter is very similar to those described in other studies with brushless doubly-fed induction generators. An optimized design using efficiency as the objective function of a dual stator winding induction generator with standard squirrel cage rotor for wind turbine applications was proposed by Keshtkar and Zarchi. The authors determined the optimal parameter values for the machine and then evaluated the machine using the finite-element method supported by Ansys Maxwell software. Their result revealed that a significant efficiency (3 times) was achieved with the optimized dual stator winding induction generator compared to conventional design. Amimeur et al. [14] has presented the detailed modelling of a dual-stator windings of self-excited induction generator in synchronous reference frame. The authors considered the effects of common mutual leakage inductance between two three-phase windings sets. The dynamics of self-excitation process, and step application of load on the machine were also presented. Similarly, Hamoud et al. [15] presented a systematic modelling, a detailed analysis and the performance analysis of self-excitation dual stator winding induction generator. The modelling of the generator took into consideration the common mutual leakage inductance between stators and the magnetizing inductance, which played a principal role in the stabilization of the output voltage in the steady state.

Complex vector modelling has also been applied in recent years. For example, Mu~noz and Lipo [16] presented a new detailed mathematical derivation of a squirrel-cage induction machine d–q model. The model was based on coupled magnetic circuit theory and complex space-vector notation which took into account the actual non-sinusoidal rotor bar distribution. It was shown that, given the structural symmetry of the induction machine, both stator and rotor circuits could be modelled by the simple set of only four coupled differential equations. The actual *n* rotor bars and end-ring currents were fully included in the model, and they were obtained directly by using a simple vector transformation. In another work, Wu, and Ojo [5] ultilised the winding-function method to calculate the inductances in induction machine. In their work, the phase-voltage and torque equations were transformed to the rotor reference frame to facilitate simplicity of modelling and using an *n/spl times/n* complex-variable reference frame transformation.

Most of the aforementioned authors have done well in modelling, simulating and analysing dual-stator winding machines, However, conventional modelling approach were adopted in most of the models. In this work, the dual-stator winding induction machine is modelled and simulated using complex vector notations. The developed model allows the computation of the rotor-bar currents. Unlike the conventional induction machine whereby both the stator and the rotor are modelled as 3-phase systems, the rotor is here modelled as an n-phase system, where n is the number of rotor bars. This analysis therefore requires complex transformation in order to obtain each rotor bar current. This method has been employed for the modelling of single stator-winding squirrel cage induction machine in [16,17].

2. Mathematical modelling of dual Stator-winding induction Machine using complex vector

In modelling the dual stator-winding induction machine, the following general assumptions have been made: (i) uniform air gap, (ii) negligible saturation, (iii) sinusoidal distribution of stator windings, (iv) naturally isolated stator windings and (v) negligible inter-bar current. In this paper, complex vector representation has been used both for the modelling and the simulation in MATLAB-Simulink.

2.1. Stator voltage equations

The stator voltage equations in machine variables may be expressed as

$$v_{abc} = r_{abc} i_{abc} + p\lambda_{abc} \Rightarrow v_{s1} = r_{s1} i_{s1} + p\lambda_{s1} \quad (1)$$

$$v_{xyz} = r_{xyz} i_{xyz} + p\lambda_{xyz} \Rightarrow v_{s2} = r_{s2} i_{s2} + p\lambda_{s2} \quad (2)$$

$$f_{s1} = [f_{as} f_{bs} f_{cs}]^T \quad (3)$$

$$f_{s2} = [f_{xs} f_{ys} f_{zs}]^T \quad (4)$$

where *f* represents voltage, current and flux linkage vector. The subscripts s_1 and s_2 denote variables and parameters associated with the first (abc) and the second (xyz) stator windings respectively; $\boldsymbol{r_{s1}}$ and $\boldsymbol{r_{s2}}$ are the diagonal 3×3 resistance matrices for abc and xyz stator windings respectively.

In complex vector variable form (1) and (2) can be written as [18]:

Please cite this article in press as: A.S.O. Ogunjuyigbe et al., Modelling and analysis of dual stator-winding induction machine using complex vector approach, Eng. Sci. Tech., Int. J. (2018), https://doi.org/10.1016/j.jestch.2018.03.013