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ScienceDirect
Journal of Electrical Systems and Information Technology xxx (2017) xxx–xxx
www.elsevier.com/locate/jesit

Modeling, implementation and analysis of a high (six) phase self excited induction generator

M. Faisal Khan [a,*], M. Rizwan Khan [b], Atif Iqbal [c]

[a] *Electrical Engineering Section, University Polytechnic, Faculty of Engineering & Technology, Aligarh Muslim University, Aligarh 202002, UP, India*
[b] *Electrical Engineering Department, Zakir Husain College of Engineering & Technology, Aligarh Muslim University, Aligarh 202002, UP, India*
[c] *Department of Electrical Engineering, Qatar University, P.O. Box 2713, Doha, Qatar*

Received 18 May 2016; received in revised form 2 October 2016; accepted 26 December 2016

Abstract

Dual d-q model of six phase-self excited induction generator (6Ph-SEIG) developed in stationary reference frame is proposed in this paper. Developed model, implemented in terms of a simulation model, is utilized to evaluate no-load and on-load characteristics along with the estimation of dynamic parameters of studied 6Ph-SEIG for each working condition. Simulation results are verified on the implemented 6Ph-SEIG test-rig with high accuracy. Inherent loading limit of 6Ph-SEIG is obtained as 68% of the rated capacity with the evaluated optimum excitation capacitance of 4 μF per phase. The reactive power of SEIG varies from 4400 VAR to 600 VAR from no-load to maximum load of 1377 W with a corresponding change in magnetizing current from 4 A to 0.64 A.

Keywords: Six phase; Multi-phase machines; Self excited induction generator; Excitation capacitance; Dynamic analysis; Renewable energy

1. Introduction

Self-excited induction generators (SEIGs) are known to be inherently rugged, compact, fault tolerant and maintenance free generators (Thomsen et al., 2014; Bansal, 2005). They are primarily deployed for electric power generation in standalone wind and mini/micro hydro based applications (Bansal, 2005). Off late they are also being explored for distributed generation in hybrid microgrids. High or multi-phase SEIGs combine the excellent attributes of high-phase (Levi et al., 2007; Levi, 2008; Singh, 2002) and SEIG technologies resulting in an extremely efficient and fault tolerant generating machine. As a consequence, the high phase SEIG research has evoked interest among the

* Corresponding author.
E-mail addresses: mfkhan.bp@amu.ac.in, mfaisal_khan@yahoo.com (M.F. Khan), mrkhan.ee@amu.ac.in (M.R. Khan), atif.iqbal@qu.edu.qa (A. Iqbal).
Peer review under the responsibility of Electronics Research Institute (ERI).

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jesit.2016.12.016
2314-7172/

Nomenclature

C_{ex} Per phase excitation capacitance, μF
$i_{dcap1,2}$, $i_{qcap1,2}$ d and q axes capacitor currents, A
$i_{Ld1,2}$, $i_{Lq1,2}$ d and q axes load currents of winding sets ABC and XYZ, A
i_{rd}, i_{rq} d and q axes rotor currents, A
$i_{sd1,2}$, $i_{sq1,2}$ d and q axes stator currents, A
I_L, I_s, I_m Load, stator and magnetizing currents, A
L_m Magnetizing inductance, H
L_{sl}, L_{rl}, L_{lm} Stator, rotor and inter winding leakage inductances, mH
P_o Active power
Q_c Reactive power
R_s, R_r, R_L Stator, rotor and load resistances, Ω
$v_{dcap1,2}$, $v_{qcap1,2}$ d and q axes instantaneous voltages across excitation capacitances of winding sets ABC(subsc_1) and XYZ(subsc_2) (volts), Wb
$V^0_{dcap1,2}$, $V^0_{qcap1,2}$ d and q axes voltages due to initial charge on excitation capacitances of ABC and XYZ winding sets, V
$V^0_{dcap1,2}$, $V^0_{qcap1,2}$ d and q axes voltages due to initial charge on excitation capacitances of ABC and XYZ winding sets, V
v^0_{rd}, v^0_{rq} d and q axes rotor induced voltages due to remnant flux, V
$V_{0dcap1,2}$ $V_{0qcap1,2}$ d and q axes voltages due to initial charge on excitation capacitances of ABC and XYZ winding sets, V
X_{ex} Reactance of excitation capacitance, Ω
Ψ_m Magnetizing flux, Wb
Ψ_{rd}, Ψ_{rq} d and q axes rotor flux, Wb
Ψ_{rd0}, Ψ_{rq0} d and q axes initial rotor flux, Wb
Ψ_{sd}, Ψ_{sq} d and q axes stator flux, Wb
ω_r Rotor electrical speed, rad/s

researchers in the recent past which has culminated in to gradual but steady progress in this field. However, available literature suggests limited modeling approaches implemented for high-phase SEIG analysis. Besides, an analysis that is missing from the existing literature is the estimation of dynamic machine parameters at no-load or under loading conditions. This paper proposes an alternate modeling approach for a six phase self-excited induction generator (6Ph-SEIG) to address above mentioned issues and to fill this gap in the realm of high-phase SEIG research. It also brings up some of the attributes of 6Ph-SEIGs compared to three phase variants to argue for increased deployment of high phase SEIGs.

One of the foremost dynamic models of a high phase order induction machine is available in Nelson and Krause (1974). The model of Nelson and Krause (1974) is developed through modular approach for *n* (multiple) sets of three phase windings each of which could be displaced from the other by any arbitrary angle between 0° to 60° with isolated or inter-connected neutrals. Subsequently, Klingshirn (1983a) laid out theory of different constructional aspects of multi-phase machines of up-to 18 phases with experimental verification presented in Klingshirn (1983b). Lipo (1980) has developed a model of dual stator winding induction machine for six phase application to devise a method for estimating slot mutual leakage inductance, L_{lm} which defines the mutual coupling between three phase winding sets. Detailed procedure of the evaluation of L_{lm} for a dual-stator induction machine is available in Tessarolo (2011). Zhao and Lipo (1995) proposes an alternate modeling approach for six-phase induction machines by formulating the problem through Vector Space Decomposition (VSD) technique.

On the basic premise of multi-phase induction machine modeling laid out in Nelson and Krause (1974), Klingshirn (1983a,b), Lipo (1980), Tessarolo (2011) and Zhao and Lipo (1995), a number of 6Ph-SEIG models have been developed (Duran et al., 2008; Singh et al., 2003, 2005, 2006; Singh, 2008; Ojo and Davidson, 2000a,b; Wang et al., 2009; Khan, 2015). In Duran et al. (2008) a VSD based 6Ph-SEIG model is presented for its performance optimization when driven

Please cite this article in press as: Khan, M.F., et al., Modeling, implementation and analysis of a high (six) phase self excited induction generator. J. Electr. Syst. Inform. Technol. (2017), http://dx.doi.org/10.1016/j.jesit.2016.12.016