International Conference on Renewable Energies and Power Quality (ICREPQ'18)
Salamanca (Spain), 21th to 23th March, 2018
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.16 April 2018

Speed Estimation of Induction Motor at Low and Zero Speed using High Frequency Signal Injection for Rotor Slot Harmonics Detection

S. Damkhi[1], M.S. Nait Said[2] and N. Nait Said[1]

[1] Department of Electrical Engineering
L.S.P.I.E., Batna University
Constantine Road – Fesdis, 05078 Batna (Algeria)
Phone/Fax number: +213 33 23 02 22, e-mail: sihemd@ymail.com, n_naitsaid@yahoo.com

[2] Faculty of Technology University of Batna 1, Chahid Boukhlouf street Mohamed el-Hadi, Banta 05000
medsnaitsaid@yahoo.fr

Abstract. Rotor position estimation based on high frequency signal injection method represents the interesting way to provide the high performances of the AC drives sensorless controlled at low or near zero speed range. So, this method requires the existence of saliencies inside the IM particularly the presence of the slots where their design constitutes the main advantageous to exploit its effect for rotor speed monitoring. First, the present paper exposes a model of the induction machine including slotting effects which it can be exploited in order to extract the harmonic saliency created by rotor slotting. Second, the high frequency signal injection method is used in order to allow tracking the characteristic harmonic saliency due to rotor slotting from which the rotor position and speed may be estimated. A High frequency voltage signal injection creates a high frequency current modulated by the saliencies presented inside the machine. To extract information about rotor position, the resulting stator current treads to heterodyning process to eliminate the disturbance components and subsequently the rotor position may be extracted by a closed-loop observer. Simulation results are shown in order to verify the validity of the proposal and to confirm the effectiveness of estimation method at zero frequency.

Key words

Induction Machine (IM), High Frequency (HF), Closed Loop Observer, Saliencies, Sensorless Control.

1. Introduction

Sensorless control techniques for AC machines that rely on the rated excitation frequency have been shown to be able providing high-performance control, e.g., field-oriented control and direct torque control, in the medium to high-speed range. However, as the speed decreases, the performance of these methods decreases and eventually be unsuccessful in very low-speed range and/or for dc excitation [1]. At zero frequency the sensorless speed operation may be only possible using signal injection methods. These methods are used to track spatial saliencies of the induction machine by the superimposing of HF signal on the stator voltage supply. Injecting the HF voltage to fundamental supply, the flux/rotor position can be determined by evaluating the current response. This current consists of two components where one of these components called negative sequence component is modulated by all spatial saliencies that are affecting the leakage inductance.

The sources of saliencies are diverse, such as the saturation of the machine by the main flux, induced saturation, modification in opening of rotor slots and slotting effects [2]. The use of slotting effects for rotor speed estimation is the best method because it is not dependent on the machine parameters and not created by modification in rotor design.

The combination between the model including the slotting effects and the use of high frequency voltage to track the rotor saliency defines the aim of the present paper. For control applications a proper modelling of induction machine including saliencies effects is very important. In literature several kinds of models can be found. Some of these kinds of models are based on finite element analysis proposed in [3],[4]. Also other models rewritten in space state form including a stator and rotor effects may be applied in the machine control applications, especially for speed sensorless induction machine control.

The proposal is focused on the estimation of rotor position using both slotting effects and high frequency signal injection. The slotting effects are introduced in induction machine (IM) model for making the machine has rotor saliency. HF signal injection voltage is employed to track harmonic saliency due to the slotting effects and after there the rotor position may be followed and tracked from the closed-loop-observer after some conform signal treatment processing.

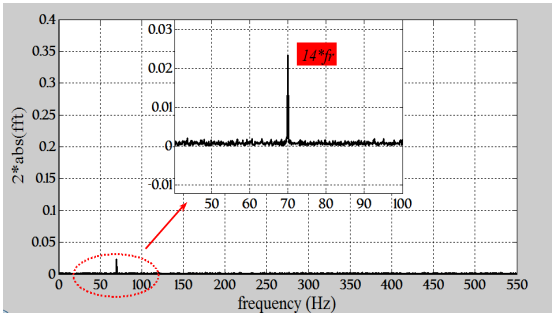

Fig. 8. Spectrum of signal position $I_{s\alpha-\theta_r}$

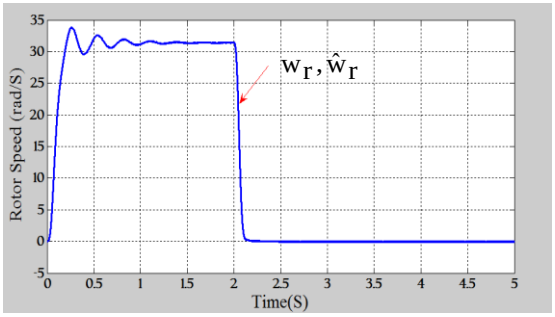

Fig. 9. Real and estimated rotor speed with HF signal injection

This additional harmonic has an influence on the trajectory of stator current which depicted in figure 7(a). However, the added signal has no detectable effect on the behaviour of rotor speed, as shown in figure 7(b), for the reason of rotor inertia filtered effect. The IM reacts to injected signal by a ripple appears in electromagnetic curve, see figure 7(c). As described in a previous section the HF injection able to track the rotor position located in stator current. This can be extracted by filtering the resulting stator current, as illustrated in figure 3. The spectrum of obtained signal position is shown in figure 8. From that figure it can be seen that there is only the harmonic located at $14 f_r$, this harmonic contains the rotor frequency information which will be extracted by tracking observer. Capability of tracking observer to estimate the rotor position confirms the effectiveness of estimation method at zero frequency using tests simulation. Going to zero speed estimation, the speed command has been changed from $31.4\,\mathrm{rad/S}$ to 0 rad/S as shown in figure 9. This test confirms that without rotor saliencies effect the zero speed estimation cannot obtain, this is considered as challenge in domain of robust speed estimation.

7. Conclusion

In this paper a new model including rotor slotting effects was proposed. This one might be suitable for some control applications. The rotor saliency produced by slotting effects has many advantageous than the other saliency which required the essential modification in machine design. For tracking the rotor saliency, the HF persistent voltage excitation is used. This excitation was superimposed to fundamental supply of induction machine. The interaction between the high frequency excitation and the saliency presented in the machine created a new additional harmonic appeared in measured stator current. This harmonic was useful for rotor speed estimation, after filtering the other undesirable harmonics. A tracking observer provides a simple and robust way to extract the rotor spatial information present in position signal. According to the presented simulations results, we can conclude that the proposed saliencies Park model was able to describe the rotor slotting effects in induction machine. Using introduced HF rotating voltage allows marking the tracking saliency due to the rotor slotting and therefore both speed and position of the rotor may be determined. Combination between the slotting effect and the use of HF signal injection makes injection makes the estimation method as very robust over a wide speed range including lower and zero speeds estimation, generally very difficult to obtain it by the analytical model methods.

Table I. – Induction Machine Data

MACHINE PARAMETERS	VALUE	MACHINE PARAMETERS	VALUE
Rated voltage	220/380 V	Speed and stator frequency	1485 rpm 50 Hz
Rated Power	4 kW	L_s	0.1568 H
Poles number	4	L_r	0.1568 H
R_s	1.2Ω	M	0.1500 H
R_r	1.8Ω	J	0.05 kgm^2
N_r	28	N_s	36

Acknowledgement

This research has been realized in cooperation of the University of Batna Department of Electrotechnical Engineering, Batna, Algeria, LSPIE Laboratory.

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