Rotating Field Voltage Analysis on the Stator and Rotor of the Inverted Rotor Induction Motor

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Abstract: Most of the induction motors are of the rotary type with basically a stationary stator and rotating rotor. In this study, an inverted rotor induction motor is designed and produced. This motor has mechanical revolving characteristics both rotor and stator. In this type of construction the rotor has three-phase winding as well, similar to the stator wound for the same number of poles as the stator winding. The wound-rotor winding terminates in slip rings mounted on the rotor shaft. Brushes ride on the slip rings. Also measurement coils are placed upper of the same slots of the stator and rotor windings of the inverted rotor induction motor. Regardless of the rotor construction employed, rotor currents in this motor are induced by the stator's changing, or rather, rotating, and magnetic fields. This induction action is the central operating principle of ac induction motors. Waveforms of the induced voltages on the rotor and stator windings are investigated. Rotating magnetic fields of the rotor and stator are measured by using these measurement coils. Experimental data have been evaluated at rotation fields of the rotor and stator by using measurement coils.

Key words: Inverted Rotor Induction Motor, Slip, Rotating Field, No-load operation, Blocked rotor operation, Power Quality, Harmonic Distortion

1. Introduction

This paper presents an original inverted rotor induction motor. In which combined special induction motor with mechanical revolving characteristic on the rotor and stator has been designed. It has been applied mechanical sensitive balance to the stator for revolving without any centrifugal force. This induction motor can be driven from stator or rotor. Waveforms of the induced voltages on the rotor and stator windings and harmonic analysis are investigated. Stator and rotor windings are wounded as two layers. Also measurement coils are placed in the same slots of the stator and rotor windings. Additional rotor rings are used for measurement coils connection to the rotor slots. Rotor measurement values could be recorded while induction motor is feeding from the stator windings. Thus, the effects of rotating fields between rotor and stator windings are investigated as experimentally.

2. Voltage variation analysis of the measurement coils on the inverted rotor induction motor

The inverted rotor induction motor has additional rotor rings. These rings are used to make connection for the rotor measurement coils. These coils have been used to investigate induced voltage on the rotor. Inverted rotor induction motor combination is used experimentally in this research is depicted in Fig.1

Fig.1 Inverted rotor induction motor construction

The terminals of the three stator phase windings are star connected. Stator winding is connected to a three- phase voltage supply; currents will flow in each phase of this winding. These voltages will be displaced from each other by 120^0, as shown in Fig.2

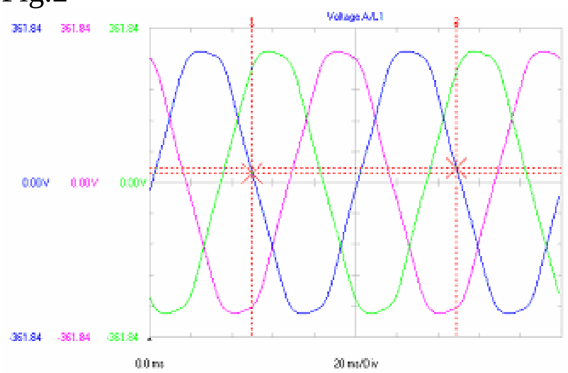

Fig.2 Three-phase voltages of the stator windings

The induce voltage equations of the magnetically coupled stator and rotor measurement circuits can be written as follows:

Stator voltage equation

$$V_s = R_s . I_s + j \frac{m_s}{2} . X_{2\delta} . I_s + E_s \qquad 1$$

Rotor voltage equation

$$E_r^{'} = \frac{R_r^{'}}{s} . I_r^{'} + j \frac{m_r}{2} . X_{r\delta}^{'} . I_r^{'} \qquad 2$$

The induce voltage equations of the magnetically coupled stator and rotor measurement circuits can be re-written by using rotor flux **(ϕ_r)** and stator flux **(ϕ_s)** terms as follows:

$$E_s = \frac{2\pi . f_s}{\sqrt{2}} . (k_s . k_d . k_f) . N_s (\Phi_s + \Phi_r) \qquad 3$$

The flux linkages of the stator and rotor windings may be written as

$$\Phi_s = \frac{m_s}{\sqrt{2}} . \mu_0 \left(\frac{k_s . k_d . k_f}{2.g} \right) . S_g . I_s \qquad 4$$

$$\Phi_r = \frac{m_r}{\sqrt{2}} . \mu_0 \left(\frac{k_r . k_d . k_f}{2.g} \right) . S_g . I_r \qquad 5$$

Note that these equations are described that the effects of the flux linkage and windings parameters on the fundamental component of each winding voltages. It can be seen that high order harmonics are occurred from the wave form analysis of the induction motor as a nonlinear load. Therefore, an induction motor has the potential for significant negative impact on utilities. Induction motors connected to the utility system, various national and international agencies have been considering limits on harmonic current injection to maintain good power quality. As a consequence, various standards and guidelines have been established that specify limits on the magnitudes of harmonic currents and harmonic voltage distortion. It is necessary to make standardization power quality and harmonics to pull down of the voltage harmonics to the certain level. Total harmonic distortion (THD) in the voltage can be calculated to that given by Eq. 6

$$THD_V = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V_1} = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + V_5^2 + \dots}}{V_1} \qquad 6$$

To quantify the distortion in the voltage waveform, a quantity called the total harmonic distortion is defined as Eq.7

$$\%THD_V = 100 \times {V_{dis}}/{V_{S1}} \qquad 7$$

Induced voltages, that caused by magnetic flux, have been investigated for no-load operation, load operation, blocked rotor operations of the inverted rotor induction motor. Measured values have been analyzed and evaluated.

3 Measurement circuits voltage analysis for no-load operation of the inverted rotor induction motor

Induced waveforms are recorded from the measurement coils are placed in same slots of the stator windings is given in Fig.3.

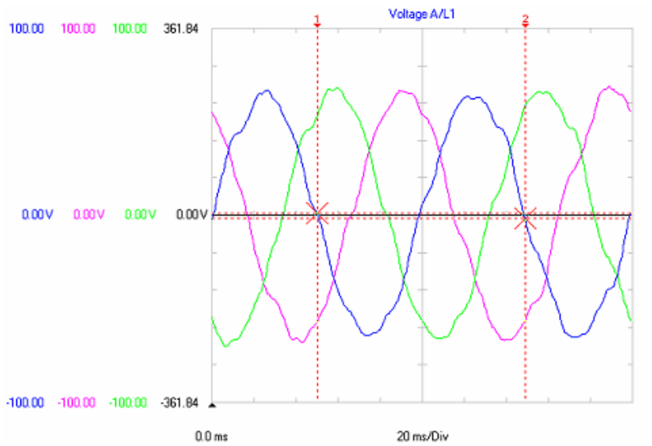

Fig.3 Induced waveforms from stator measurement coils for no-load operation

This waveform in Fig.3 is seen different than input waveform in Fig2. Harmonic spectrum of this waveform is given in Fig.4.

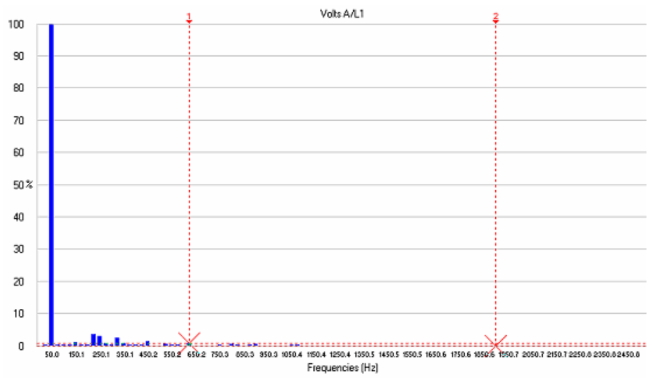

Fig.4 Harmonic spectrum of induced waveforms from stator measurement coils for no-load operation

This waveform on the measurement circuits results magnetic flux in the air gap. Rotor measurement windings induce the voltage by cutting this air gap flux. This induced wave form is given in Fig.5

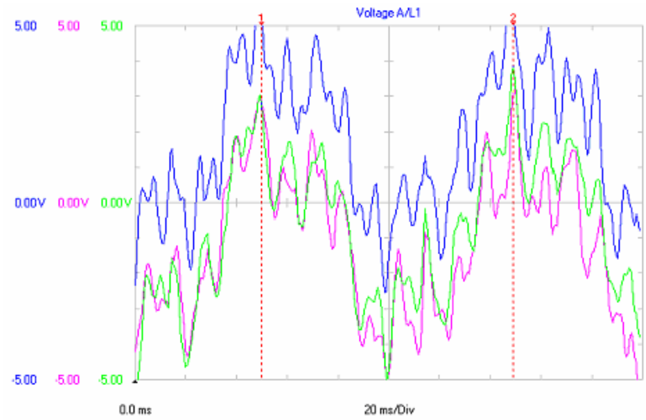

Fig. 5 Induced rotor voltage waveform of rotor measurement windings for no-load operation

The rotor revolves at very nearly the synchronous speed of the stator field during the no-load operation. The difference in speed is just sufficient to produce enough current in the rotor to overcome the mechanical and electrical losses. There must always be a difference in speed between the rotor and rotating field. This difference in speed is called slip and is expressed as a percentage of the synchronous speed. Slip value is measured (s = % 2) for no-load operation of the motor. Moreover, an induction motor has core losses, copper losses and rotational losses. Harmonic components of the voltage wave form of the air gap have been varied as odd components such as (n=3,5,7,..). Harmonic spectrum of this waveform is given in Fig.6.

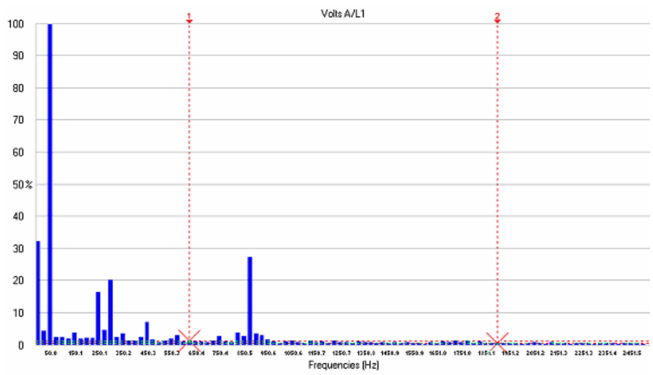

Fig. 6 Harmonic spectrum of induced rotor voltage waveform of rotor measurement windings for no-load operation

Harmonic spectrum of induced rotor voltage gives idea variations of the high order harmonics by taking into the consideration as a reference to the stator measurement coil. High order harmonics of the rotor voltage of the measurement coils are more than the stator voltage of the measurement coils.

Therefore, we should investigate the effect of the slip on these two voltage harmonics. For this reason, we should have done load operation and blocked rotor operations of this motor. Harmonic analysis is performed by using these experimental values.

3 Measurement circuits voltage analysis for load operation of the inverted rotor induction motor

Measured waveforms of the stator measuring circuit for load operation are given in Fig.7

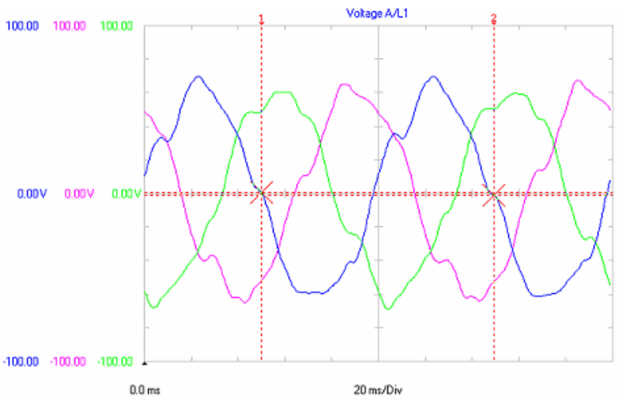

Fig.7 The waveforms of the stator measuring circuit for load operation

These wave forms are different than input wave forms. Harmonic spectrum of these waveforms shows the presence of the high order harmonics as seen in Fig.8.

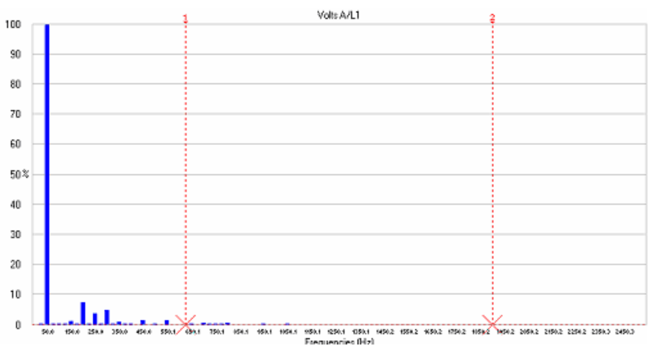

Fig. 8 Harmonic spectrum of induced waveforms from stator measurement coils for load operation

Induced rotor voltage waveform of the rotor measurement windings for the load operation is given in Fig.9.

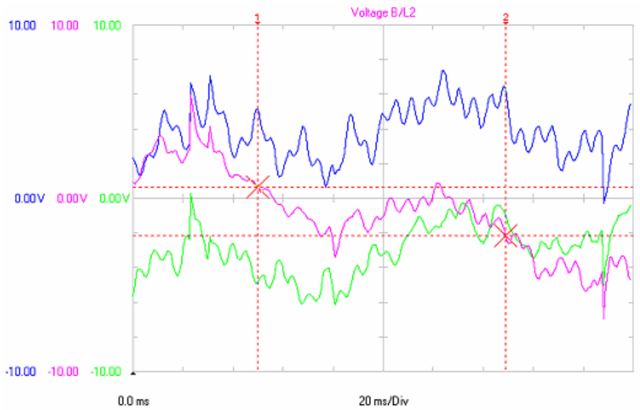

Fig.9 Induced rotor voltage waveform of the rotor measurement windings for the load operation

Slip value increased under the load operation of the motor. Slip value is measured (s = % 6) for load operation. In this case, losses on the stator and rotor circuits are increased. High order harmonic components of the rotor voltage are varied depend upon to the air-gap power. Harmonic analysis spectrum of this wave form is given in Fig.10.

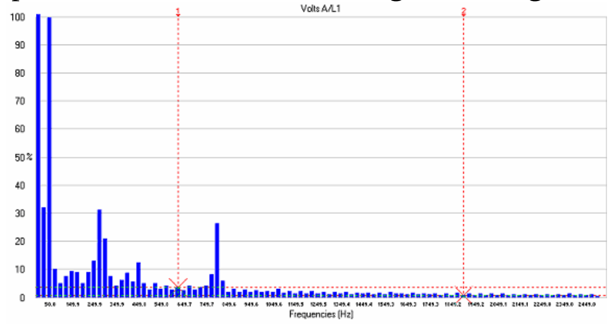

Fig. 10 Harmonic spectrum of induced rotor voltage waveform of rotor measurement windings for load operation

These variations are clarified how much changes occurs the high order harmonic variations of the rotor induce voltage under the load operation by taking into the consideration as a reference to the stator measurement coil. It has been seen many differences induced voltage waveforms of the induction motor between no-load and load operations.

5 Measurement circuits voltage analysis for the blocked rotor operation of the inverted rotor induction motor

Measured waveforms of the stator measuring circuit for the blocked rotor operation, such that the rotor is prevented from turning are given in Fig.11.

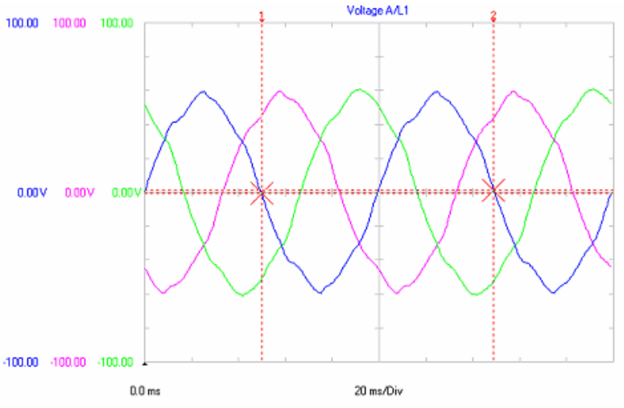

Fig. 11 The waveforms of the stator measuring circuit for the blocked rotor operation

The input waveforms of the blocked rotor operation are different than the no-load operation and load operation wave forms. Harmonic analysis of this waveform is given in Fig.12

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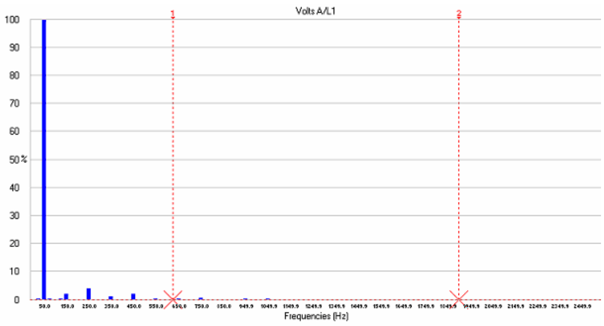

Fig.12 Harmonic spectrum of induced waveforms from stator measurement coils for the blocked rotor operation

Induced rotor voltage waveform of the rotor measurement windings for the blocked rotor operation is given in Fig.13

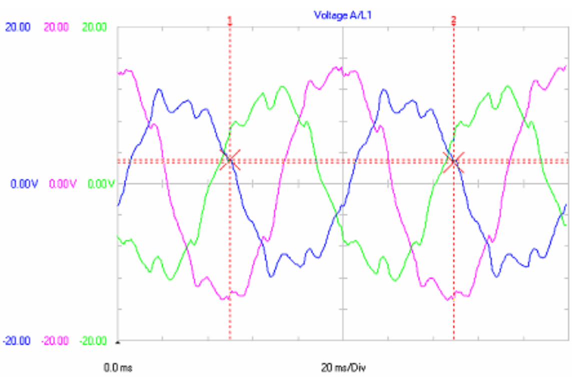

Fig. 13 Induced rotor voltage waveforms of the rotor measurement windings for the blocked rotor operation

Since rotor can not turn, n_r =o and slip s = 1 or 100% for the blocked rotor operation. This corresponds to the condition at start up and we would expect currents that are five to six times their rated value. For this reason, as with transformers during the short-circuit operation, that the applied stator voltage is reduced to such a voltage, permitting rated stator current to flow. Furthermore, at this greatly reduced input voltage, about 10 to 20 % of rated voltage. Induction motor runs like a transformer which has air-gap flux relatively small. Harmonic analysis spectrum of this wave form is given in Fig.14.

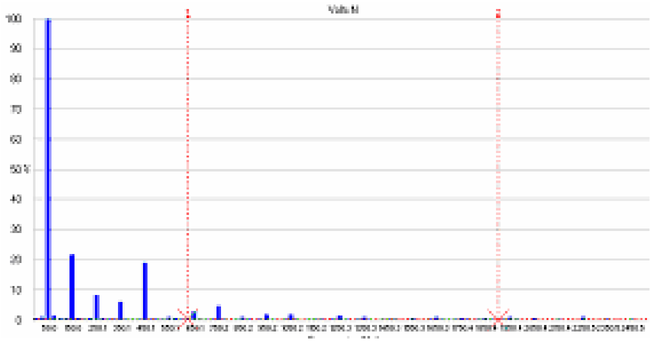

Fig. 14 Harmonic spectrum of induced rotor voltage waveform of rotor measurement windings for the blocked rotor operation

These variations are clarified how much changes occurs the high order harmonic variations of between rotor and stator induce voltages under the blocked rotor operation by taking into the consideration as a reference to the stator measurement coil.

It can be seen different induced waveforms, depends upon working type of the induction motor.

6. Conclusion

Induced voltages in the rotating field of the stator and rotor of the inverted rotor induction motor have been analyzed by performing no-load operation, load operation and the blocked rotor operations. As the measurement values implies, evaluations has to be proposed three different types. Although variations of the high order harmonics from no-load operation in the stator less than fundamental wave as seen in Fig.4; high order harmonics of the rotor voltage are increased as seen in Fig.6. Slip and rotating field effect to each other causes these harmonics.

It has been seen incremental variations of the high order harmonics respect to the fundamental wave as seen in Fig.7 from evaluation of the load operation. Increasing the difference between stator and rotor magnetic flux is caused increasing of the high order harmonics.

Since the slip s=1 in the blocked rotor operation, harmonic effect of the input waveform has been decreased as seen in Fig.11.

Experimental measurements and harmonic analysis have shown that slip causes increasing the high order harmonics of the induction motor as a nonlinear load. In this case, induction motors can be added to the inherent power line disturbances by distorting the utility waveform due to harmonic currents injected into the utility grid and producing electromagnetic interference. In addition to the voltage waveform distortion, some other problems due to the harmonic currents are as follows: additional heating and possibly over voltages (due to resonance conditions) in the utility's distribution and transmission equipment, errors in metering and malfunction of utility relays, interference with communication and control signals, and so on. Moreover to these problems, harmonics in the utility voltage waveforms result in a very poor power factor of operation. In conclusion, induction motors should be run as possible as in a condition of low slip value under the rated load.

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