A Novel Automated Stator Transient Inductance Measurement Algorithm For Induction Motor Drives

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ABSTRACT

Principals of high dynamic performance AC motor control algorithms are well known for many years. However they still suffer from the necessity of motor parameter identification. As accurately as the motor parameters are measured (estimated), the performance of control algorithm evaluates. This paper deals with identification of stator transient inductance at standstill during the self commissioning (auto tuning) stage of inverter fed induction motors. The novel identification procedure is well established and experimental results are also included.

1. INTRODUCTION

Complex but high dynamic performance induction motor control algorithms require precise measurement of motor parameters at standstill during startup. Most commercial induction motor drives have auto tuning property. During auto tuning period, short voltage pulses at desired wave shapes are applied to the stator windings, and the voltage and/or current response of the motor is measured [1]. Motor parameters are identified from the measured signals and the drive is ready to operate after auto tuning. Motor parameters are used in motor models, such as flux and speed estimation [2]. Current and flux controllers are also calculated by using motor parameters.

Speed sensorless vector control algorithms gained wide attention in the literature [3]. Stator transient inductance is used in particularly estimation of rotor flux vector in speed sensorless vector control algorithms utilizing voltage model. Stator transient inductance parameter is also used in determination of current and flux controllers [4]. Rotor flux oriented voltage model is based on the following equations:

$$\vec{\psi}_s = \int (\vec{U}_s - R_s \vec{I}_s) dt \qquad (1)$$

$$\vec{\psi}_r = \frac{L_r}{L_m} (\vec{\psi}_s - \sigma L_s \vec{I}_s) \qquad (2)$$

Here,

$\vec{\psi}_s$	Stator flux vector
$\vec{U}_s$	Stator voltage vector
$\vec{I}_s$	Stator current vector
R_s	Stator resistance
$\vec{\psi}_r$	Rotor flux vector
L_r	Rotor self inductance
L_m	Mutual Inductance
σL_s	Stator transient inductance

In this paper, a novel stator transient inductance measurement algorithm is presented. For this purpose, first; conventional stator transient inductance measurement procedure is described with its drawbacks. Secondly, the innovative method is given in details. Experimental results of the implemented offline stator transient inductance measurement technique are given. Finally; the advantages of innovative method are highlighted.

2. CONVENTIONAL METHOD

Stator transient inductance term refers to the motor inductance that is measured from the stator terminals and it is the parameter that is active in the transient states.

Conventional stator transient inductance measurement algorithm for induction motor drives at standstill is given below [5]:

In the stationary reference frame, stator voltage equation of induction motor may be written as given:

$$\vec{U}_s = R_s \vec{I}_s + L_s \frac{d\vec{I}_s}{dt} + L_m \frac{d\vec{I}_r'}{dt} \qquad (3)$$

If rotor current space vector is written by using rotor magnetizing current:

$$\vec{U}_s = R_s \vec{I}_s + \sigma L_s \frac{d\vec{I}_s}{dt} + (1-\sigma) L_s \frac{d\vec{I}_{mr}}{dt} \qquad (4)$$

by substituting $\vec{I}_{mr} = \vec{\psi}_r / L_m$ (5)

$$\vec{U}_s = R_s \vec{I}_s + \sigma L_s \frac{d\vec{I}_s}{dt} + \frac{(1-\sigma)Ls}{Lm} \frac{d\vec{\psi}_r}{dt} \qquad (6)$$

When the machine is de-energized and the initial flux is zero at standstill, if a voltage pulse is applied to stator phase windings; for the very short time duration the rate of change of flux for this small time interval is zero [6].

So, within the sub-transient region, induction motor is not different from series connected R-L load, and modeled with the equation given below:

$$\vec{U}_s = R_s \vec{I}_s + \sigma L_s \frac{d\vec{I}_s}{dt} \qquad (7)$$

If appropriate short voltage impulses are applied by the inverter itself which supplies the induction machine, during the very small time duration of current starts to rise from zero linearly. During this time interval current waveform equation is given by

$I_s(t) = (U_s / \sigma L_s)\, t$ (8)

and in very first beginning of current rise (so small time duration compared to stator transient time constant), inductance is dominant and resistance has no effect on current waveform. By this way, stator transient inductance could be measured from the current rise.

for t < Stator transient time constant

$\sigma L_s = (U_s / I_s)\, t$ (9)

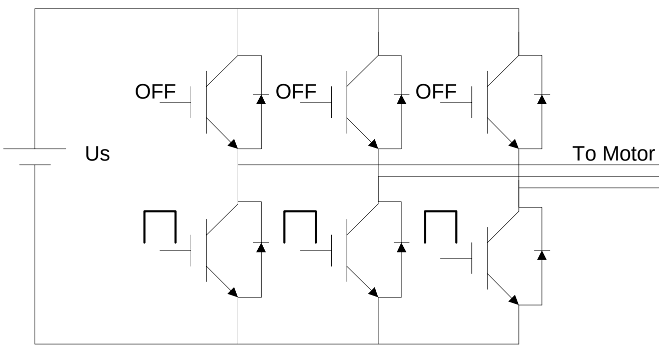
The method described above for measuring stator transient inductance is easy to implement but has some drawbacks in real life. First of all, while the machine is at standstill, no back emf is induced in stator windings and the DC link voltage is too big to apply to low resistance stator windings. So voltage impulse duration should be very small in order not to damage inverter semiconductor switches and even motor windings. Also; since leakage inductance parameters are related with current value, stator current value should not be exceeded rated value in order to implement accurate measurement. However a few microseconds time duration for measurement is so critical. Because any noise, and/or offset variation coming from sensors are multiplied by 10^6 in σL_s equation which affects the accuracy of the method. Finally; the method fails if the distance between motor and the inverter increases as the cable capacitance increases.

An innovative offline stator transient time constant and inductance measurement algorithm which overcomes the drawbacks of the conventional measurement method and has a better performance is given in detail below.

3. NOVEL STATOR TRANSIENT TIME CONSTANT MEASUREMENT

To overcome the disadvantages of impulse apply stator transient inductance measurement algorithm, a method developed in which the stator transient inductance is not measured from current rise but current decay.

In this method, at first rotor flux is built up by forcing dc voltage to stator windings. This is a standard procedure to measure stator resistance namely "DC Test" for self commissioning. After rotor flux is built up and measuring stator resistance during DC test, stator terminals are short circuited suddenly. This is done by turning on all the lower power switches connected to ground bus bar of the inverter.



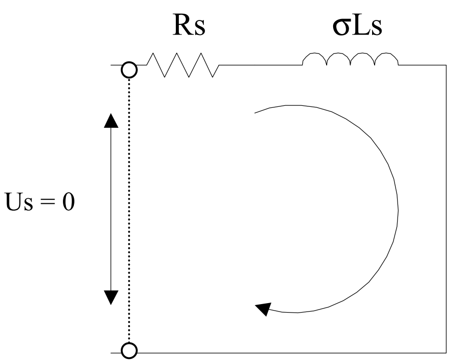
As soon as the stator terminals are short circuited, stator voltages reaches to zero. And the current decays at first very quickly and then after a predefined time duration, slowly to zero. During the first sub-transient region by using the stator voltage equation

$$\vec{U}_s = R_s \vec{I}_s + \sigma L_s \frac{d\vec{I}_s}{dt} + \frac{(1-\sigma)Ls}{Lm}\frac{d\vec{\psi}_r}{dt} \qquad (10)$$

since rotor flux variation is negligibly small, it yields:

$$\vec{U}_s = R_s \vec{I}_s + \sigma L_s \frac{d\vec{I}_s}{dt} \qquad (11)$$

And under this conditions induction machine is modeled as given in Figure below:



As soon as the rotor flux changes, rotor circuit should be included to the equivalent circuit. But for approximately stator transient time constant duration, current follows the trajectory determined by stator resistance and transient inductance. In the sub-transient region, stator phase current decays from initial dc value to a lower value with a very high rate of decrease. The current response of the stator phases in sub-transient region may be modeled as:

$$Is(t) = I_{s0}\, e^{-t/\tau} \qquad (12)$$

So τ time constant is equal to

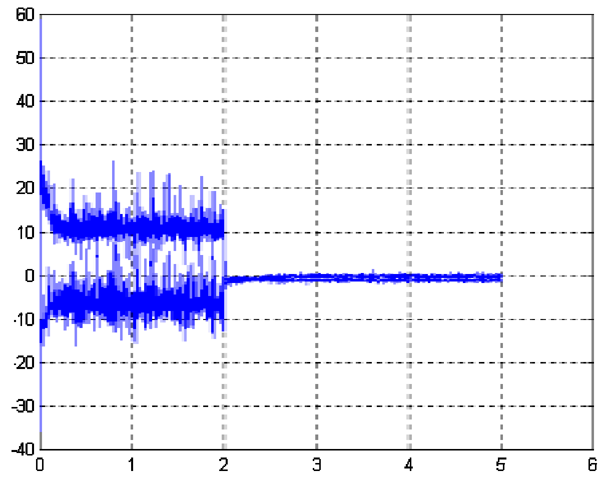
$$\tau = \frac{\sigma Ls}{Rs} \qquad (13)$$

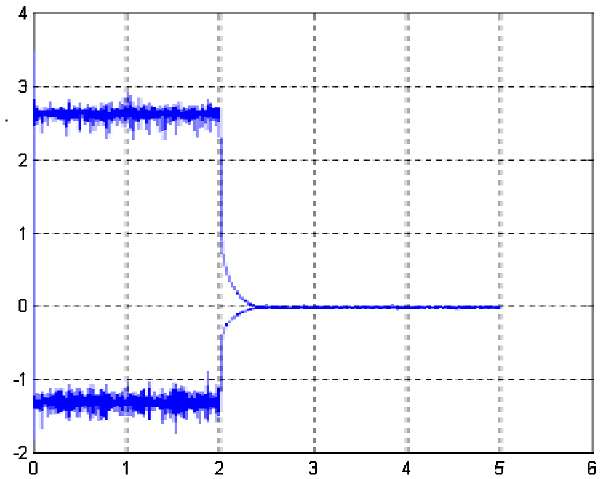
After finding stator transient time constant, since stator resistance was measured from DC test, stator transient inductance is found as:

$$\sigma Ls = \tau * Rs \qquad (14)$$

4. EXPERIMENTAL RESULTS

The novel automated offline stator transient inductance measurement algorithm is implemented on a TMS320C3150 DSP controller board based IGBT inverter which is operated at speed sensorless FOC (Field Oriented Control) using voltage model. Control cycle is 100 micro seconds.





In Figure-3, star connected induction motor stator phase voltages are shown during the implemented automated stator transient inductance measurement algorithm.

Method starts by forcing a dc voltage to stator windings in order to built up rotor flux. After rotor flux is built up, stator resistance is measured with DC test. And suddenly, stator phases are short circuited by turning on all lower switches of the inverter where turning off all upper switches. As soon as stator phase windings are short circuited, phase voltages suddenly reaches to zero at t = 2 s. At this instant current starts to decay with a high slope. From the start of decay, for approximately 5 ms. current decreases linearly. Stator phase current decreases from initial dc value to a lower value with a very high rate of decrease as may be seen from Figure-5. The current response of the stator phases in sub-transient region may be modeled as:

$$Is(t) = I_{s0}\, e^{-t/\tau} \qquad (12)$$

At t = 2 ms by substituting variables:

$$1.85 = 2.7\, e^{-0.002/\tau}$$

$$e^{-0.002/\tau} = 0.685$$

$$\frac{-0.002}{\tau} = -0.378$$

$$\tau = 5.29 * 10^{-3}$$

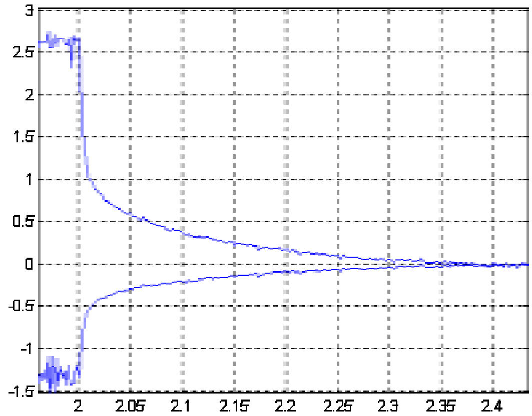
Current trajectory may be divided into two regions according to rotor flux variation and in the first region since rotor flux variation is negligibly small time constant τ, is calculated by using equation given before:

$$\sigma Ls = \tau * Rs \qquad (14)$$

By substituting stator resistance which is measured from dc test; (Rs=4.8) value, into the time constant equation, stator transient inductance is found to be as:

$$\sigma L_s = 0.02539$$

is measured as 25 mH during locked-rotor test.



5. ADVANTAGES OF NOVEL ALGORITHM

Advantages of the novel stator transient inductance measurement algorithm is given below:

- First of all it is easily ready to implement by all commercial induction motor drives during self commissioning stage. It may be easily included after offline stator resistance measurement algorithm DC test.

- Conventional stator transient time constant measurement algorithm requires to disable PWM generator and the inverter is driven from a binary port. However the novel method is implemented by using PWM generator [6].

- Measured current response is a noise free signal which makes the accuracy better than the conventional method and easy to implement.

- There may be at least tens of measurements until the rotor flux variation is effective, compared to conventional method which utilizes only one measurement.

- Initial dc current value may be easily predetermined and set by PWM generator and current controllers.

- So no damage risk for inverter and motor.

- Holtz’s rotor time constant measurement algorithm may easily be utilized within the current decay after rotor flux variation.

- It is less sensitive to distance between motor and inverter because it takes more than a few mili seconds to measurement.

- The conventional method is very sensitive to the position of the shaft namely the position of rotor bars. However novel method is less sensitive to the position of rotor bars.

- The novel measurement algorithm is carried over at desired (rated) flux which makes the accuracy higher than the conventional one. Although saturation has negligible effect on leakage inductance but it is so for mutual inductance which is a component of stator transient inductance [7].

5. CONCLUSIONS

Self commissioning concepts and methods were developed and well known for years. However precise measurement of motor parameters is still developing in order to increase the performance of the motor drive. In this paper, a novel automated self commissioning algorithm for stator transient inductance measurement is developed. The developed algorithm has many advantages over the conventional one. Novel algorithm is given in details and experimental results showing validity of method are also included. Novel algorithm may easily be adapted to commercial drives.

Motor Rated Values:
Δ / Y   220/380 V
4.7/2.7 A
1 kW. Cos Ø = 0.76
2830 rpm. 50 Hz.

REFERENCES

[1] Lin, Y. , Chen, C. , Automatic IM Parameter Measurement Under Sensorless Field-Oriented Control, IEEE Transactions on Industrial Electronics Vol 46 No 1 February 1999

[2] Akın, E. , “Stator Alan Akısı Üzerinden Asenkron Motorun Rotor Akısı Yönlendirmesi İçin Bir Yöntem”, Doktora Tezi, Fırat Üniversitesi, 1994

[3] Bose, B. , Patel, N. , Quasy-Fuzzy Estimation of Stator Resistance Estimation of Induction Motor, IEEE Trans On Power Electronics, Vol. 13, No. 3, May 1998, pp 401-409.

[4] Lai, Y. , Chang, Y. , “Design and Implementation of Vector Controlled Induction Motor Drives Using Random Switching Technique with Constant Sampling Frequency” IEEE Transactions on Power Electronics, Vol. 16, No. 3 May 2001.

[5] Vas, P. , “Parameter Estimation, Condition Monitoring, and Diagnosis of Electrical Machines”, Clarendon Press, Oxford,1993.

[6] Khambadkone, A. M. , Holtz, J. , “ Vector Controlled Induction Motor Drive With a Self Commissioning Scheme”, IEEE Transactions on Industrial Electronics Vol 38 No 5 October 1991

[7] Klaes, N.R. , “Parameter Identification Of An Induction Machine With Regard To Dependencies On Saturation”, IEEE Transactions On Industry Applications, Vol.29, No.6, November/December 1993.