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Effect of Equal Current Increment for Computation of Flux Linkage Characteristics on Performance of S R Motor

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Abstract: The data of look-up table of flux linkage characteristics is an obligatory requirement for predicting the performance of switched reluctance (SR) motor. This data is obtained through the experiments on an existing machine under locked rotor test. This paper analyses the effect of selection of an equal current increment for the computation of intermediate data points of flux linkage characteristics with respect to rotor position on phase instantaneous current of the drive. The need of intermediate data points is of worth importance if experimental data points are not available. The resulting effect can also be observed from the copper loss at each equal current increment. The findings of the paper are helpful for developing an improved and accurate simulation model of the machine.

KeyWords: Magnetization Characteristics, Single pulse, Current chopping, voltage PWM, Switched Reluctance Motor, interpolation

1. INTRODUCTION

Switched reluctance motor is getting attraction in different applications due to its' simple structure and good performance over the wide range of speed. Rotation in the motor is produced by magnetic pull of energized stator pole to its' nearest rotor pole (Miller, 2001).

The switched reluctance motor operates in three possible modes i.e. single pulse mode, current chopping mode and voltage pulse width modulation mode separately. The motor phases receive electronically controlled voltage pulses through a converter via switching devices. The switching devices in a converter remain in 'ON' state for the duration of the voltage pulse applied to their base –emitter terminals. Current in the particular energized phase starts increasing due to minimum inductance, and motor winding see positive voltage. Further that as the inductance and motional E.M.F start rising, the current in response to that rise starts decaying until the switch is opened at switch-off position. In this case winding sees negative voltage (Lawrenson, *et al.*, 1980).

The above mode of operation is called a single pulse. The motor control during the single pulse mode operation is performed by either switch-on or switch-off angle, or applied voltage (Corda and Olaca, 1993). The current chopping mode is applicable when motor speed is relatively low. In this condition the phase current needs to be controlled; this can be achieved by limiting it at pre-defined set level of current (Corda and Olaca, 1993) i.e. current chopping. In voltage PWM (pulse width modulation) mode the phase current of motor can be controlled by on/off-switching of the switching devices used in the converter (Corda and Olaca, 1993). For purpose of an illustration **(Fig.1)** shows instantaneous current waveforms in three possible modes of the drive.

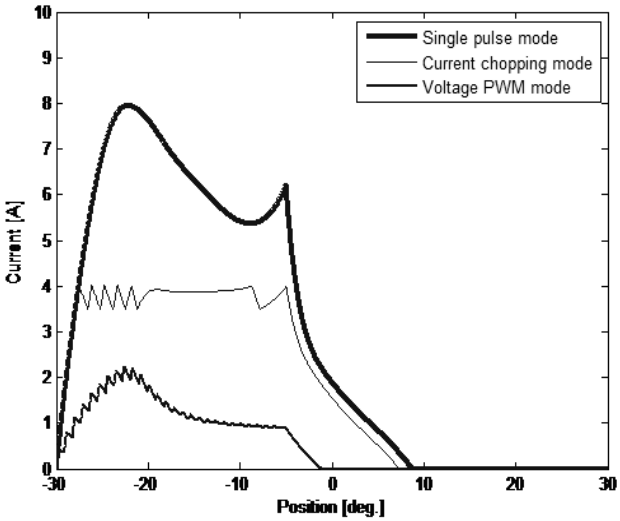


Fig.1. Instantaneous current waveforms in different modes of the motor

For the computation of instantaneous and steady state performance of the machine, the input data of static characteristics that include flux linkage characteristics $\psi(\theta, i)$, co energy characteristics $W'(\theta, i)$ and static torque characteristics $T(\theta, i)$are required (Lawrenson, *et al.*, 1980). Appreciable efforts have been put in order to predict the performance of motor with a suitable and an improved model. Literature

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review discloses different approaches to obtain the data of flux linkage characteristics through the experiments e.g. by help of flux meter (Jones, 1967), using integrator (Corda, 1979) and through LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) (Corda and Jamil, 2010), (Cheok and Ertugrul, 2001). Co energy is area under the flux linkage curves. The static torque can be calculated from the data of co energy that uses the data of flux linkage characteristics.

In order to achieve this best data fit technique has always been selected to suit the predicted results with those obtained from the experiments. Bi-cubic spline interpolation (Charles, 1967), a chain series curve fitting (Chan, *et al.*, 1997) and piecewise parametric Hermite cubic spline with combination of Fourier series (Cao and Tseng, 198) are used to find intermediate points of flux linkage characteristics. After all, probably less attention have been paid to what is the effect of an equal current increment to calculate intermediate data points of flux linkage characteristics for range of rotor position of the motor if data from experiments is not available.

2. MATERIAL AND METHODS

Experiments

(a) Measurement of flux linkage characteristics

The purpose-built set up for the measurement of flux linkage characteristics is shown in **(Fig.2)** (Corda and Jamil, 2010), The data of current and induced E.M.F is captured by using shunt resistor and voltage probe, and stored by data storage oscilloscope respectively. The captured data of induced E.M.F is integrated to get flux linkage curves shown in **(Figs. 3 (a) and 3 (b))** at different rotor positions for range of the current.

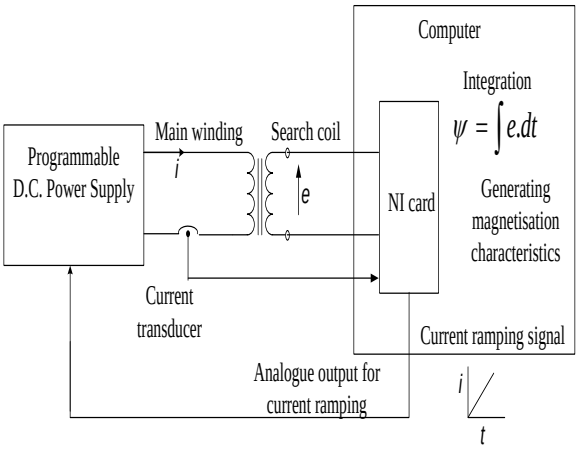


Fig.2. The purpose-built set up for the measurement of flux linkage characteristics (*Corda and Jamil, 2010*)

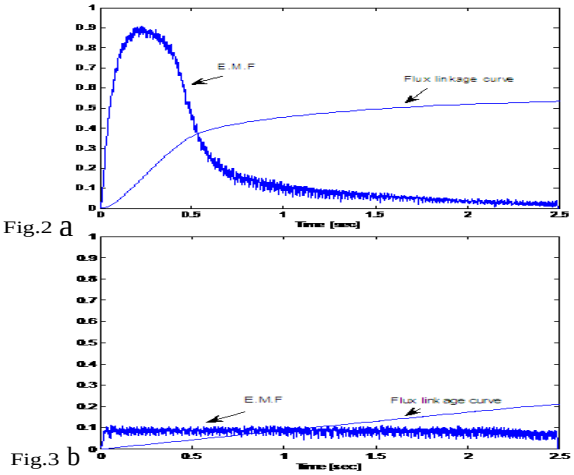


Fig.3 (a). Measured E.M.F and calculated flux linkage curve at rotor position (3^0) (Memon, 2012).

(b). Measured E.M.F and calculated flux linkage curve at rotor position (-27^0) (Memon, 2012).

The set of measured flux linkage characteristics for range of current at different rotor position is shown in the **(Figs.4 (a) and 4 (b))**. Rotor position indicated as (-30^0) is produced when rotor departs away from the energized stator pole i.e. unaligned position. In this position inductance is minimized and reluctance is maximized (Lawrenson, *et al.*, 1980). Similarly, rotor position (0^0) designates for aligned position where inductance is maximized, reluctance is minimized and the rotor poles are fully covered with the stator poles.

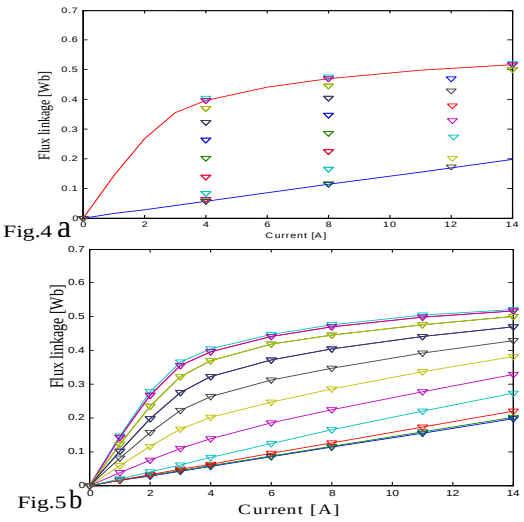


Fig.4 (a). Measured flux linkage characteristics (upper curve for aligned rotor position, 0^0 and lower for unaligned position -30^0) (Memon, 2012).

(b). Measured flux linkage characteristics at different rotor position for range of current (*Memon, 2012*).

(b) Instantaneous current waveforms

The experiment is performed on an existing 8/6 pole switched reluctance machine operating in ingle pulse mode. The operating parameters are:
Switch-on angle = -36.95^0, switch-off angle = -6.95^0, conduction angle = 30^0, R = 3.57 [Ω], T_{sh}= 4.8 [Nm], Speed = 1915 rpm.

The data of current waveforms in four phases of the drive was captured by four channel data storage oscilloscope. The copper loss is calculated from the captured data of instantaneous current waveforms of four phases by using relation

$$P_{cu} = 4I_{rms\,(ph)}^2 R \qquad (1)$$

For the experimental results shown in **(Fig. 5)**, the calculated average copper loss is 300 W.

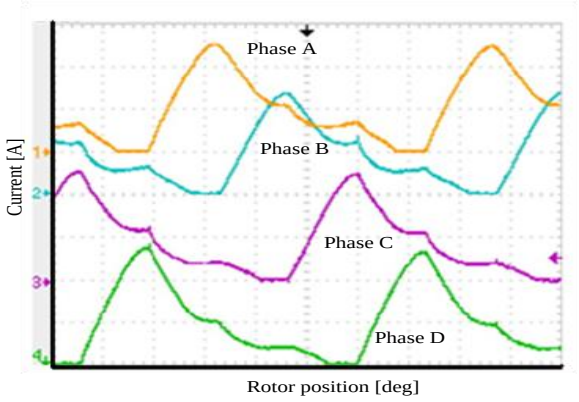


Fig.5. Oscilloscope traces of current (scale: 4 a/ div) waveforms for four phase SR machine.

(c) Problem Statement And Solution

(Fig.4 (a)) shows the experimentally measured data of flux linkage characteristics for the current ranging from 0A to 14 A at interval (equally spaced) of 4 A at different rotor positions. In this case, the intermediate data points of flux linkage are required for the same range of current at equal current increments. If this current increment selected as 1 A, 1.5 A, 2 A 2.5 A and 3 A separately, the effect of such a selection on computation of instantaneous phase current waveform is needed to be carefully investigated. On the other hand in **(Fig.4 (b))** the measured data points of flux linkage characteristics are closely taken as compared to **(Fig.4 (a))**. In this case the required intermediate data points of flux will be chosen precisely small. And hence the error will also be not significant.

This paper mainly focuses towards the selection of appropriate step of the equal current increment to determine the intermediate data points of expanded flux linkage data for different rotor position. This issue is significant when experimentally obtained data points are not closely available. Although data interpolation techniques are equally important in order to suit the experimental results. In this research we have examined the effect of selecting equally spaced current on the simulation results of instantaneous phase current under single pulse mode of the operation of drive. Furthermore, resulting effect of the selection of each current step on the phase current waveform and hence copper loss variation have also been investigated. Flow of stator current in the motor is given by the equation

$$v = Ri + \frac{d\Psi}{dt} \qquad (2)$$

where v is the applied voltage, R represents the winding resistance and ψ is used for the flux linking the coil.

3. RESULTS AND DISCUSSION

The simulation results shown in **(Fig. 6)** are produced under same operating conditions for which the experimentally obtained current waveforms were recorded **(Fig. 5).**

The effect of selecting equal current increment for the computation of expanded flux linkage data is seen from the resulting distortion of the current waveforms **(Fig.6).** This distortion causes the variation of the copper loss. This is shown in **(Table1).**

Table 1. Current increment and calculated copper loss from resulting current waveforms.

Current increment [A]	Copper loss [W]
1	300
1.5	300.4
2	305
2.5	315

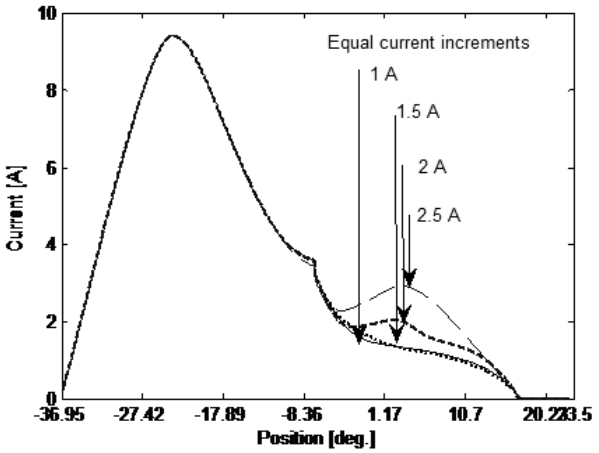


Fig.6. Predicted traces of current waveform for one phase of SR machine.

If the switch-on angle is delayed as compared to switch-on angle for which results are shown in (**Fig. 6).** The example shown in **(Fig.7)** shows the trend of variation of the instantaneous phase current, instantaneous torque and flux waveforms with different equal current increments.

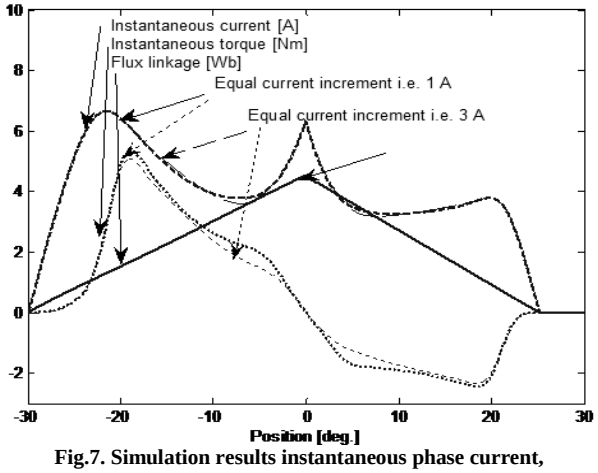


Fig.7. Simulation results instantaneous phase current, instantaneous torque and flux waveforms

4. CONCLUSIONS

An important issue of equal current increment for finding out intermediate points to compute flux linkage characteristic for range of rotor position has been discussed.

The experimentally obtained current waveforms are compared with predicted results from the model which uses the data of flux linkage characteristics. It is detectable from the predicted results that for the current increment i.e. 1 A, the current waveform under same operating conditions is fairly same as obtained through experiment. If current increment increases the distortion in the current waveform and their effect on copper loss also increase. From these findings it is recommended that measured data of flux linkage should be taken as close as possible to avoid any error. Otherwise, equally spaced current increment in the simulation model may be selected as small to minimize the discrepancy.

REFERENCES:

Corda. J and S. M. Jamil. (2010) "Experimental determination of equivalent-circuit parameters of a tubular switched reluctance machine with solid-steel magnetic core," Industrial Electronics, IEEE Transactions, Vol. **(57)**: No.1, 304-310.

Cheok. A. D and N. Ertugrul. (2001)"Computer-based automated test measurement system for determining magnetization characteristics of switched reluctance motors," Instrumentation and Measurement, IEEE Transactions, Vol. **(50)**: No. 3, 690-696.

Cao. S., and K. J. Tseng. (1998) "A new method for accurate analytical modeling of switched reluctance motor," Power Electronic Drives and Energy Systems for Industrial Growth, Proceedings. International Conference, Vol. **(2):** 540- 545.

Charles V. and K. Jones, (1967) "The Unified theory of Electrical Machines". London, Butterworth's.

Corda. J and M. Olaca (1993) "Analysis of losses in power electronic converter of SR drives," Power Electronics and Applications, Fifth European Conference, Vol. **(6)**: 49-53. Brighton, UK.

Corda. J. (1979) 'Switched Reluctance Machine as a Variable-Speed Drive'.PhD thesis, University of Leeds (School of Electronic and Electrical Engineering), Leeds, UK.

Lawrenson. P. J, J. M. Stephenson. P. T, Blenkinsop. J. Corda. and N.N. Fulton. (1980) "Variable-speed switched reluctance motors," Electric Power Applications, IEE Proceedings B, Vol. **(127)**: No. 4. 253-265.

Moreira, J. C. (1992) "Torque ripple minimization in switched reluctance motors via bi-cubic spline interpolation," Power Electronics Specialists Conference, PESC'92 Record.23rd Annual IEEE, Vol. **(2)**: 851-856. Toledo.

Memon A.A, (2012) "Prediction of compound losses in a switched reluctance machine and inverter'', PhD thesis, University of Leeds (School of Electronic and Electrical Engineering), Leeds, UK.

Wei Min C., and W. F. Weldon. (1997) "Development of a simple nonlinear switched reluctance motor model using measured flux linkage data and curve fit," Industry Applications Conference, Thirty-Second IAS Annual Meeting, IAS '97, Conference Record of the 1997 IEEE , Vol. **(1):** 318-325. New Orleans.

Miller. T. J. E, (2001) "Electronic Control of Switched Reluctance Motors", Newness Power Engineering Series, Oxford, UK.