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Control of Resistance Estimation of Switched Reluctance Motor

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ABSTRACT: *Control of a Switch Reluctance (SRM) Motor is one of the tasks addressed now. Novel approaches utilize a Magnetic Flux Estimator. The determination of the SR motor phase resistance is then one of the key factors in determining accurate position estimation, hence improving the efficiency of the drive and smoothing the torque ripple of the motor. This paper presents an on-fly phase resistance estimation which addresses the problem of the phase resistance drift. Necessary theory and computer simulation results are shown in order to highlight the effect of the phase resistance drift and to explain the principles of the presented technique. It also shows that the on-fly phase resistance estimation of an (SRM) motor requires neither additional sensors nor excessive computational power, making it applicable to today's systems.*

Keywords: *Switch Reluctance, Magnetic Flux Estimator, on-fly phase resistance estimation.*

1. INTRODUCTION

Now (SRM) motors are more and more popular in new applications. Typically the SR motor requires position feedback for motor phase commutation. In many cases, this is addressed by using some position sensors like encoders, motion sensors. Traditionally, developers of motion control products attempt to lower the system costs by reducing the number of sensors. A variety of algorithms for senseless control have been developed, most of which involve the variation of some magnetic circuit parameters on the rotor position.

2. PHASE WINDING RESISTANCE AS A KEY PROBLEM

Novel approaches use an estimate of the flux linkage and a set of magnetic characteristics to determine the angle of the rotor position. All these techniques then require accurate magnetic flux estimation in order to guarantee usable precision for the position estimation. If the position is not estimated correctly the behavior of the Switched Reluctance Motor (SRM) deteriorates, because the control cannot be kept at the optimal point. One of the most important factors of the magnetic flux estimation is the resistance of the phase winding. This resistance(R) strongly depends on the temperature. During a motor operation, the variation of the resistance can be more than (25%) of the nominal value. This variation causes an inaccurate estimation of the flux linkage, hence generates position estimation errors. Because the effect of the phase resistance drift is significant at low and middle speed ranges, the senseless techniques based on such simple magnetic flux estimations do not give satisfactory results. Therefore, for an accurate and robust algorithm for senseless control, the actual value of the winding resistance must be accurately measured or estimated. The flux linkage estimator calculates the flux linkage using the following formula (see [2]).

$$u = R.i + \frac{d\psi}{dt} \quad (1)$$

$$\psi_{Est} = \int_{t1}^{t} (uR^{*}.i)dt \quad (2)$$

$$R^{*} = R + \Delta R \quad (3)$$

Where:

u - is the voltage applied to the motor phase (coil) winding?

i - is the phase current.

R* - is the assumed phase winding resistance.

R - is the actual phase winding resistance.

R - is the resistance error caused by temperature drift, inaccurately.

Obtained value.

Ψ - is the phase flux linkage.

Ψ_{Est} - is the estimated phase flux linkage.

t1 - is time when motor phase winding starts to be energized.

Fig (1) illustrates the flux linkage waveforms calculated by the estimator during a typical working cycle of one phase of a SR Motor. The shape is defined by the control strategy, the rotor position and the magnetization characteristic (see [1], [3]). The individual waveforms have been generated for different resistance errors R**.** Because the flux estimation is a result of integration (see (Eq. 2.)), the total flux estimation error at the end of the working cycle is quite significant. It can be seen that the resistance error can cause a position estimation error of several electrical degrees.

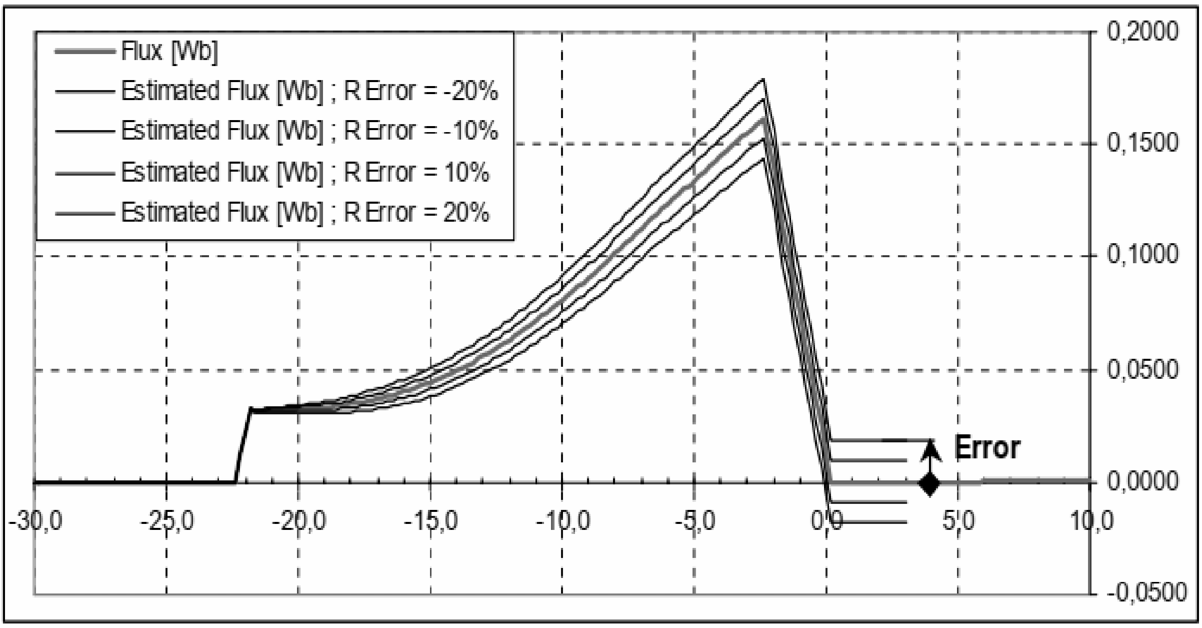

Fig.1. a typical waveform of the actual flux and the estimated flux as a function of the rotor position for a set of assumed phase resistances.

3. ON-FLY RESISTANCE ESTIMATION

As described in the previous section, the determination of the phase resistance determination is the key for an accurate position estimation of the (SRM) algorithm. Therefore the main focus was put on the development of a simple and robust phase resistance estimation algorithm, which can be easily incorporated into the system and which does not significantly increase the need for computing power of the drive controller. Fig. (2) Shows the block diagram of the system approach.

As can be seen, the system incorporates:

- Magnetic Flux Estimator.
- Phase Current Integrator.
- Phase Resistance Estimator

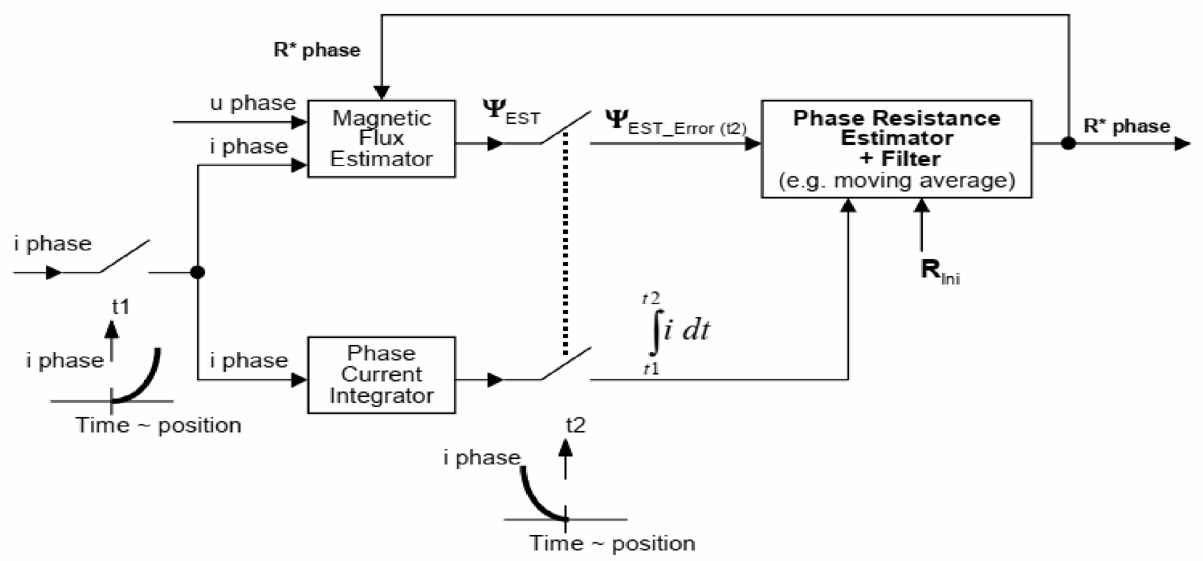

Fig.2. Resistance Estimation Algorithm

While the Magnetic Flux Estimator can be found in number of novel sensor less techniques the Phase Current Integrator and Phase Resistance Estimator are unique blocks. The system does not require any additional input signal (sensor). It uses standard phase current and voltage sensing.

1. The algorithm system operates in the following way: At time when the motor phase starts to be powered (t1) the Magnetic Flux Estimator starts to estimate the magnetic flux using the initial value of the phase resistance.
2. After the motor phase is no longer powered, the phase current falls to zero (t 2). Because of the resistance error, the estimated flux value at time t2 is the flux estimated error. This error is further processed by a Phase Resistance Estimator (see Fig. 2.). The estimated phase resistance value can be filtered using a (PI) or a moving average filters or processed in another way in order to eliminate external disturbances as well as measurement and calculation errors.
3. The obtained estimated value of the phase resistance is fed back to the Magnetic Flux Estimator. This assures that the estimated flux is equal or close to the real value.
4. As a result of this closed loop system, the estimated phase resistance tracks the actual phase resistance and eliminates the influence of the phase resistance drift. The presented solution of the Phase Resistance Estimator is based on the fact that if the phase current is zero then the magnetic flux must be zero as well. Because the SR motors are driven in way in which the motor phases are energized sequentially, the phase current rises from zero at the beginning of the cycle (t1) and falls back down to zero again at the end of the cycle (t 2). This fact enables one to calculate the flux estimation error at the time point (t 2), using the following formula.

$$\Psi_{EstErr}(t_2) = \int_{t1}^{t2} R^{*}.idt \qquad (4)$$

Let's assume that the rate of change of the phase resistance is small (this is valid for the temperature drift.

$$\frac{\Delta R}{t_2 t_1} \cong 0 \qquad (5)$$

Using the above assumption, the resistance error can be expressed.

$$\Delta R = \frac{\Psi_{EstErr}(t_2)}{\int_{t_1}^{t_2} idt} \qquad (6)$$

The Phase Resistance Estimator can also provide an estimation of the whole power circuit resistance, thus reflecting the given power stage topology (see (Fig. (3)). While this is not an issue for high voltage systems (the voltage drop on the power devices is negligible), it is more sensitive for the low voltage systems.

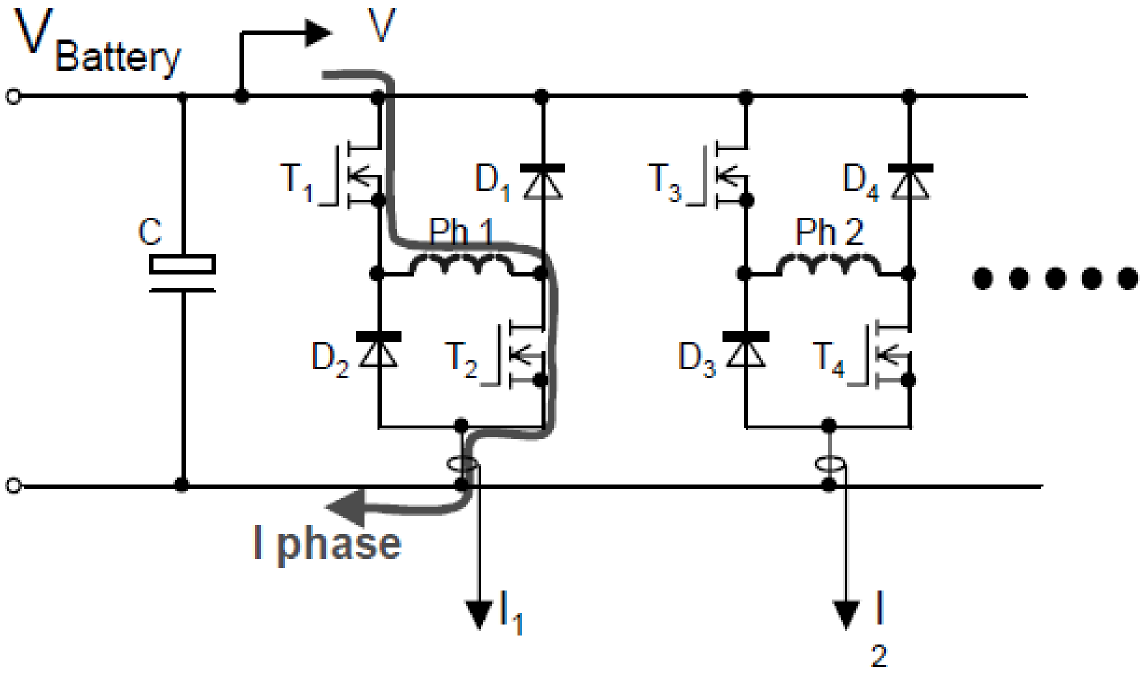

Fig.3.TheTotel Circuit Resistance Estimation

Then the Magnetic Flux Estimator utilizes the following equation instead of (Eq. 2.):

Where:

U_{Drop} - is the voltage drop on all elements which are in series with the motor resistance

R_{totel} - is the estimated resistance as a total serial resistance of the current path (e.g. including the power devices - RdsON).

Using this new approach, the estimation error at the middle and lower speeds is below 1%, which Significantly improves the position estimation, hence the efficiency of the Switched Reluctance Motor drive, smooth's the torque ripple of the motor and decreases its acoustic noise.

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4. CONCLUSION

In the paper a novel phase resistance estimation algorithm for Switched Reluctance Motors was presented. The algorithm enhances the existing Magnetic Flux Estimator by providing a cycle by cycle tracking of the value of the phase resistance of the motor. The implementation of the presented Phase Resistance Estimator can be easy to incorporate into the existing algorithms for Sensorless SRM control. Standard mathematical calculations are used, which are fully supported by dedicated motor control chips. The phase resistance estimation algorithm uses just a fraction of the total computing power of the controller and does not require any additional hardware sensing. Thus it can be very attractive for real applications.

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