THE DYNAMIC CONTROL OF A SWITCHED RELUCTANCE DRIVE USING FUZZY LOGIC

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Abstract – **This work presents the method of controlling the motor currents to minimize the torque ripple, using a neuro-fuzzy compensator. By this method, the compensating signal is added to the output of a classical PI controller, in a current-regulated speed control loop.**

Keywords: *torque ripple, neuro-fuzzy compensator, switched reluctance drive b, compensating signal, PI controller.*

1. INTRODUCTION

The dynamic control of Switched Reluctance (SR) drive with fuzzy logic and neural networks is used in drive systems. Artificial intelligence based fuzzy, neural and fuzzy - neural controllers have a number of advantages over conventional controllers [1], [2]. The advantages for SR Drives are: no requirement of an accurate model; possibility of design based exclusively on linguistic information. Fuzzy logic control of a SR drive is implemented in variable-speed drives [3], [4] and in applications where some degree of torque ripple is tolerated, as is the case in many industrial applications. But, in servo control applications or when smooth control is required at low speeds, the elimination of the torque ripple becomes the main issue for an acceptable control strategy. In this case, even using a fuzzy PI like control is not satisfactory, because the controller's output signal, which is used as a reference signal for the current control in the power converter, gives rise to sustained torque pulsations in steady-state. Then, this torque ripple changes with the speed of the SR motor and with the load applied to it.

2. THE COMPENSATION METHOD

With a PI-like control alone, it is not possible to obtain a ripple-free output speed at any speed range, because it would also require a ripple-free output torque, for this purpose. If on supposed that the output speed is constant and equal to the reference speed in steady-state, then the PI controller's output signal (what is the reference current) would be constant. Though the constant current reference would produce an oscillating torque (Figure 1), rendering the ripple-free speed control unfeasible.

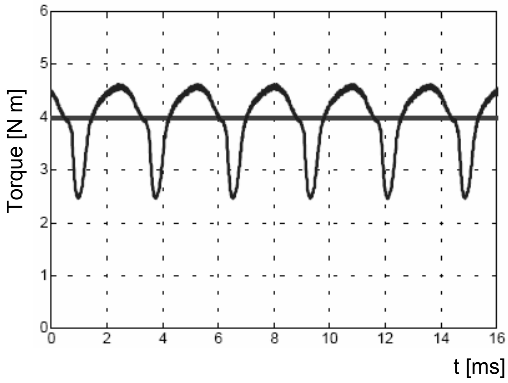

Figure 1: Torque ripple produced by constant current reference signal (simulation).

The simulations correspond to the current regulated, full load operation of a 750 W SR motor, with rated speed 1800 rpm. At high speeds, the torque pulsations would occur at higher frequencies, thus causing less speed ripple, due to the natural filtering provided by the mechanical load inertia. In this work, the compensation method is based upon a self-tuning neuro-fuzzy compensator [5], [6].

2.1. The compensating scheme

Figure 2 presents a block diagram of the SR drive speed control system.

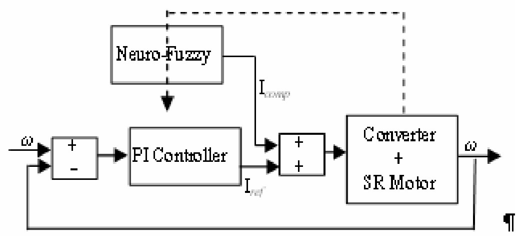

Figure 2: Diagram of compensation scheme.

Where: I_{comp} shows the output signal produced by the compensator; I_{comp} , added to the PI controller's output signal - I_{ref} , which should be ideally constant in steady-state but producing significant ripple.

The resulting signal after the addition is used as a compensated reference signal for the current-controlled SR drive converter. The compensating signal should then be adjusted in order to produce a ripple-free output torque.
The compensating signal is adjusted iteratively, through a neuro-fuzzy training algorithm, where the training error information is derived from some internal variable of the SR drive system. The torque ripple used as the training error variable, but this approach would not be very practical for on-line implementation in a real system, since the dynamic torque is a variable which is difficult to measure. For continuous on-line training, other variables could be more appropriate, such as acceleration or speed ripple. However, the torque could still be used directly in an off-line training system, such as for converter programming on a test rig at the factory.

2.2. The simulation model

The neuro-fuzzy compensator is a fuzzy logic system with five fixed triangular membership functions for each input. The rotor angular position θ and the PI controller's output the signal I_{ref}, are used as inputs to the compensator representing in relation as $\Delta I_{comp} = f(\theta, I_{ref})$. The procedure consists on whose adjusting the rule consequents by a hybrid training algorithm, which combines back propagations and least squares minimization. At each iteration, the dc component is removed from the compensating signal, so that the ripple compensator does not try to change the mean value of the output torque. As a result, when the control system operates in steady-state, after the training, the PI controller will really produce a constant output signal, while the neuro-fuzzy compensator will produce a zero-mean-value compensating current reference, the ΔI_{comp} signal. Training data are obtained from simulations of steady-state operation of the complete SR drive system. To each iteration, the dc component is removed from the torque signal. This torque ripple data is then tabulated against the mean value of the PI output reference current, and against the rotor angular position. This data set is then passed to the training algorithm, so that the torque ripple is interpreted as error information for each current-angle pair. The output of the neuro-fuzzy compensator is then readjusted to reduce the error (which is in fact the torque ripple), being this process repeated until some minimum torque ripple limit is reached. The choice of stopping criteria is very important for the stability of the method, since the converter may not be able to produce the required compensated currents at any speed or load. In this case, persisting on training may lead to output windup at the compensator.

2.3. Simulation results

For comparison purposes, the drive system on simulated without compensation, at full-load torque (4 Nm mean value), 500 rpm. The rated speed is 1800 rpm. The output torque signal shows in Figure 3 and its harmonic components are shown in Figure 4. The torque signal shown from Figure 4 is produced by a constant current reference. As a result, the phase current pulses are flat-topped.

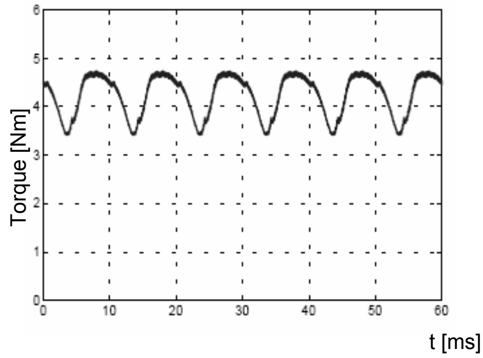

Figure 3: Output torque for non-compensated (constant current reference) operation at 500 rpm.

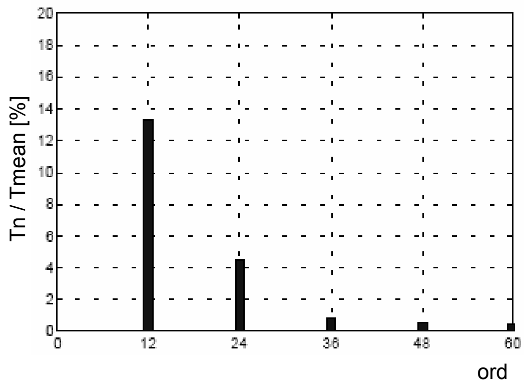

Figure 4: Harmonic content of non-compensated torque signal of Figure 3.

For the 6/4 SR motor, the converter produces 12 current pulses per rotor turn. Therefore, the torque pulsations occur at a frequency 12 times higher than the frequency of rotation. The harmonic spectrum shown in Figure 4 exhibits non-zero components only for orders multiple of 12. The magnitudes of the harmonics are expressed as percentage of the mean value. It should be noticed that the first non-zero harmonic (12 th) exhibits a quite high magnitude (approximately 13%). After one iteration, the harmonic content of the output torque is already significantly lower, as shown in Figures 5 and 6. The 12 th harmonic has a relative magnitude of only 3% approximately. In this situation, the compensated current reference produces phase current pulses which are no larger flat-topped, as will be shown afterwards.

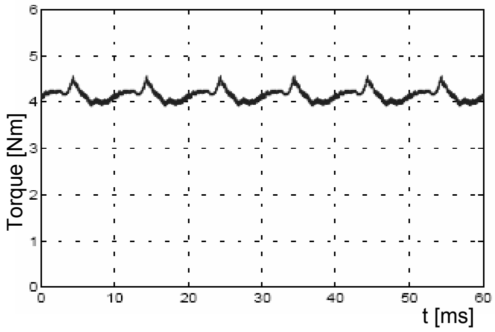

Figure 5: Compensated torque after first iteration.

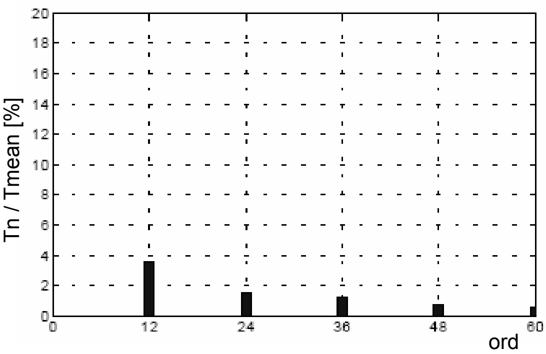

Figure 6: Harmonic content in torque signal of Fig. 5.

Figure 7 shows the output torque waveform for a compensated current reference after 10 training iterations. It can be seen that the total harmonic content is very low, and the 12th harmonic is lower than 0,5% of the mean torque.

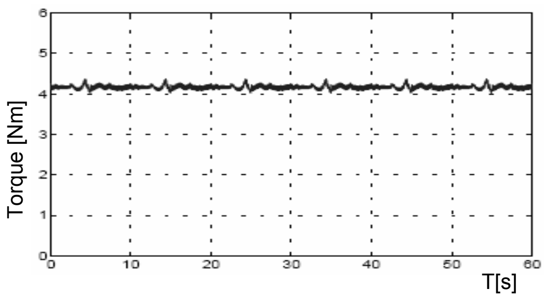

Figure 7: Compensated torque after 10 iterations.

After 10 training iterations, the compensated current reference produces phase current pulses like those shown in Figure 8. As expected, the current values are higher at the beginning and at the end of the current pulse.

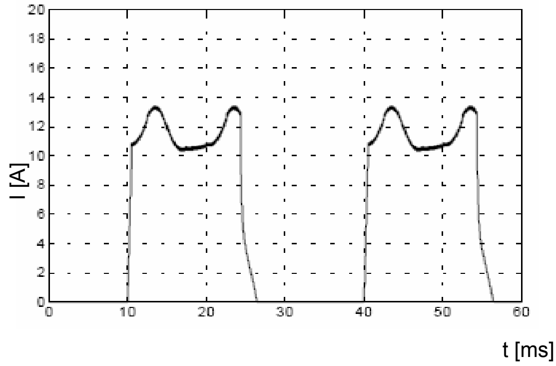

Figure 8: Harmonic content in torque signal of Fig. 7.

3. CONCLUSIONS

This modeling to ripple reduction in SR motor was investigated. The simulations of the switched reluctance drive show that is possible to incorporate a compensating signal in the current waveform for minimize the torque ripple. By this method, the compensating signal is added to the output of a classical PI controller, in a current-regulated speed control loop. This concept may be used in an experimental drive and may be incorporate another signal.

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