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Digital PI Controller Using Anti-Wind-Up Mechanism for A Speed Controlled Electric Drive System

Srikanth Mandarapu, Sreedhar Lolla, M.V.Suresh Kumar

Abstract — ***This paper discusses the implementation of Digital PI Controller Using Anti Wind-Up Mechanism For A Speed Controlled Electric Drive System. To eliminate the system zeros relocated proportional integral controller is implemented. Which in turn reduces the over shoots. The torque is not limited, inspite of the use of relocated proportional integral controller. The motor windings get damaged, if the torque reaches higher values. In order to limit this torque, we introduce a torque limiter, which limits the torque value to the permissible limits. Due to limited torque, over shoots are produced for large inputs. To eliminate these overshoots, with limited torque, we implement the anti-windup mechanism.***

The scheme is implemented in MATLAB and from the obtained results its possible use and limitations are studied for torque limits varying from ±3000 to ±7000 N-m.

Index Terms— ***anti wind –up, digital pi controller, quantizer, torque limiter.***

List of symbols:

ω	Rotational speed (rad/sec)
ω^*	Reference speed (rad/sec)
$\Delta\omega$	Speed error = ω^* - ω (rad/sec)
ω_{BW}	Closed loop band width (Hz)
J	Inertia of the moving parts (kgm$^{2)}$
B	Friction coefficient
T_{ref}	Reference torque (Nm)
T_L	Load toque (Nm)
T_{em}	Driving torque (Nm)
K_m	Motor torque constant (Nm)
K_P	Proportional gain.
K_I	Integral gain.
T_S	Sampling period (sec)
T_{max}	Maximum value of the allowable torque (Nm)
f_n	Natural frequency (Hz)
ξ	Damping factor
ω_{max}	Maximum value of the allowable speed (rad/sec)

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I. INTRODUCTION

Electric drives are dynamic systems which require highly controllable inputs. These manipulations are usually transferred to the system using actuators. What happens during, actuators saturation depends critically on the ability of control strategy (the controller) to handle a saturation event as well as on the properties of controlled system. In a PI controller windup or rollover is a widely studied problem [1–6]. Typically this problem arises if the input error to the controller is large or the input error remains nonzero for a long time. A controller under saturation may give delayed response to any change in the input and this delay would be more if the controller goes into deeper saturation level.

In order to avoid the unwanted Windup phenomenon, the maximum integrator output value will be kept within limits; strategy which is known as Anti-Windup (AW). Studies of such techniques are discussed in [1-3]. Specifically the Anti-windup Schemes for Proportional Integral controllers are discussed in [4]. The impact of quantizer errors on windup compensation for the case speed control of power electronic converter are studied in [5]. Another solution of continuously tuning the PI parameters to keep the response undamped at all times is discussed in [6].

In this paper studies on 'Anti-windup' scheme for PI controller and their applicability in solving windup problem in speed control of electric drives is discussed. The basis of the wind-up problem in speed controlled electric drives and the compensation method (AWU) were simulated in MATLAB

II. RELOCATED DIGITAL PI SPEED CONTROLLER WITHOUT TORQUE LIMITER

Fig 1 shows the implementation of speed control using digital PI controller with relocated Kp & K_I without torque limiter. The relocation of the gain K_P removes at the same time the closed loop zero and the overshoot in the step responses obtained with $\xi \geq 1$. However, the overshoot suppression is obtained with slower responses, due to the absence of the zero in the closed-loop transfer function W_{SS} (s). The transfer function of the PI controller with relocated gains is given by,

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$$W_{SS}(s) = \frac{\omega(s)}{\omega^*(s)}\bigg|_{T_L=0} = \frac{K_I}{s^2 J + s(K_P + B) + K} = \frac{1}{1 + s\frac{K_P + B}{K_I} + s^2 \frac{J}{K_I}} \quad (1)$$

With the proportional gain relocated from the direct path into the feedback loop, the pulsations of the driving torque Tem are reduced. The speed reference signal ω*(t) is not multiplied by K_P, therefore, the fluctuations of the reference do not have a direct contribution to Tem pulsations. On the other hand, in motion-control systems where the speed controller is one of the inner loops, the absence of the closed-loop zero makes the task of tuning the outer loops more difficult to achieve.

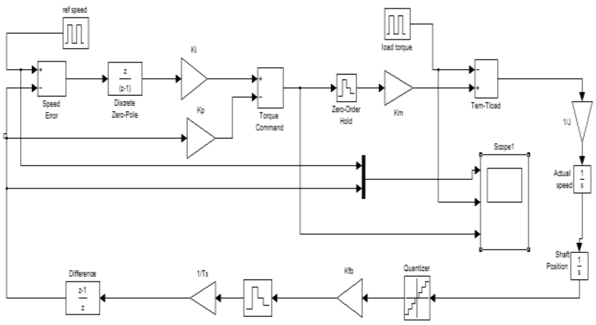

Fig 1. Relocated digital PI speed controller without torque limiter

III. PARAMETER SETTING OF KP, KI

From fig 2 the shaded surface corresponds to the speed error integral. The smaller the shaded area, the faster the step response. It is necessary to express the criterion function *Q* in terms of *p* and *i*.

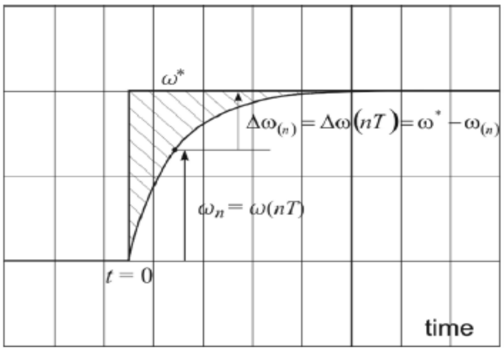

Fig 2 A strictly aperiodic step response.

Each element *Q*(*n*) of the series is the sum of the speed error samples for the interval [0..*nT*], With *n*→∞, the series *Q*(*n*) converges to the criterion function *Q*. The criterion function can be found as the final value of the sample train, namely, the value of *Q*(n) obtained for *n*→∞.

$$Q = Q_{(\infty)} = \lim_{z\to 1}\left(\frac{z-1}{z} Q(z)\right) = \lim_{z\to 1}\left(\frac{1}{z}\Delta\omega(z)\right) = \lim_{z\to 1}(\Delta\omega(z)) \quad (2.1)$$

Q(*z*) can be related to Δω(*z*) and obtained as a function of *p* and *i* parameters. Eventually, the optimized parameter setting can be found, leading to a minimum value of *Q*.

$$Q = Q_{(\infty)} = \lim_{z\to 1}(\Delta\omega(z)) = \omega^*\left(\frac{p}{i} - \frac{1}{2}\right) \quad (2.2)$$

The criterion function *Q* can be minimized by applying the feedback gains *p* and *i* with the minimum possible ratio *p* /*i*. In the subsequent developments, the optimized values of normalized gains are found in a procedure searching for the maximum value of $Q_1 = i/p = 1/Q$. The criterion function Q1 = *i* /*p* can be expressed in terms of the closed-loop poles as well

$$Q_1 = \frac{i}{p} = \frac{\sigma_1\sigma_2 + \sigma_2\sigma_3 + \sigma_3\sigma_1 - 1}{\sigma_1\sigma_2\sigma_3}. \quad (2.3)$$

Maximising Q_1 we will get σ_1, σ_2, and σ_3. Further steps are facilitated by introducing the reciprocal values of the closed-loop poles, namely, $x = 1/\sigma_1$, $y = 1/\sigma_2$ and $v = 1/\sigma_3$. In order to obtain the fastest strictly aperiodic step response, the characteristic polynomial *f*(*z*) has to assume the following form:

$$f(z) = (z-\sigma_1)(z-\sigma_2)(z-\sigma_3) = (z-\sigma)^3. \quad (2.4)$$

The optimized values of the closed-loop poles σ_1, σ_2, and σ_3 and the corresponding values of the normalized feedback gains P_{OPT} and I_{OPT} are given in Eq. (2.5).

$$\sigma_1 = \sigma_2 = \sigma_3 = \sigma = 0.587$$
$$p_{OPT} = \sigma^3 = 0.2027$$
$$i_{OPT} = 3\sigma^2 - 1 = 0.03512. \quad (2.5)$$

IV. SPEED CONTROL WITH TORQUE LIMITER

The speed is controlled using the proportional integral controller. This gives strictly aperiodic response for small input excitations. But the main dis-advantage occurred in this method is that the torque is not limited. High values of torque, lead to the damage of motor. To eradicate this problem, we introduce a torque limiter. Using this, the torque is brought under control and is limited to the required values. Fig 3 shows the implementation of PI speed controller with torque limiter.

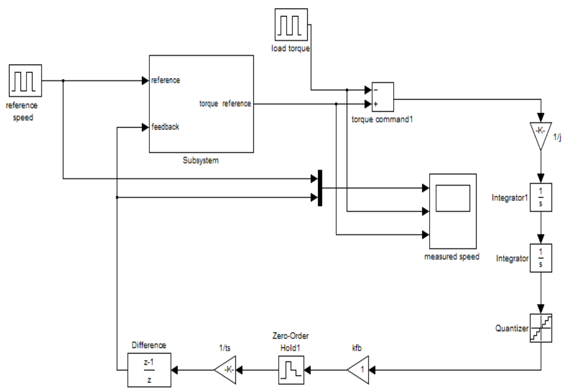

Fig 3 digital PI speed controller with torque limiter

With Δω(*t*) = 0, it would be convenient to drive the torque down to zero, thus keeping the speed at the reference value. With the above speed controller structure bringing the torque to zero at Δω(*t*) = 0 cannot be achieved. The error integrator is well beyond the T_{MAX} level.

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In other words, it is charged or *wound up*.

For the torque to decay, the error integrator must be discharged first, but driving torque remains at the positive limit even after the speed reaches the set point. Therefore the speeds overshoots are produced. The oscillating phenomena originate from an interaction between the system nonlinear elements, such as the torque limiter and the speed error integrator, contained within the speed controller. Such a detrimental interaction is known as the *wind-up*.

V. SPEED CONTROL WITH ANTI-WIND-UP

The effects caused by the windup are not acceptable. Therefore, the speed controller has to include measures devised to suppress the wind-up in the error integrator. Such measures are known as the *Anti-Wind-Up* (AWU). Implementation of AWU in the incremental form of the PI controller is to eliminate the wind-up in the error integrator and to provide a strictly aperiodic step response even in case with large input disturbance. Fig 4 shows the simulation model used for speed controller with proportional action in the feedback path. The implementation is incremental and comprises the AWU structure.

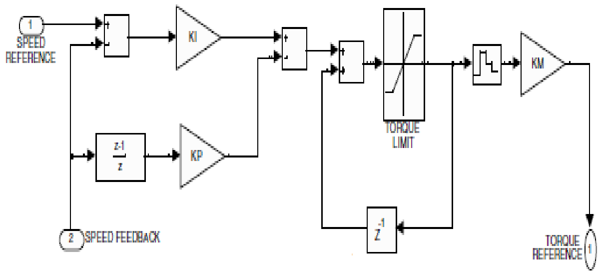

Fig 4 speed controller in incremental form comprising the anti wind-up structure

VI. RESULTS

Figs 5, Fig 8 are for PI controller without torque limiter; Fig 6, Fig 9 are for PI controller with torque limiter; Fig 7, Fig 10 are for PI controller comprising the proposed AWU mechanism.

From the fig 8, we observe that the motor torque produced is very high in the order of 23500 Nm which can be considered as the worst case in our observation regarding PI speed controller without torque limiter. In fig 9, torque limiter is introduced to limit this high motor torques, we observe overshoots even though torque is limited. For a reference speed of 1500 RPM, load torque of 2000 Nm and the maximum torque limit of 7000, we obtain **minimum convergence** of the measured speed with the reference. In fig 10, where anti windup mechanism is used, the over shoots are reduced along with the maximum torque limiter value needed. Here we observe that for a reference speed of 1500 r.p.m, load torque is 2000 Nm, instead of using a maximum torque limit of 7000 a torque limit of 4000 only is enough to obtain the **minimum convergence** of the measured speed with the reference.

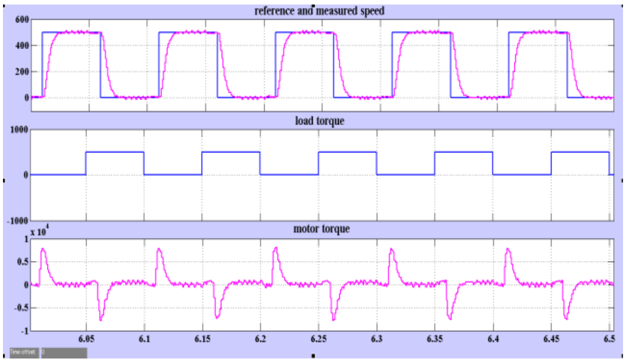

Fig 5: With ref speed = 500 RPM, and load torque = 500 Nm

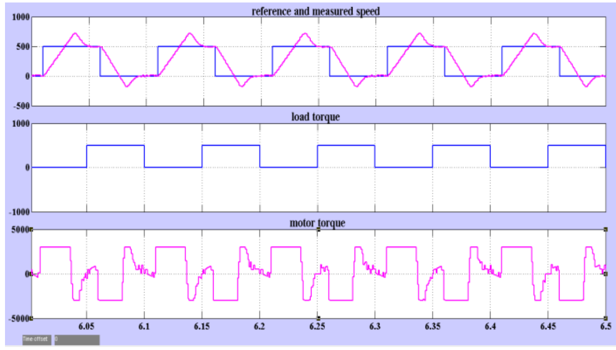

Fig 6: With ref speed = 500 RPM, load torque = 500 Nm, limiter value = -3000 to +3000

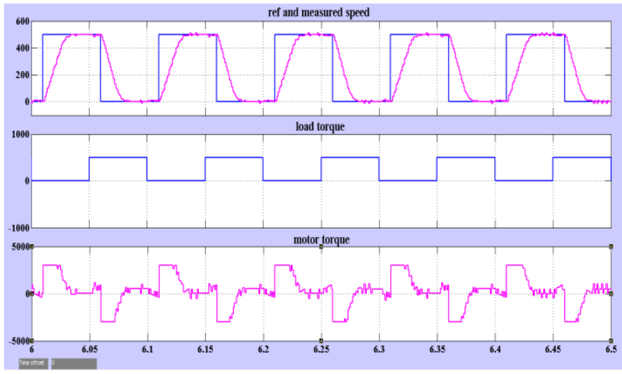

Fig 7: With reference speed = 500 RPM, load torque = 500 Nm and torque limit = -3000 to +3000

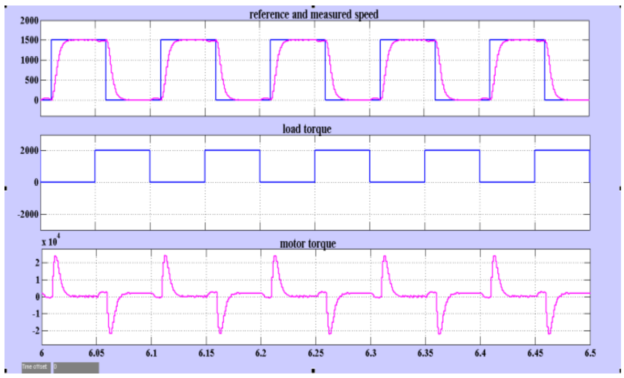

Fig8: Reference speed=1500 RPM, load torque =2000 Nm

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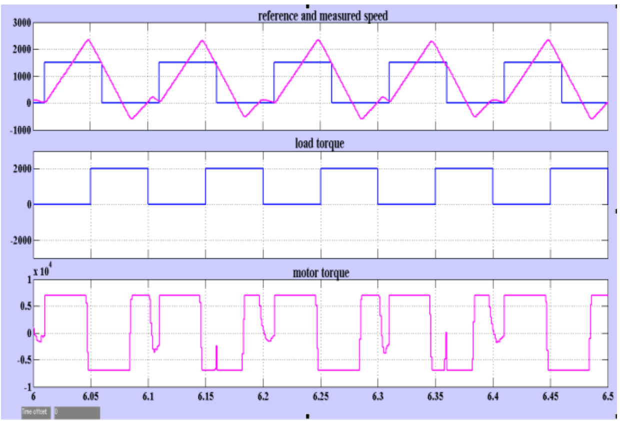

Fig9: Reference speed=1500 RPM, load torque=2000 Nm, torque limit= -7000 to +7000

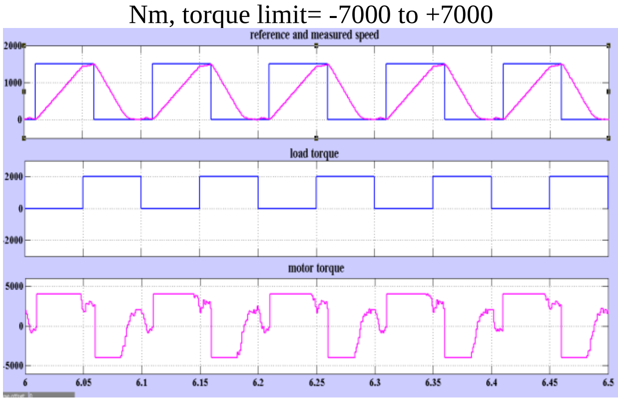

Fig 10: Reference speed=1500 RPM, load torque=2000 Nm, torque limit= -4000 to +4000

VII. CONCLUSION

Hence by introducing anti wind up mechanism we obtained lesser speed error. Hence, the high torque values observed in the PI speed controller implementation with torque limiter are eliminated.

It is also been observed that the worst case of torque limiter value for minimum tracking of output speed with reference speed employing anti wind up is very much less when compared to the model without anti wind up mechanism.

Thus, convergence of the measured speed, to the reference speed at low torque values is possible using anti wind up mechanism, unlike PI speed controller with torque limiter, which is a definite advantage.

REFERENCES

1. O¨ hr, J., 2003. On Anti-Windup and Control of Systems with Multiple Input Saturations: Tools, Solutions and Case Studies, 221 pp. Uppsala. ISBN 91-506-1691-9.
2. A. Visioli. Modified anti-windup scheme for pid controllers. IEE Control Theory and Applications, 150(1):49—54, January 2003.
3. C. Bohn and D. P. Atherton. An analysis package comparing pid antiwindup strategies. IEEE Systems Magazine, 15(2):34—40, April 1995.
4. Anti-windup Schemes for Proportional Integral and Proportional Resonant Controller, Anirban Ghoshal and Vinod John, National Power Electronic Conference 2010.
5. Digital control in power electronics, Simone Buso and Paolo Mattavelli, ISBN – 10: 1598291130, 2006 by Morgan & Claypool.
6. Yu-Sheng Lu, “Non-overshooting PI control of variable-speed motor drives with sliding perturbation observers”, ELSEVIER, Mechatronics. vol.15, pp.1143-1158, March 2005.

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