Integral Anti-Windup for PI Controllers

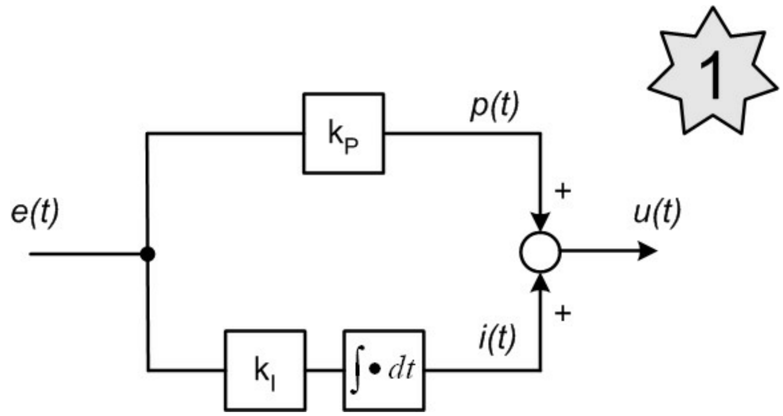

Fig. 1: Linear PI controller

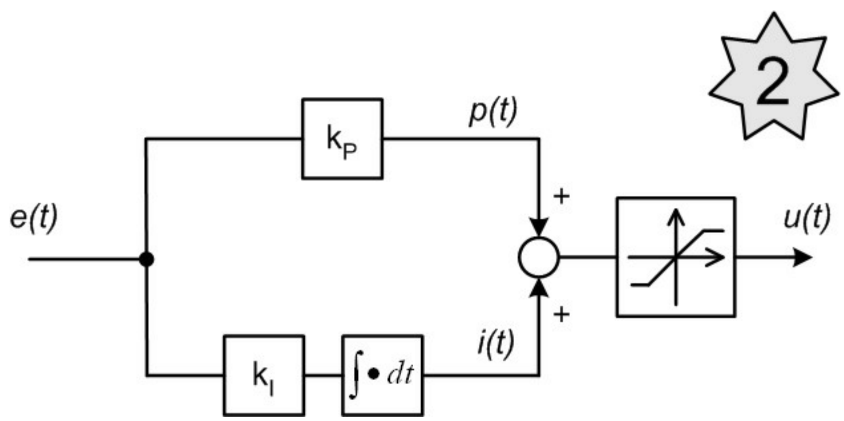

Fig. 2: Actuator saturation → integrator wind-up phenomenon (discussed in detail in [6])

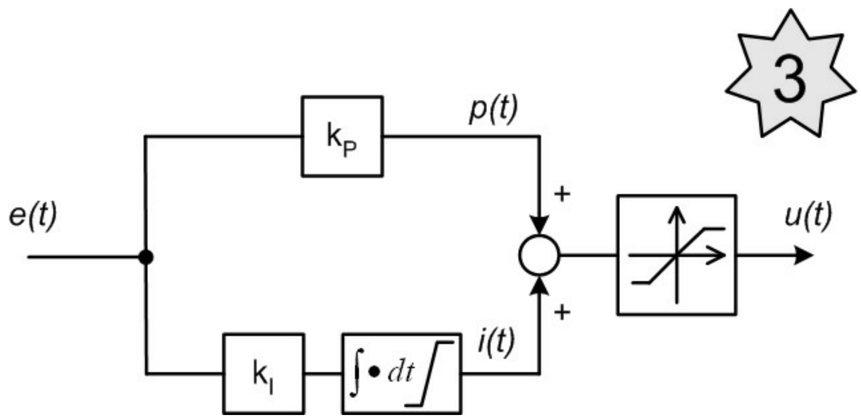

Fig. 3: Limited integrator (hard limits imposed) → conditional integrator, integrator clamping [5][3]

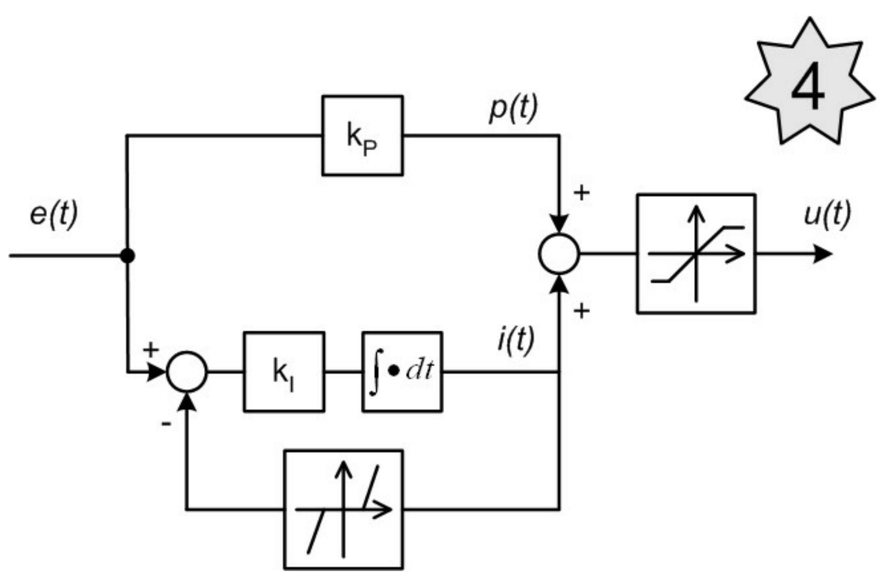

Fig. 4: Limited integrator (high feedback gain → Scheme 3) [4][1]

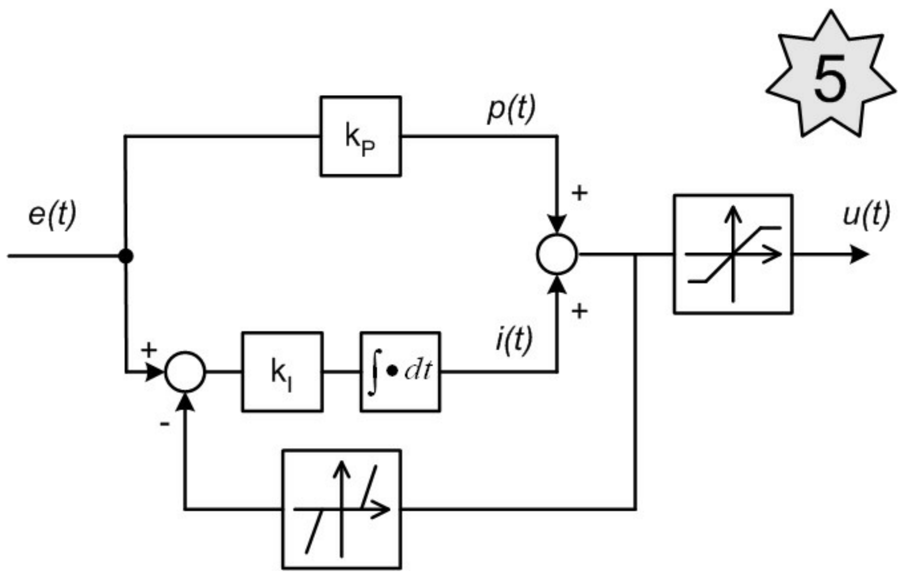

Fig. 5: Tracking anti-windup [4][1][2]

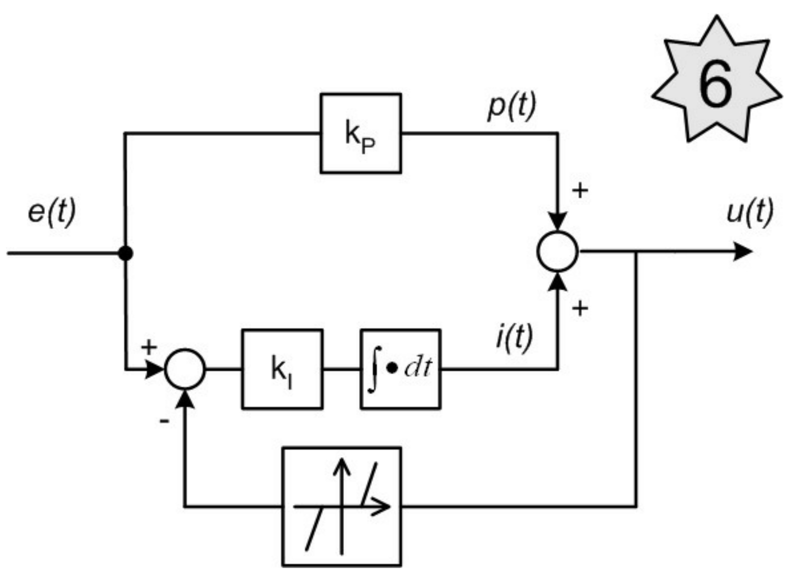

Fig. 6: Tracking anti-windup with unrestricted control signal (for actuators described by linear dynamics followed by a saturation) [4][1]

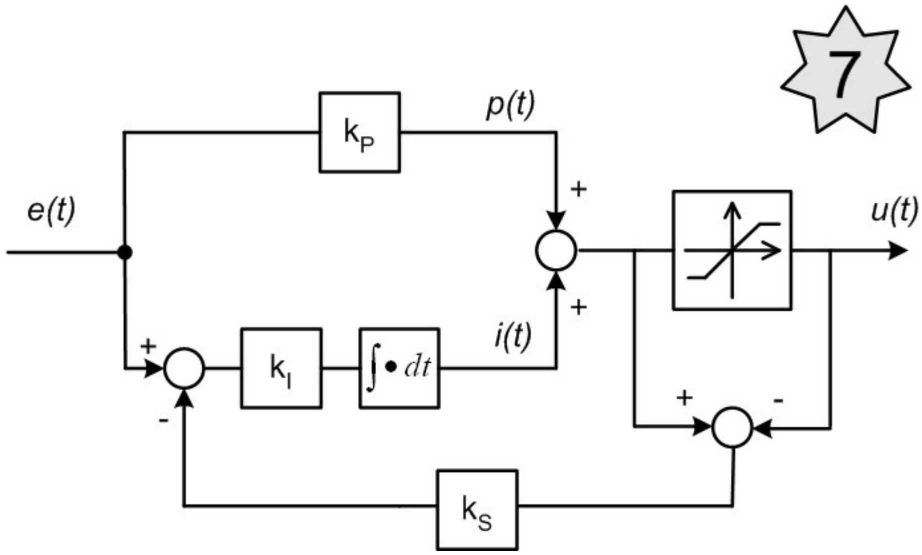

Fig. 7: Tracking anti-windup, back-calculation (equivalent to Scheme 5) [4][1]

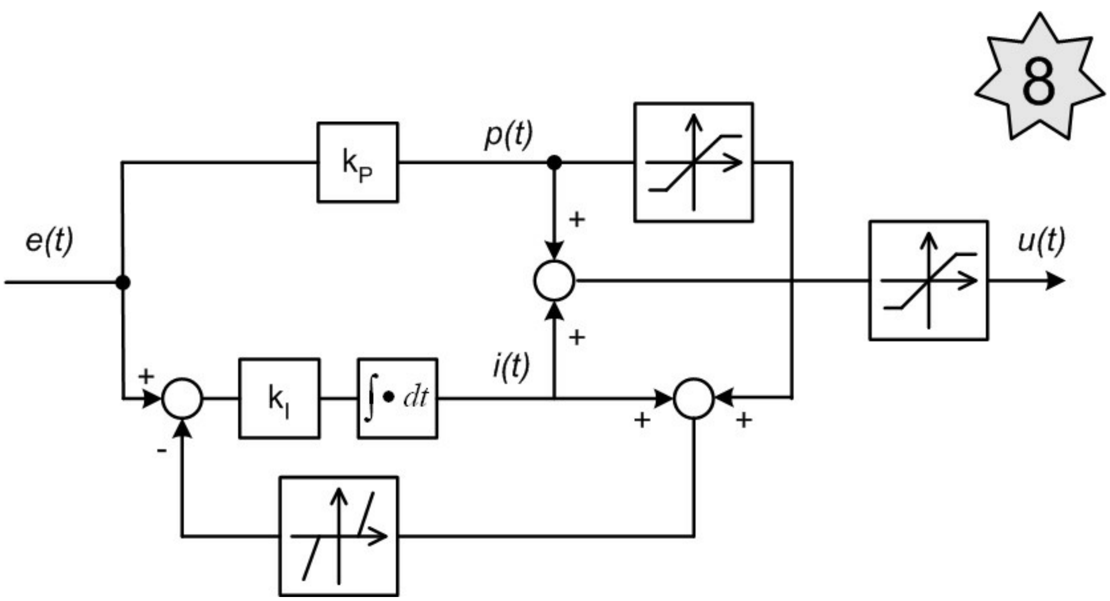

Fig. 8: Modified tracking anti-windup (introduction of an additional limit on the proportional part of the control signal used to generate the anti-windup-feedback signal) [4][1]

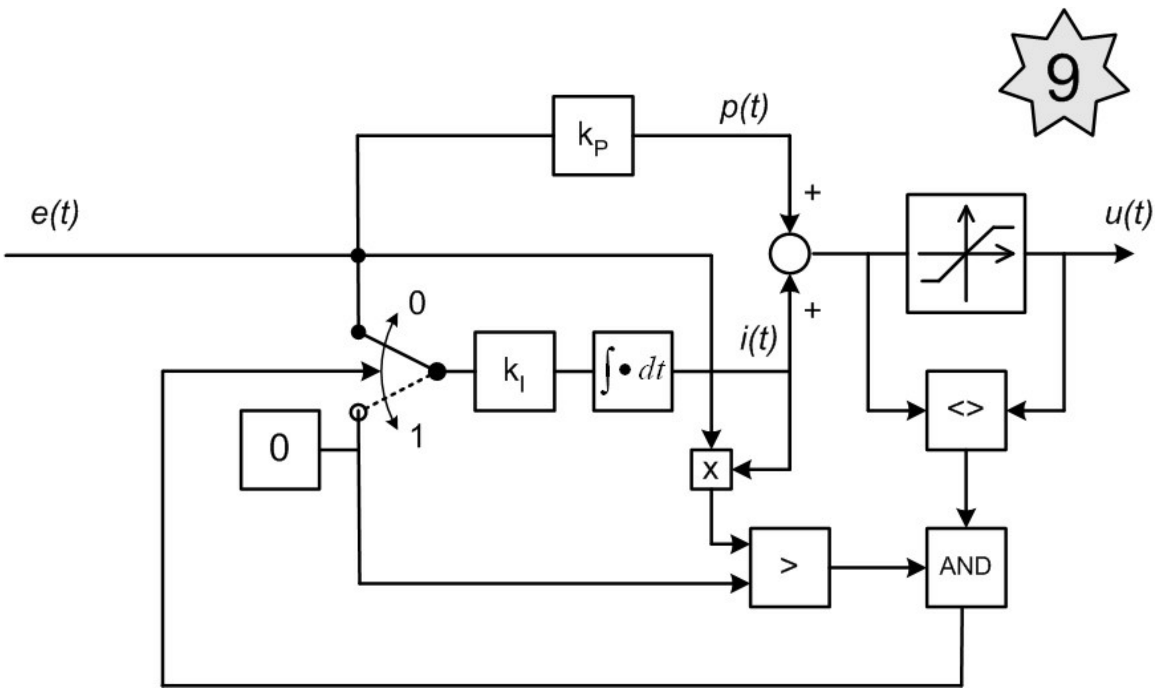

Fig. 9: Conditional integration $(e(t) \cdot i(t) > 0) \rightarrow$ flexible limits (modified Scheme 3)

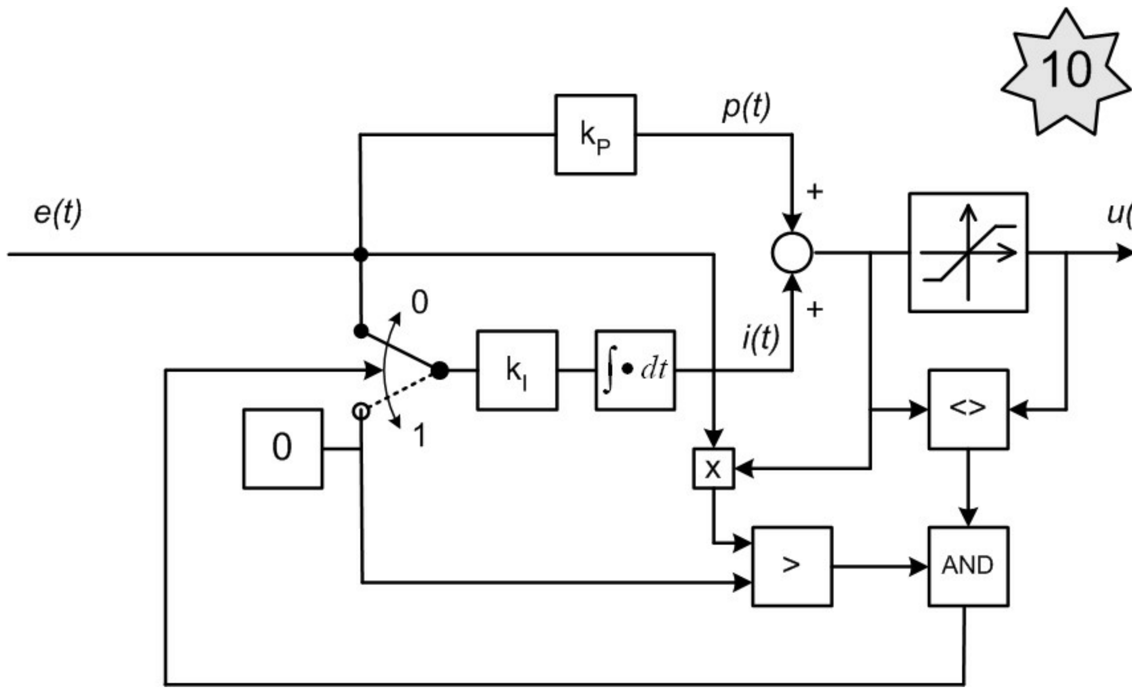

Fig. 10: Integrator clamping $(e(t) \cdot u(t) > 0) \rightarrow$ found to be the best [5][3]

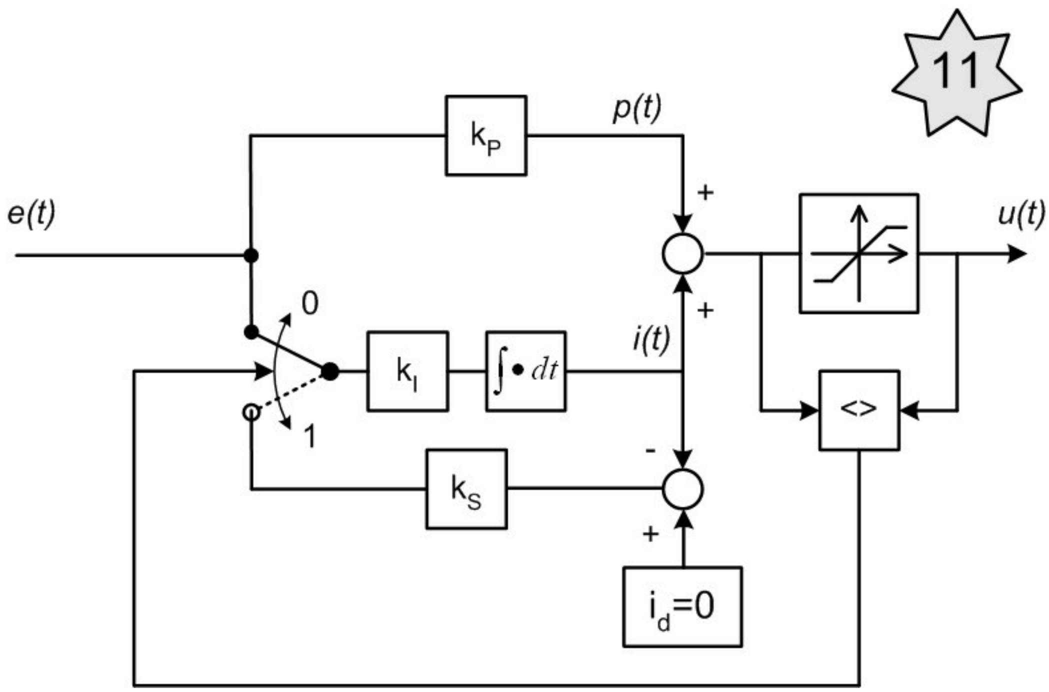

Fig. 11: Preloading ≡ The integrator output $i\,(t)$ is dynamically (bumpless transfer protection) driven to the offline predetermined value i_d [3]

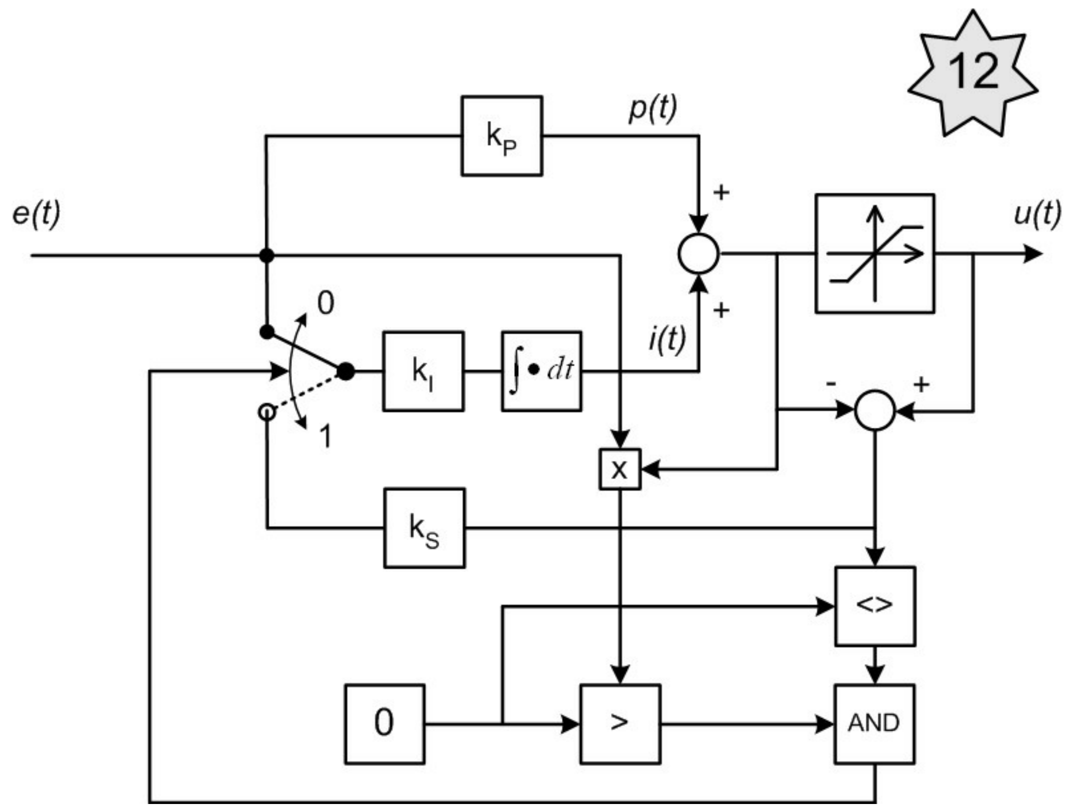

Fig. 12: Integral part variable limit (algorithm dynamically drives the integrator so that $p(t) + i(t)$ lies at the edge of the saturation region), proposed in [3]

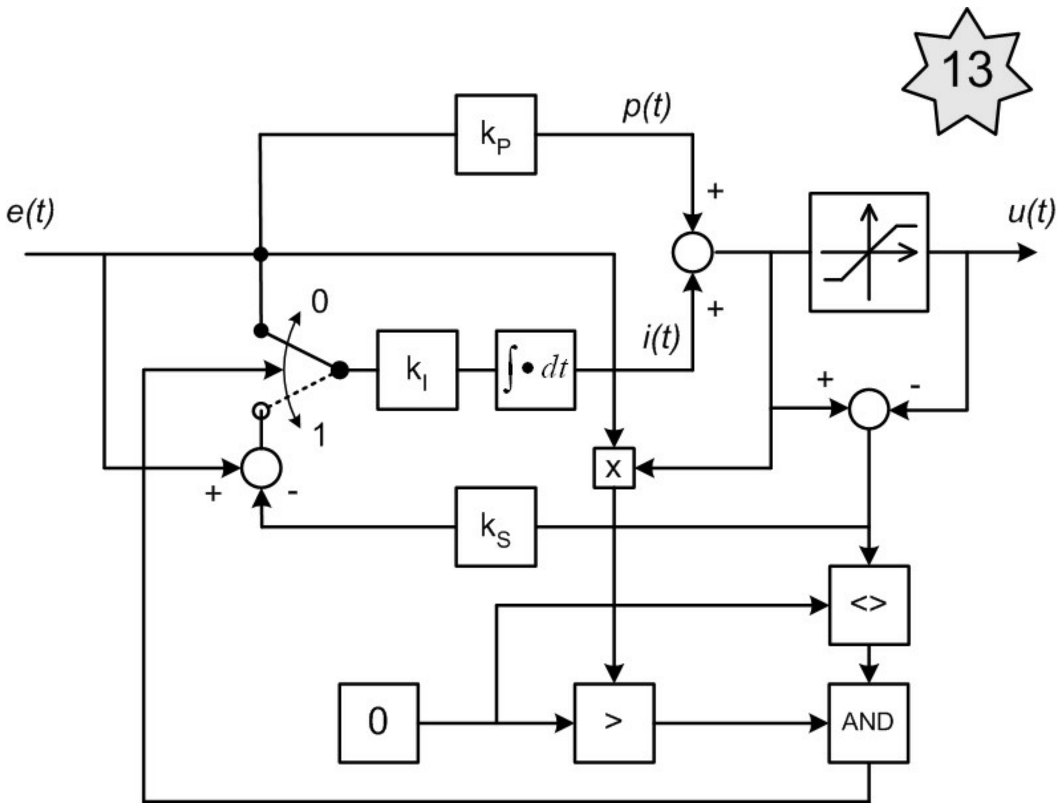

Fig. 13: Conditional integration combined with back-calculation approach (proposed in [5])

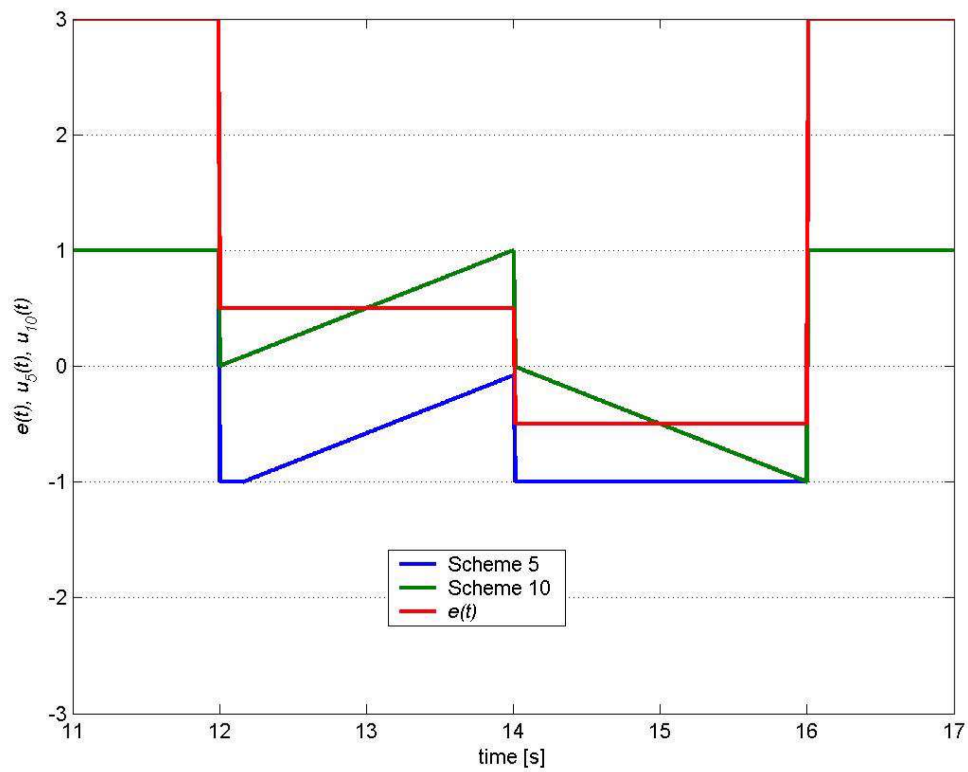

Fig. 14: Scheme 5 and Scheme 10 performance comparison

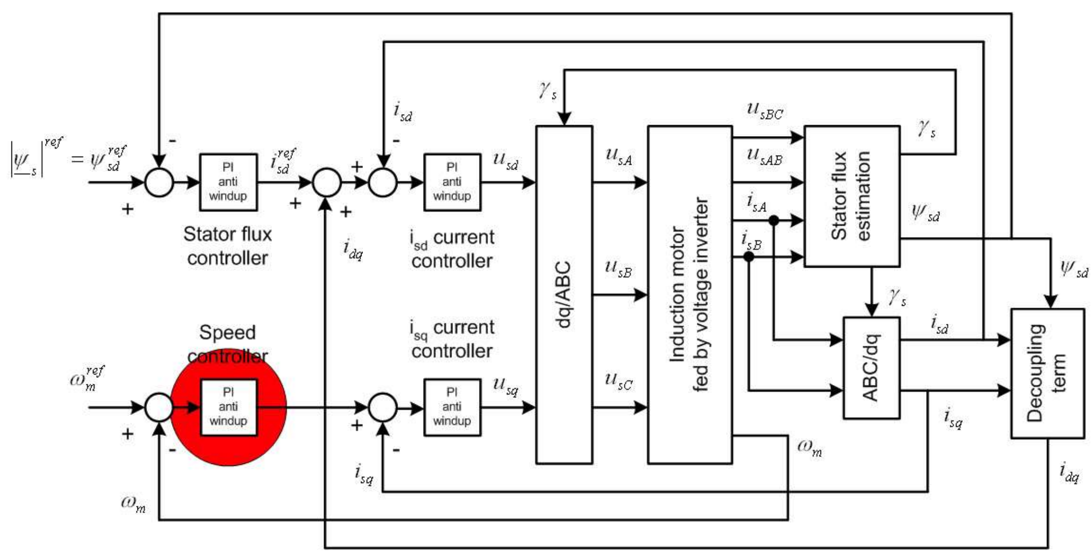

Fig. 15: Direct Stator Field Oriented Control scheme

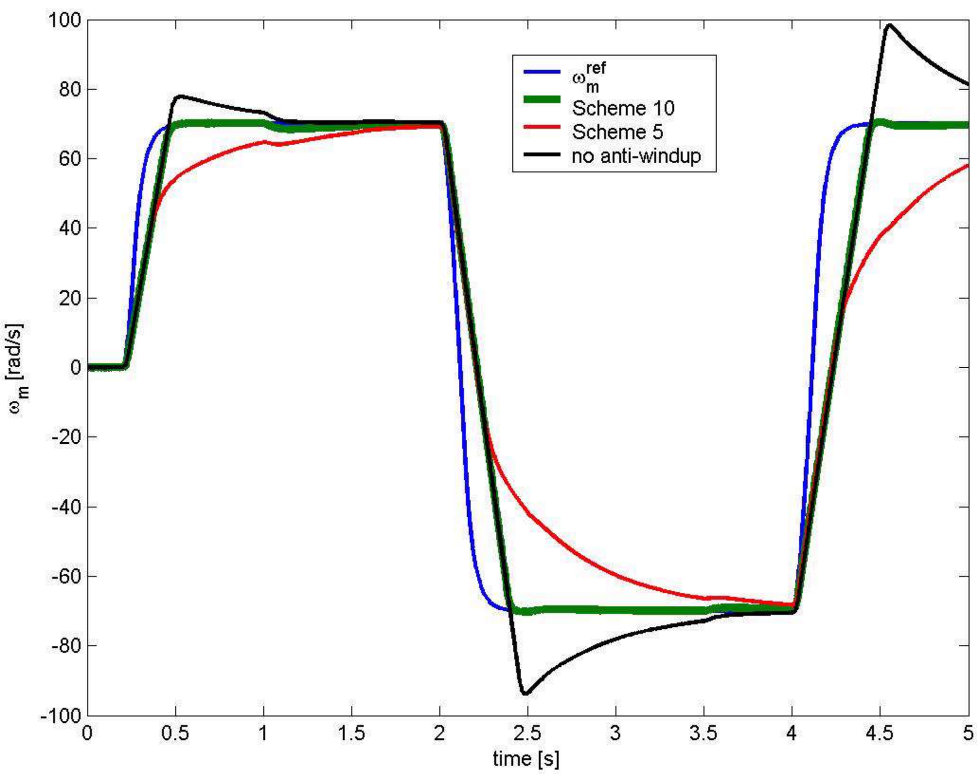

Fig. 16: Various DSFOC drive behaviour as a result of different PI anti-windup configuration

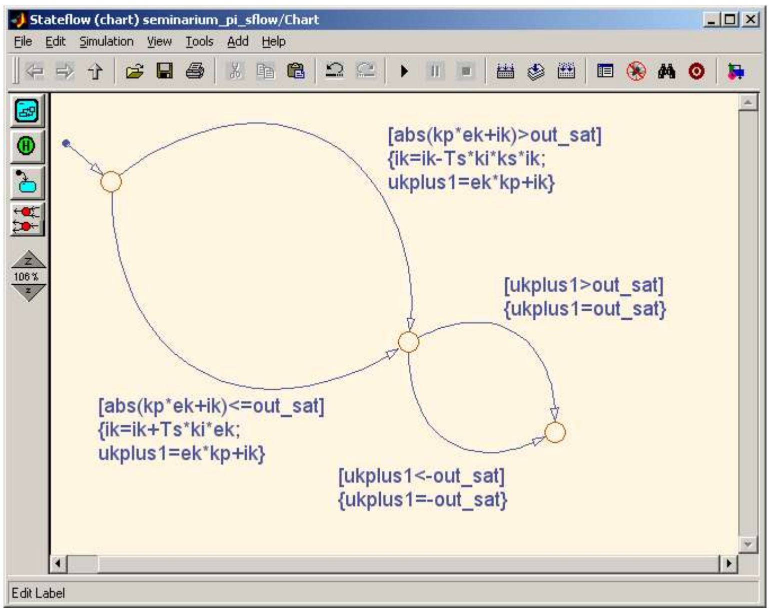

Fig. 17: Model in StateFlow® (Scheme 11)

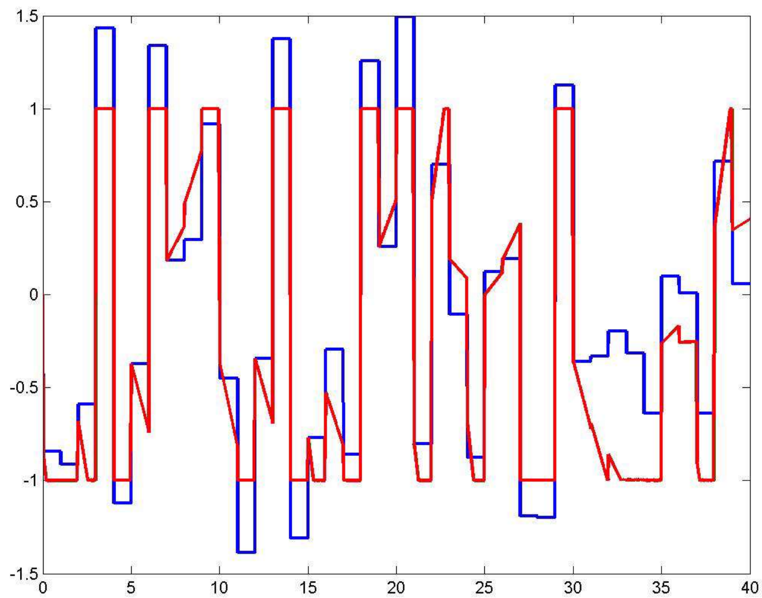

Fig. 18: Continuous states vs. discrete StateFlow®

References

[1] C. Bohn and D. P. Atherton. An analysis package comparing pid anti-windup strategies. *IEEE Systems Magazine*, 15(2):34–40, April 1995.

[2] M. Hamdan and Zhiqiang Gao. A novel pid controller for pneumatic proportional valves with hysteresis. *IEEE Industry Applications Conference*, 2:1198–1201, October 2000.

[3] A. Scottedward Hodel and C. E. Hall. Variable-structure pid control to prevent integrator windup. *IEEE Transactions on Industrial Electronics*, 48(2):442–451, April 2001.

[4] M. Tharayil and A. Alleyne. A generalized pid error governing scheme for smart/sbli control. *IEEE American Control Conference*, 1:346–351, May 2002.

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[6] D. Vrančić. *Design of Anti-Windup and bumpless Transfer Protection.* PhD thesis, University of Ljubljana, Slovenia, 1997.