

# Integral Anti-Windup for PI Controllers

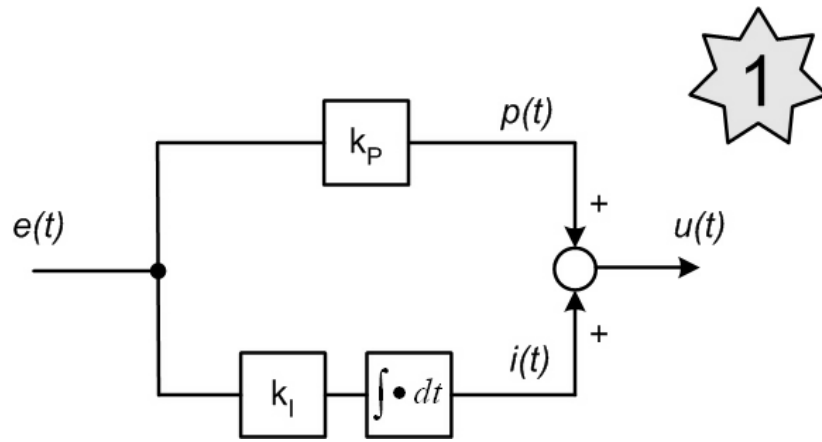


Fig. 1: Linear PI controller

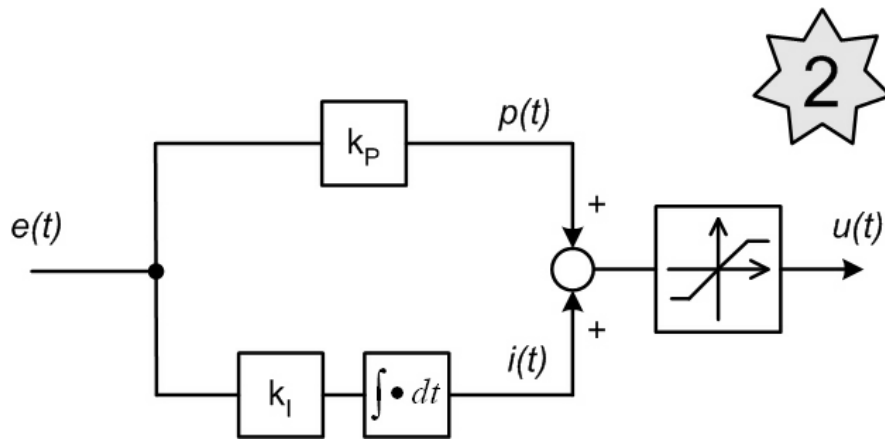


Fig. 2: Actuator saturation  $\rightarrow$  integrator wind-up phenomenon (discussed in detail in [6])

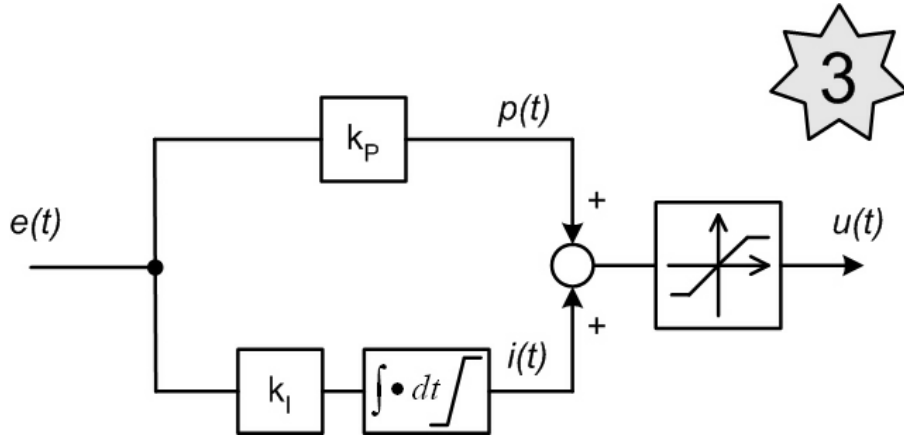


Fig. 3: Limited integrator (hard limits imposed)  $\rightarrow$  conditional integrator, integrator clamping [5][3]

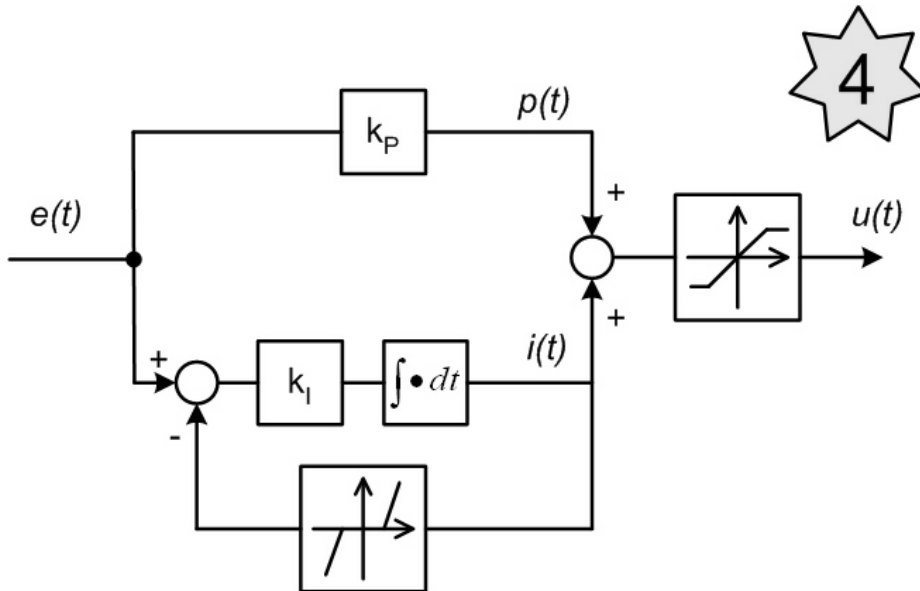


Fig. 4: Limited integrator (high feedback gain  $\rightarrow$  Scheme 3) [4][1]

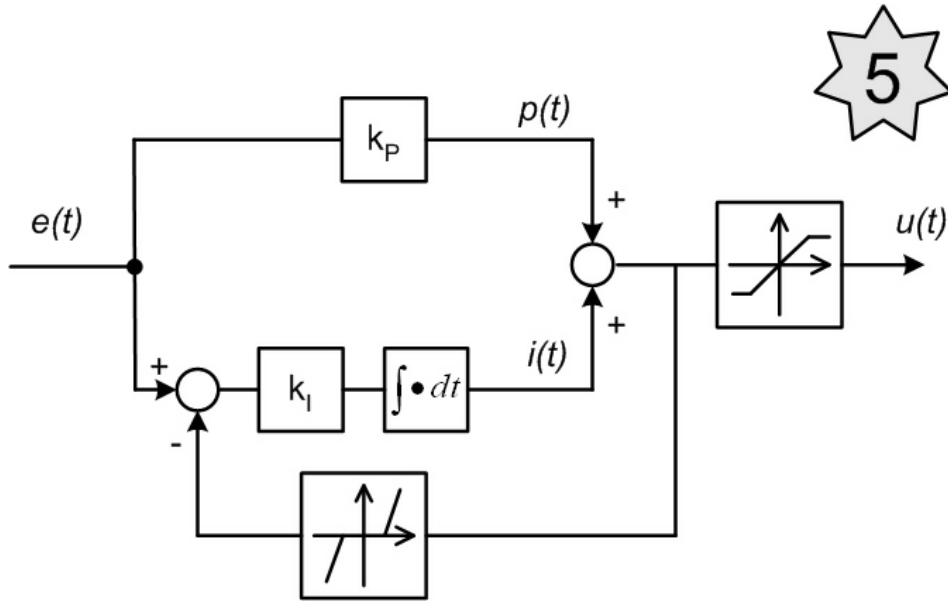


Fig. 5: Tracking anti-windup [4][1][2]

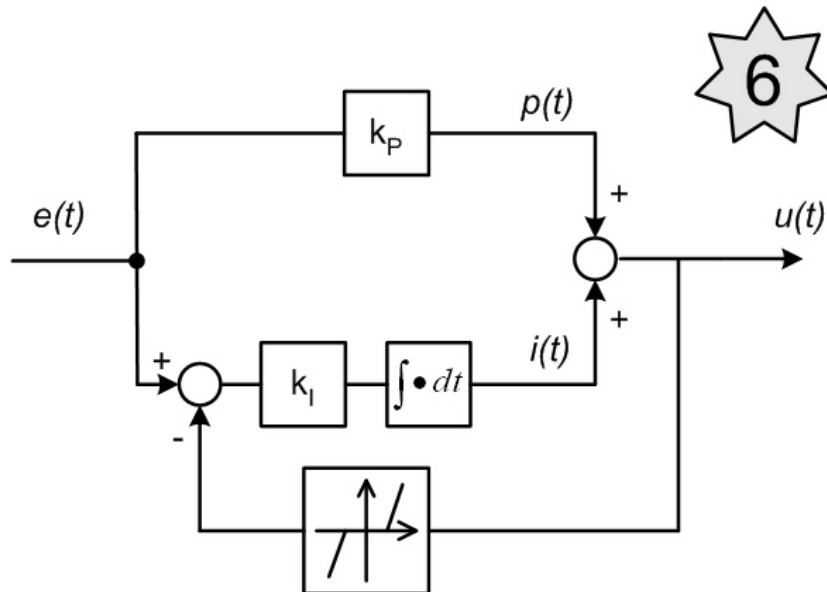


Fig. 6: Tracking anti-windup with unrestricted control signal (for actuators described by linear dynamics followed by a saturation) [4][1]

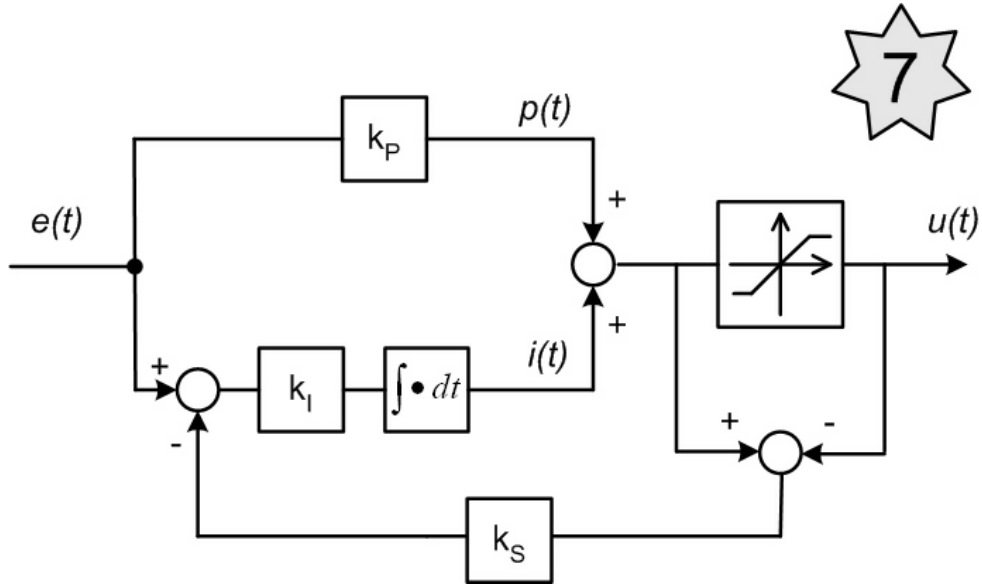


Fig. 7: Tracking anti-windup, back-calculation (equivalent to Scheme 5) [4][1]

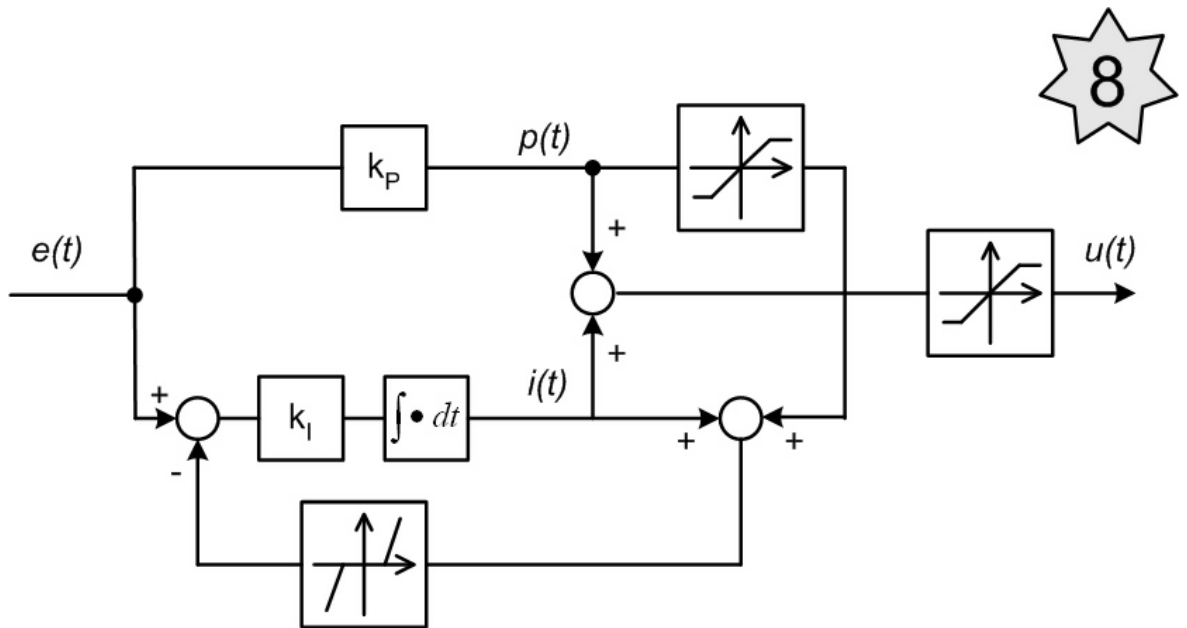


Fig. 8: Modified tracking anti-windup (introduction of an additional limit on the proportional part of the control signal used to generate the anti-windup-feedback signal) [4][1]

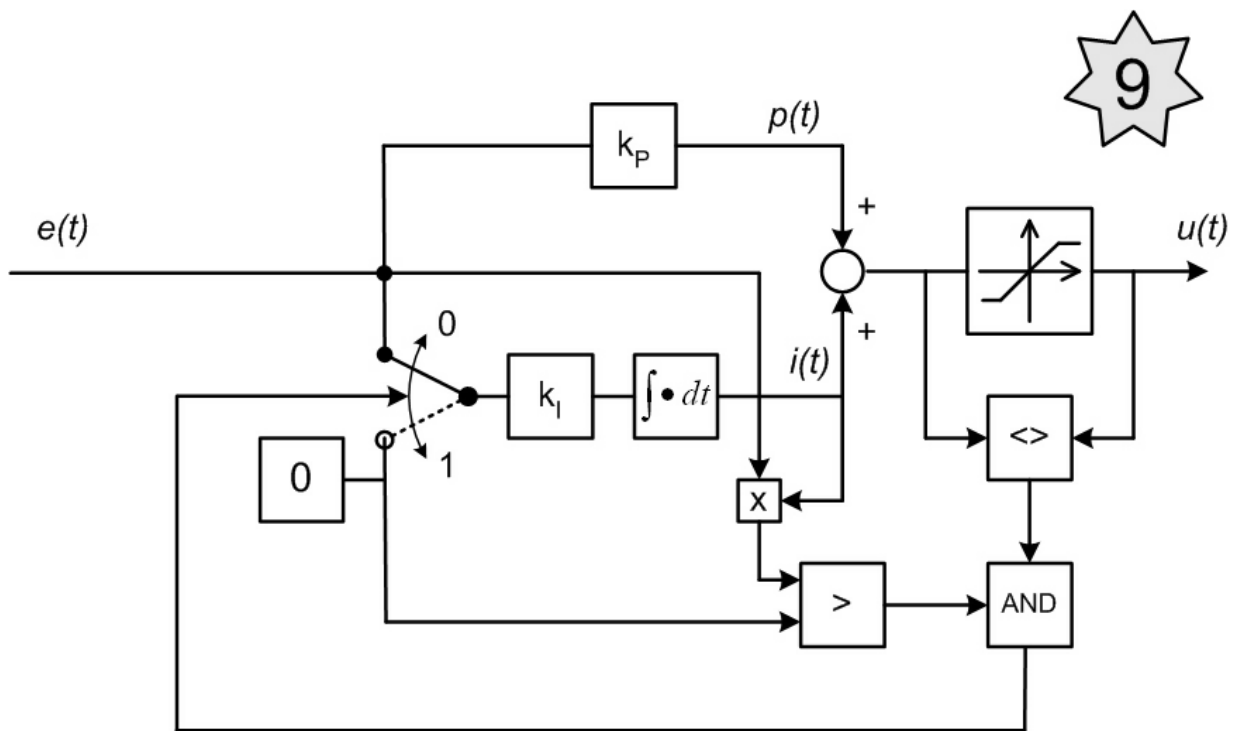


Fig. 9: Conditional integration  $(e(t) \cdot i(t) > 0) \rightarrow$  flexible limits (modified Scheme 3)

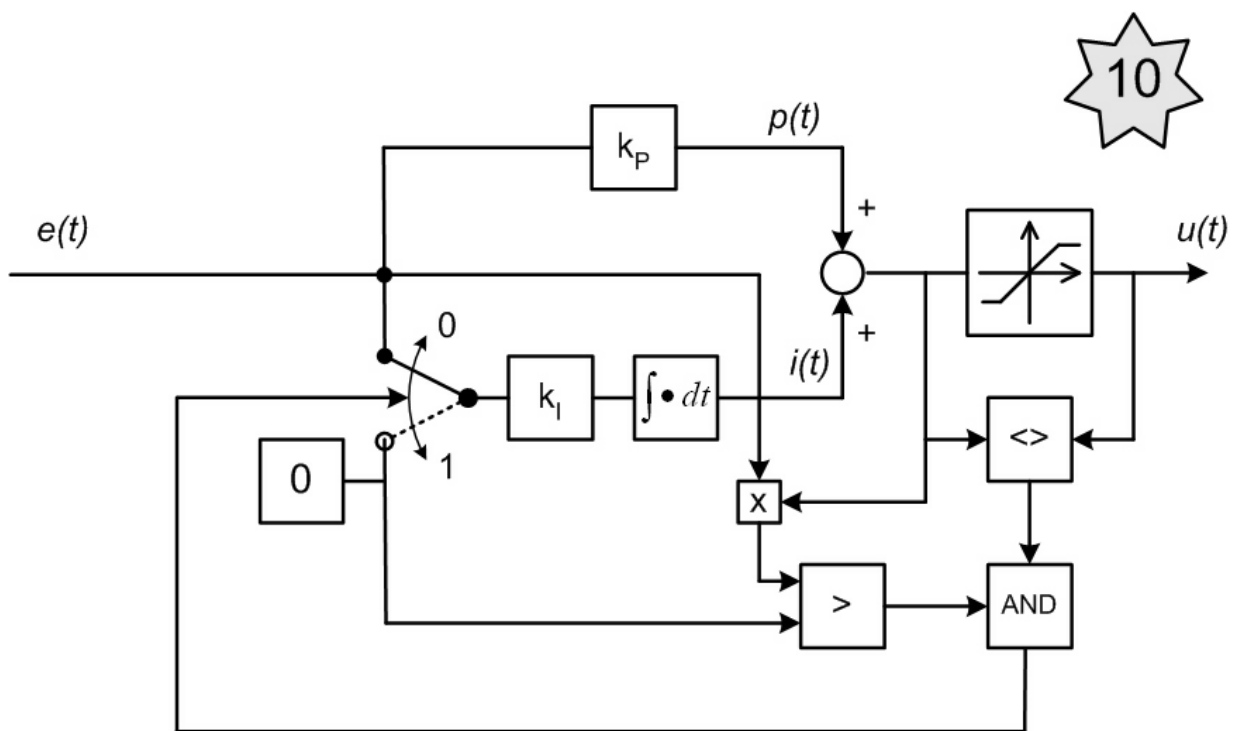


Fig. 10: Integrator clamping ( $e(t) \cdot u(t) > 0$ )  $\rightarrow$  found to be the best [5][3]

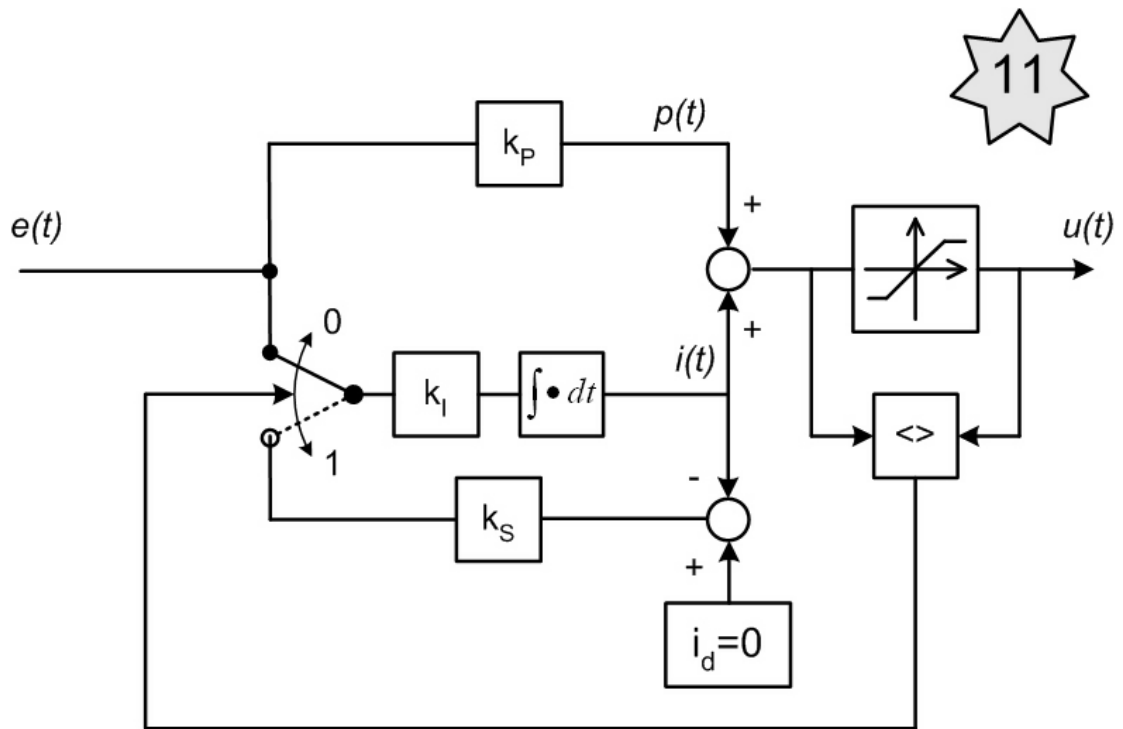


Fig. 11: Preloading  $\equiv$  The integrator output  $i(t)$  is dynamically (bumpless transfer protection) driven to the offline predetermined value  $i_d$  [3]

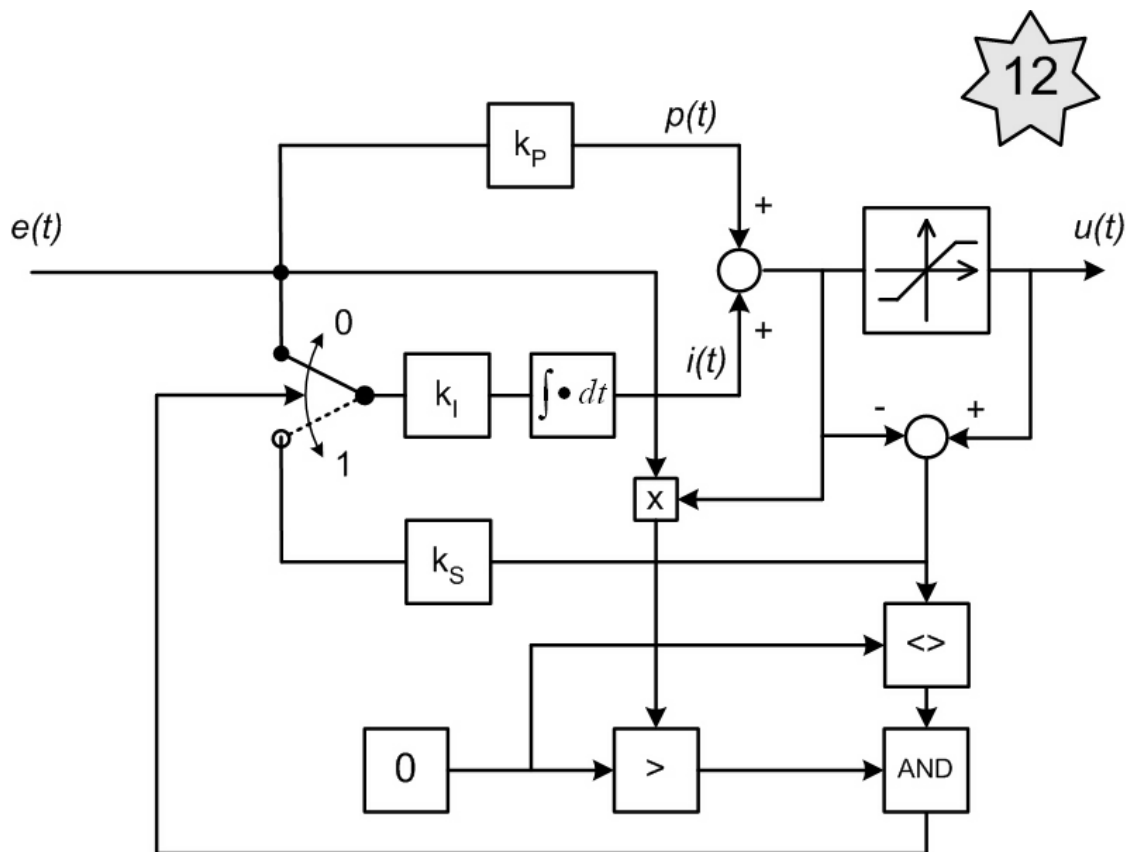


Fig. 12: Integral part variable limit (algorithm dynamically drives the integrator so that  $p(t) + i(t)$  lies at the edge of the saturation region), proposed in [3]



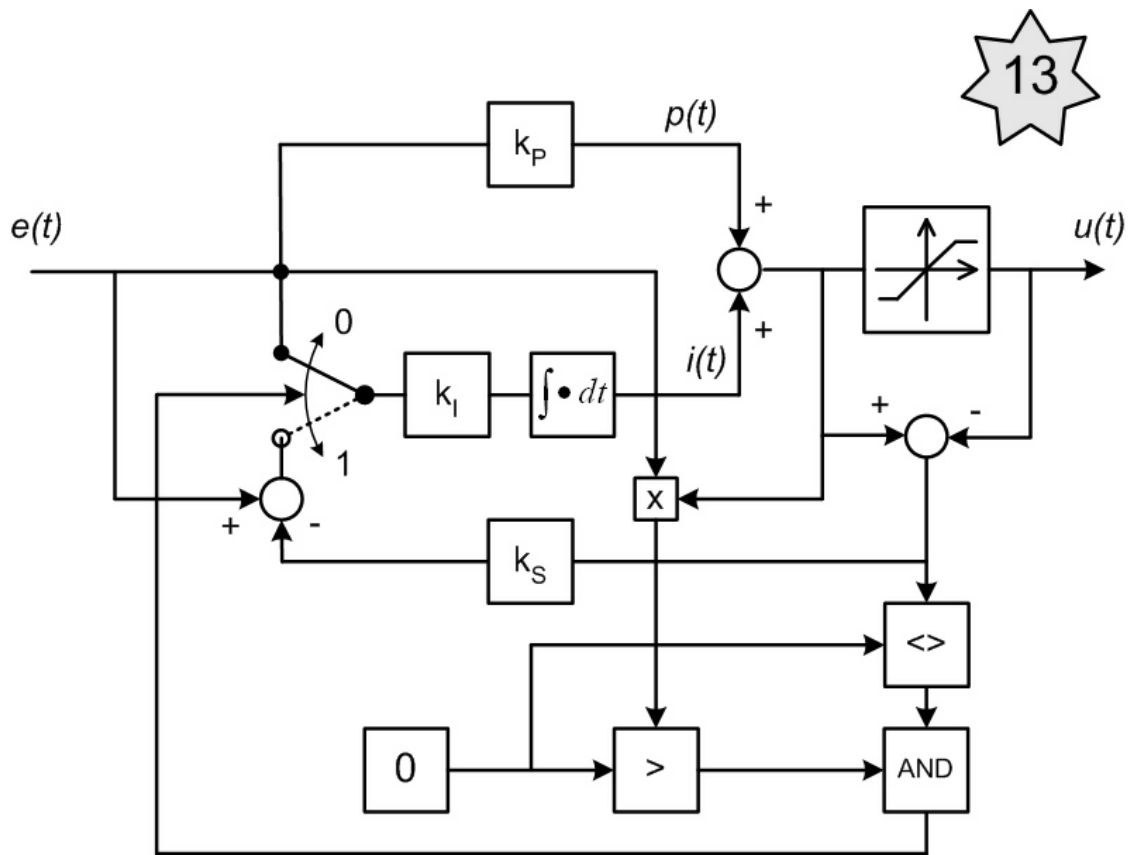


Fig. 13: Conditional integration combined with back-calculation approach (proposed in [5])

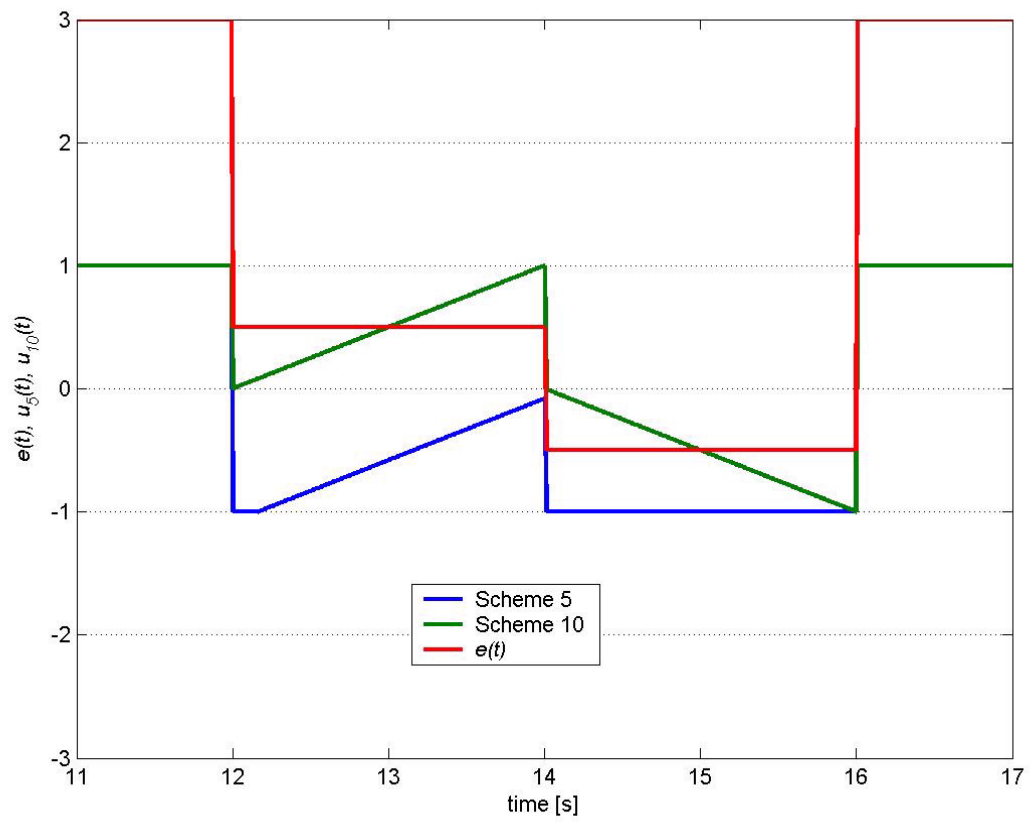


Fig. 14: Scheme 5 and Scheme 10 performance comparison

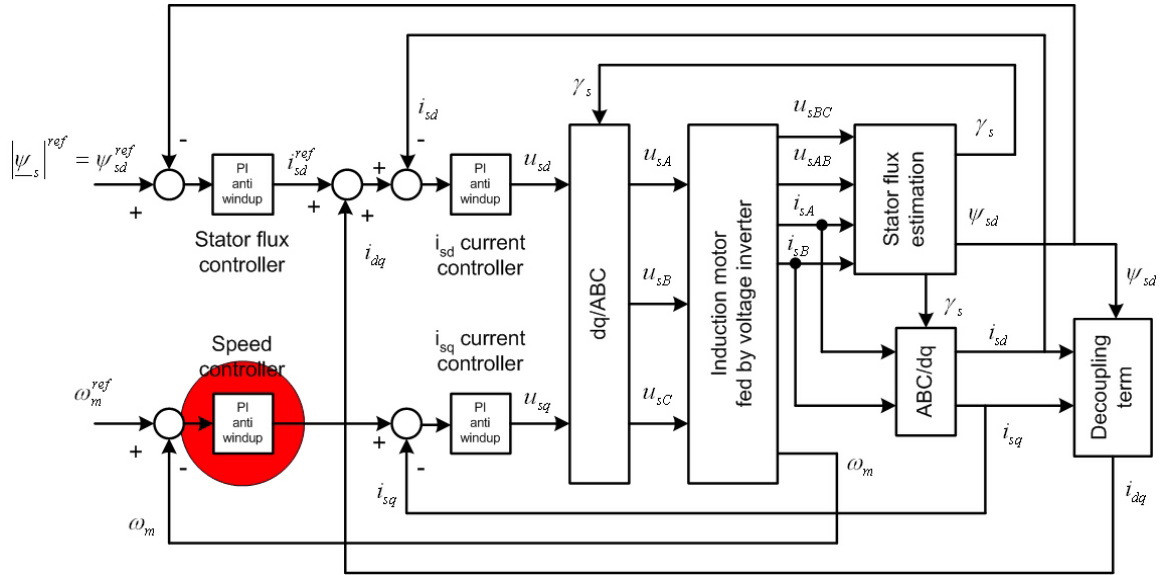


Fig. 15: Direct Stator Field Oriented Control scheme

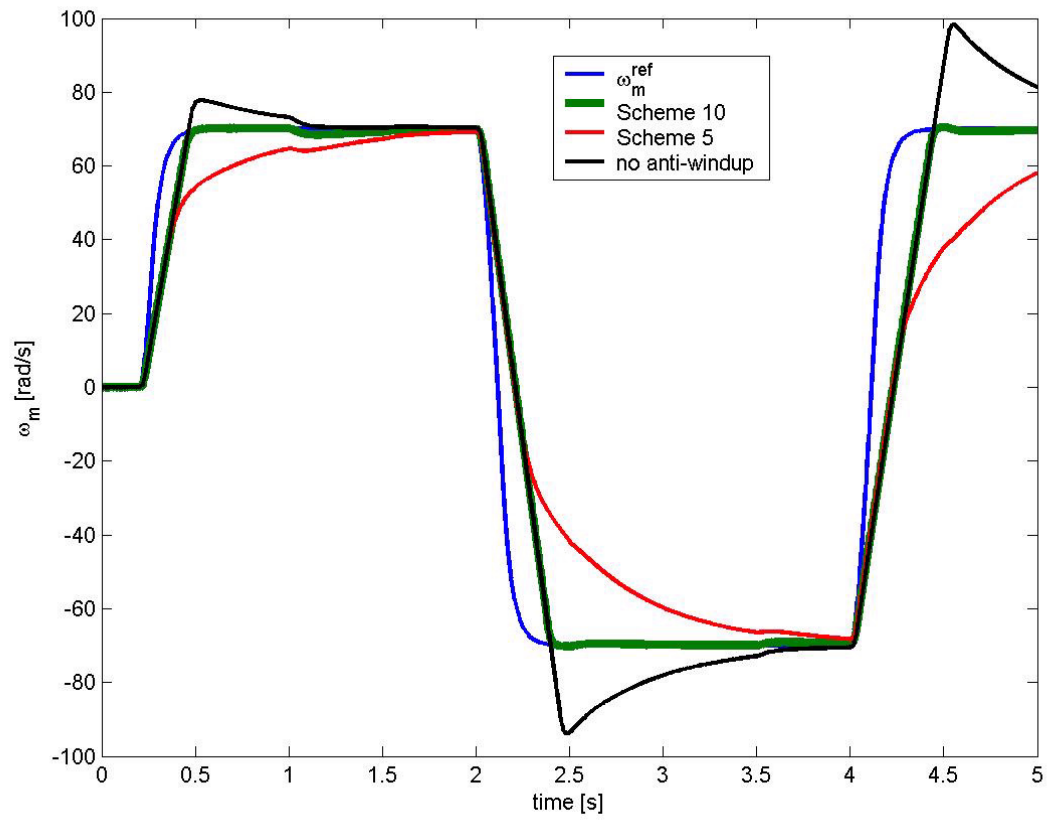


Fig. 16: Various DSFOC drive behaviour as a result of different PI anti-windup configuration

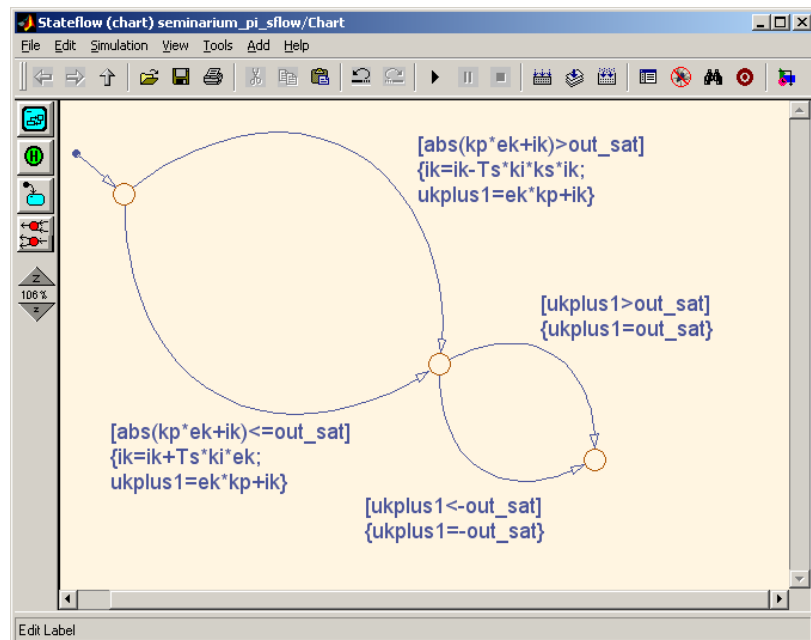


Fig. 17: Model in StateFlow<sup>®</sup> (Scheme 11)

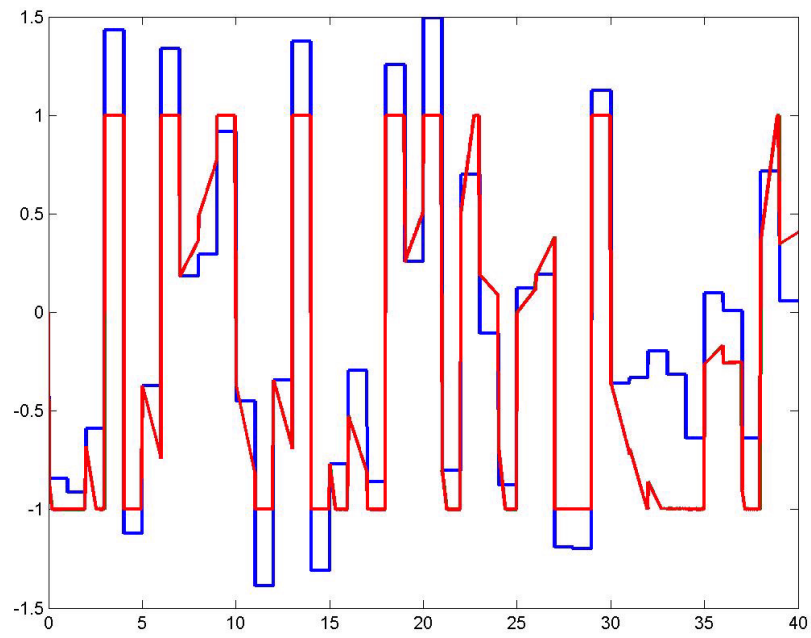


Fig. 18: Continuous states vs. discrete StateFlow<sup>®</sup>

## References

- [1] C. Bohm 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.
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