Regulisani elektromotorni pogoni sa asinhronim mašinama – **vektorsko upravljanje**

Istorijski pregled
Načini realizacije
Određivanje parametara regulatora
Pregled karakteristika
Prevazilaženje nedostataka

Prva publikacija

Indirektno vektorsko upravljanje

TECHNISCHE
UNIVERSITÄT
DARMSTADT

K. Hasse,
“O dinamici brzinski
regulisanog pogona sa
asinhronom mašinom sa
kratkospojenim rotorom
napajanom iz pretvarača”
Doktorska disertacija na
Visokoj tehničkoj školi
Darmštadt, 1969.

K. Hasse,
“Zur Dynamik
drehzahlgeregelter Antriebe
mit stromrichtergespeisten
Asynchronkurzschlußläufer
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Ph.D. dissertation,
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1969.

Prva publikacija

Direktno vektorsko upravljanje

F. Blaschke,
"The principle of field orientation as applied to the new TRANSVECTOR closed loop control system for rotating field machines,"
Siemens Rev., vol. 34,
pp. 217-220,
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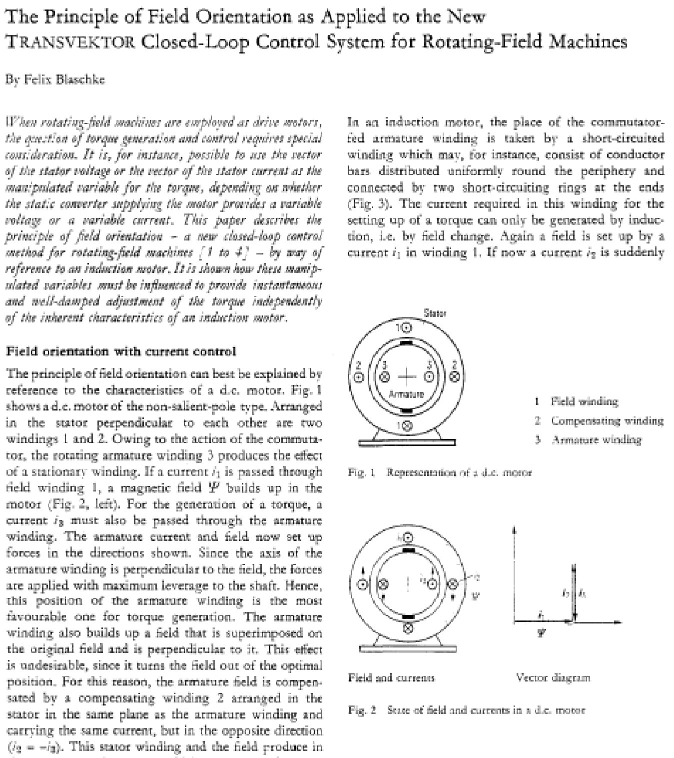


The Principle of Field Orientation as Applied to the New TRANSVEKTOR Closed-Loop Control System for Rotating-Field Machines

By Felix Blaschke

When rotating-field machines are employed as drive motors, the question of torque generation and control requires special consideration. It is, for instance, possible to use the vector of the stator voltage or the vector of the stator current as the manipulated variable for the torque, depending on whether the static converter supplying the motor provides a variable voltage or a variable current. This paper describes the principle of field orientation – a new closed-loop control method for rotating-field machines [1 to 4] – by way of reference to an induction motor. It is shown how these manipulated variables must be influenced to provide instantaneous and well-damped adjustment of the torque independently of the inherent characteristics of an induction motor.

Field orientation with current control

The principle of field orientation can best be explained by reference to the characteristics of a d.c. motor. Fig. 1 shows a d.c. motor of the non-salient-pole type. Arranged in the stator perpendicular to each other are two windings 1 and 2. Owing to the action of the commutator, the rotating armature winding 3 produces the effect of a stationary winding. If a current i_1 is passed through field winding 1, a magnetic field Ψ builds up in the motor (Fig. 2, left). For the generation of a torque, a current i_3 must also be passed through the armature winding. The armature current and field now set up forces in the directions shown. Since the axis of the armature winding is perpendicular to the field, the forces are applied with maximum leverage to the shaft. Hence, this position of the armature winding is the most favourable one for torque generation. The armature winding also builds up a field that is superimposed on the original field and is perpendicular to it. This effect is undesirable, since it turns the field out of the optimal position. For this reason, the armature field is compensated by a compensating winding 2 arranged in the stator in the same plane as the armature winding and carrying the same current, but in the opposite direction ($i_2 = -i_3$). This stator winding and the field produce in the stator a reaction torque which acts against the armature. The currents and the field may
vector diagram* shown on the rigl
machine, therefore, current i_1 forr
rents i_2 and i_3, together with the fiel

In an induction motor, the place of the commutator-fed armature winding is taken by a short-circuited winding which may, for instance, consist of conductor bars distributed uniformly round the periphery and connected by two short-circuiting rings at the ends (Fig. 3). The current required in this winding for the setting up of a torque can only be generated by induction, i.e. by field change. Again a field is set up by a current i_1 in winding 1. If now a current i_2 is suddenly

Stator
Armature

1 Field winding
2 Compensating winding
3 Armature winding

Fig. 1 Representation of a d.c. motor

Field and currents

Vector diagram

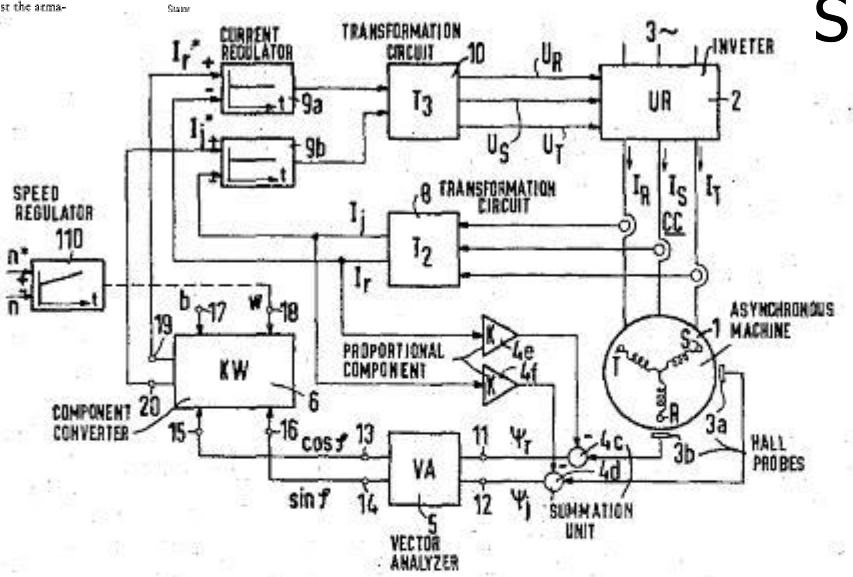
Fig. 2 State of field and currents in a d.c. motor

Stator

Dipl.-Ing. Felix Blaschke, Siemens Aktier
Measurement and Process Engineering D

* For a definition as space vectors due t
[5]. Space vectors and matrices are der

Siemens Review XXXIX (1972) No. 5



Načini realizacije vektorskog upravljanja

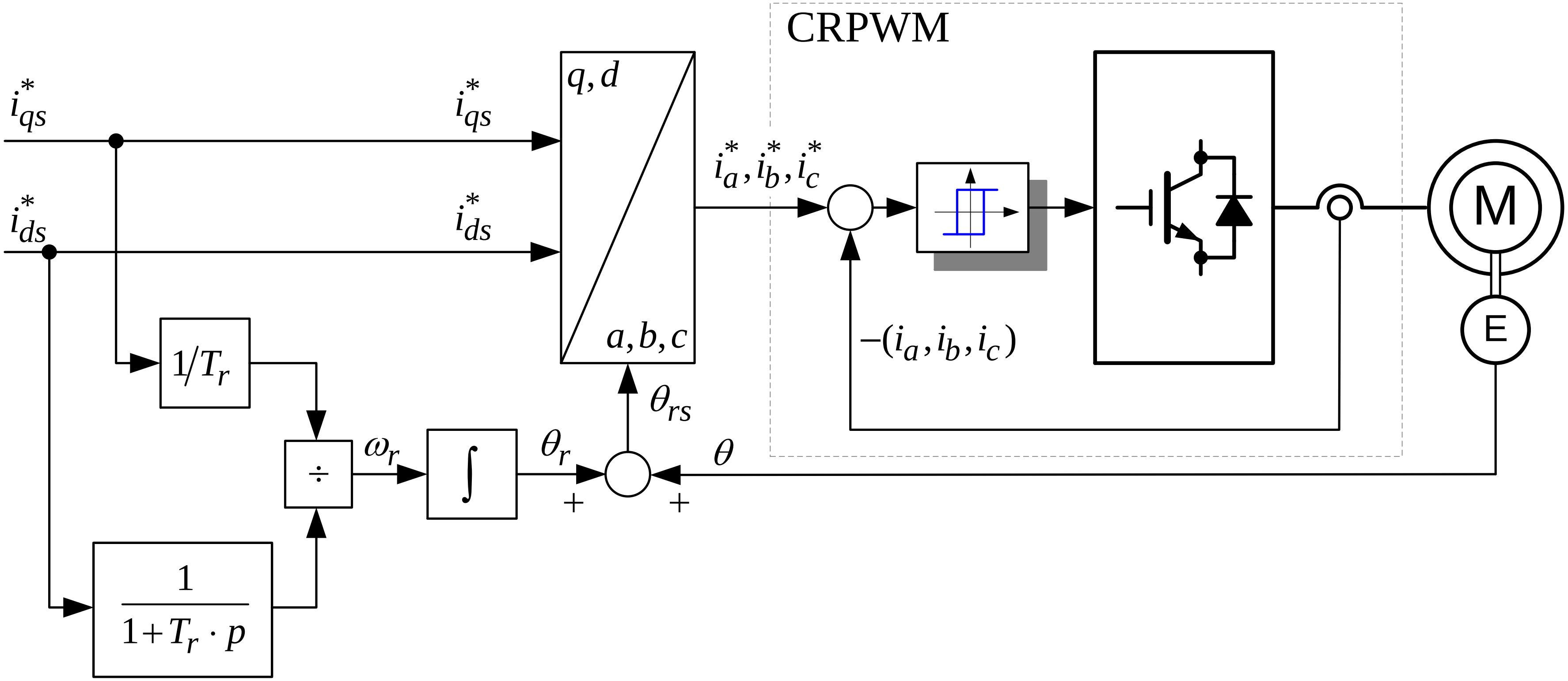
Indirektno vektorsko upravljanje Feed-Forward

- Na osnovu zadatih struja izračunava se rotorska učestanost (ω_r)
- Zbir rotorske učestanosti i brzine se koristi kao brzina referentnog sistema, a ugao sistema se dobija integracijom brzine referentnog sistema.
- Varijanta sa integracijom učestanosti rotorskih struja je bolje prilagođena realizacijama sa enkoderom.

Direktno vektorsko upravljanje Feed-Back

- Ugao referentnog sistema se određuje iz proračuna flukseva (na bazi merenja struja, podataka o naponu i brzini).
- Može se realizovati i bez podatka o uglu (brzini) vratila motora.

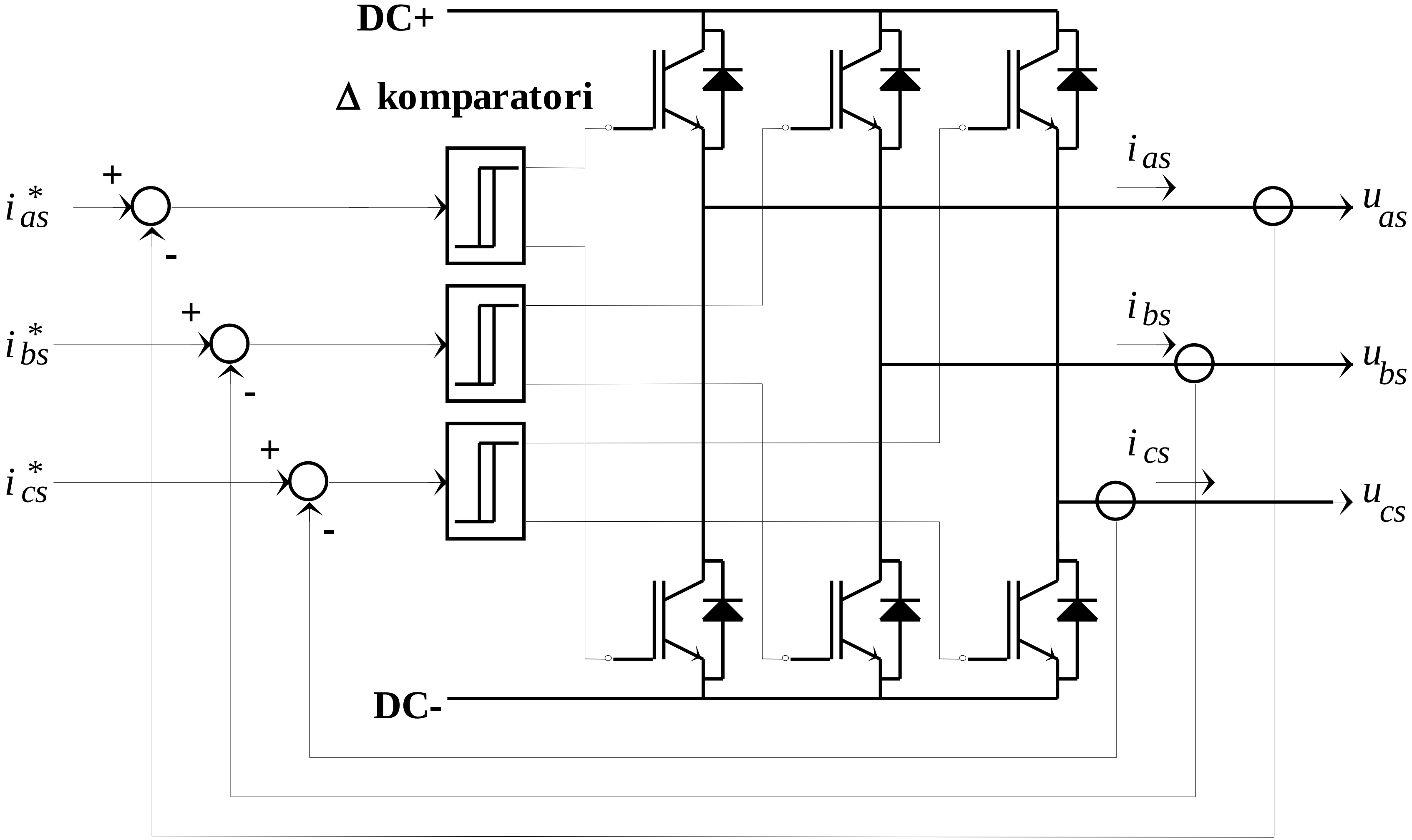
Indirektno vektorsko upravljanje
sa strujno regulisanim IŠM invertorom



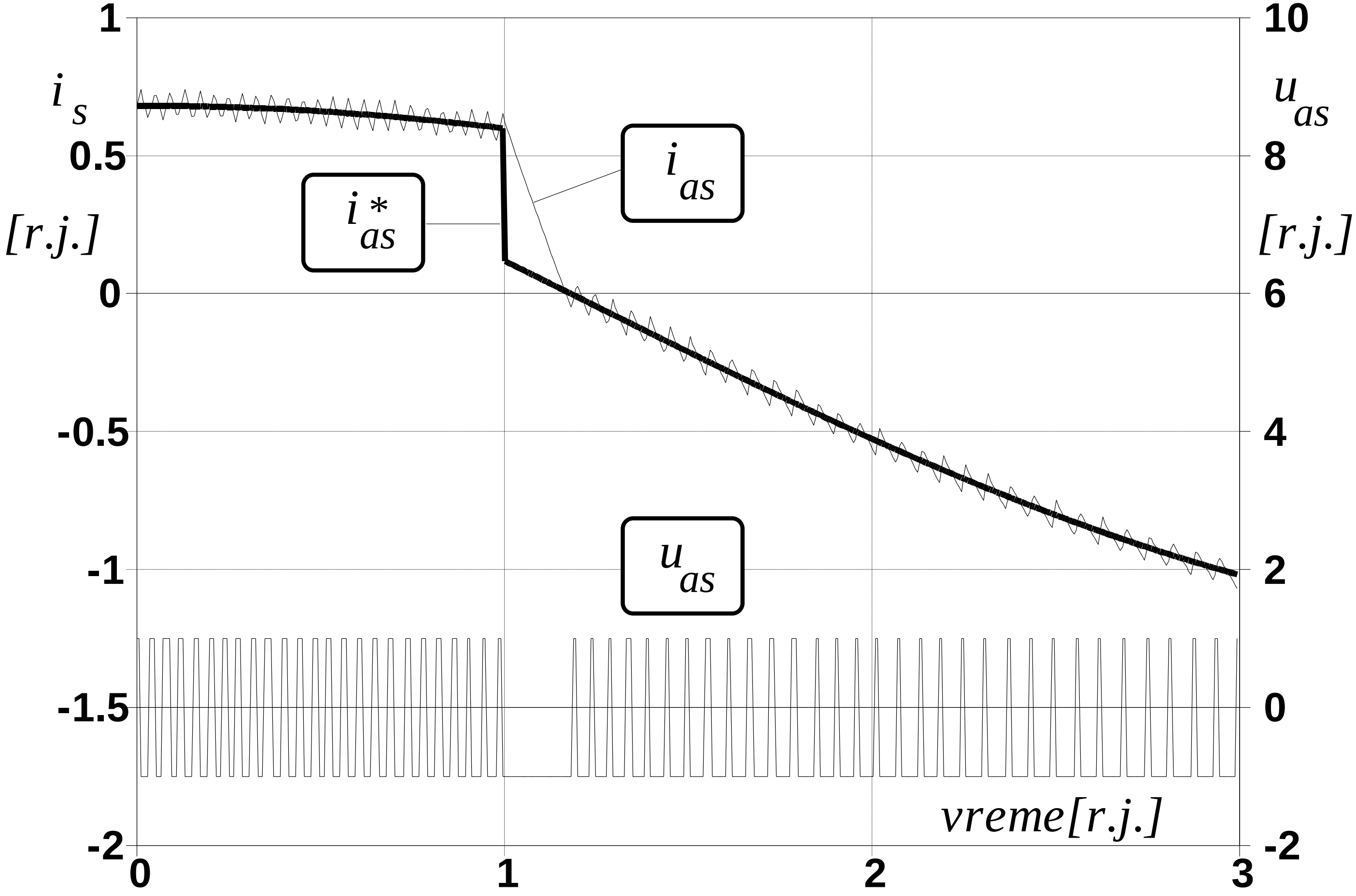
E – Enkoder, davač pozicije vratila motora

CRPWM
Current Regulated Pulse Width Modulated inverter

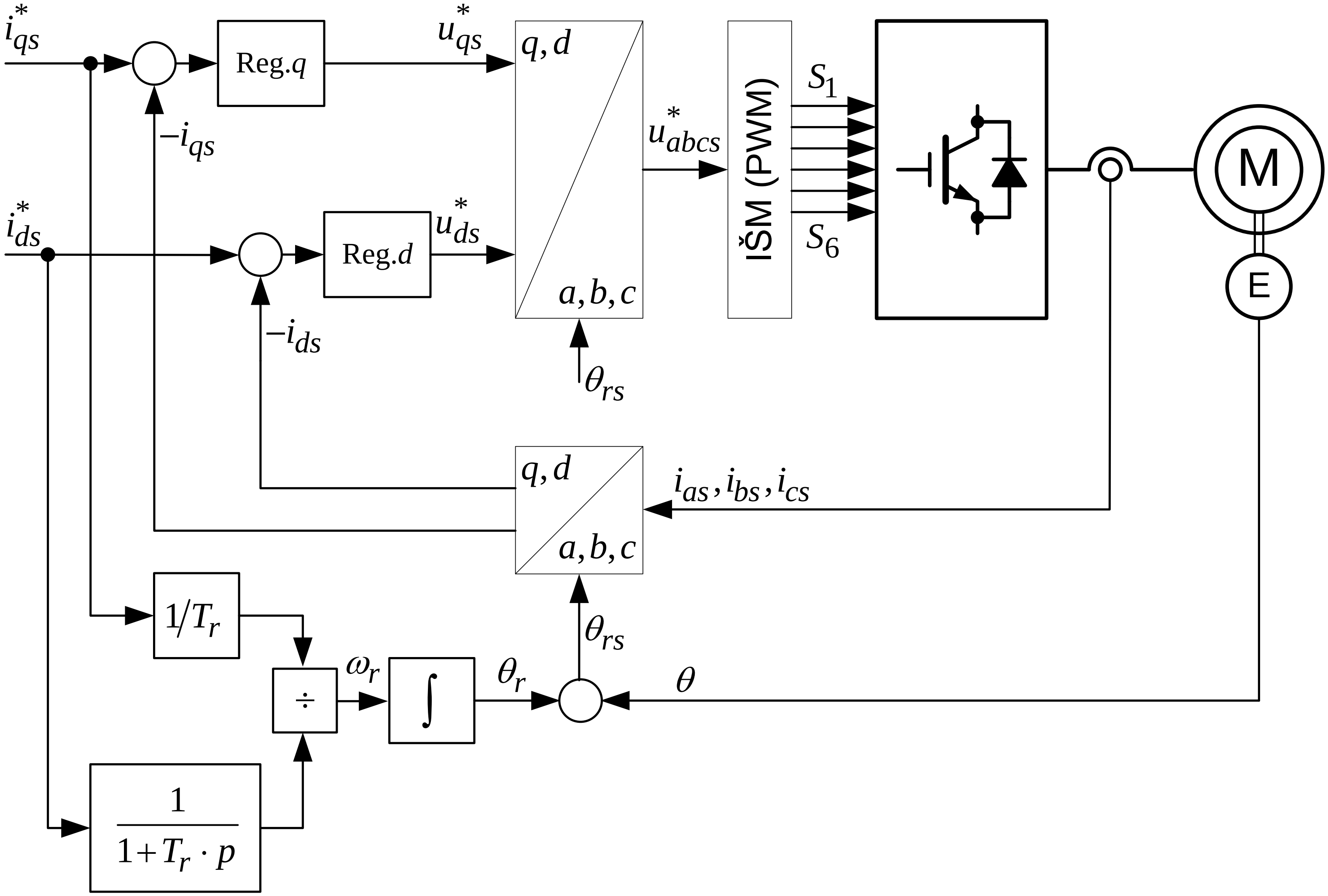
Principijelna blok šema strujno regulisanog IŠM (CRPWM) invertora



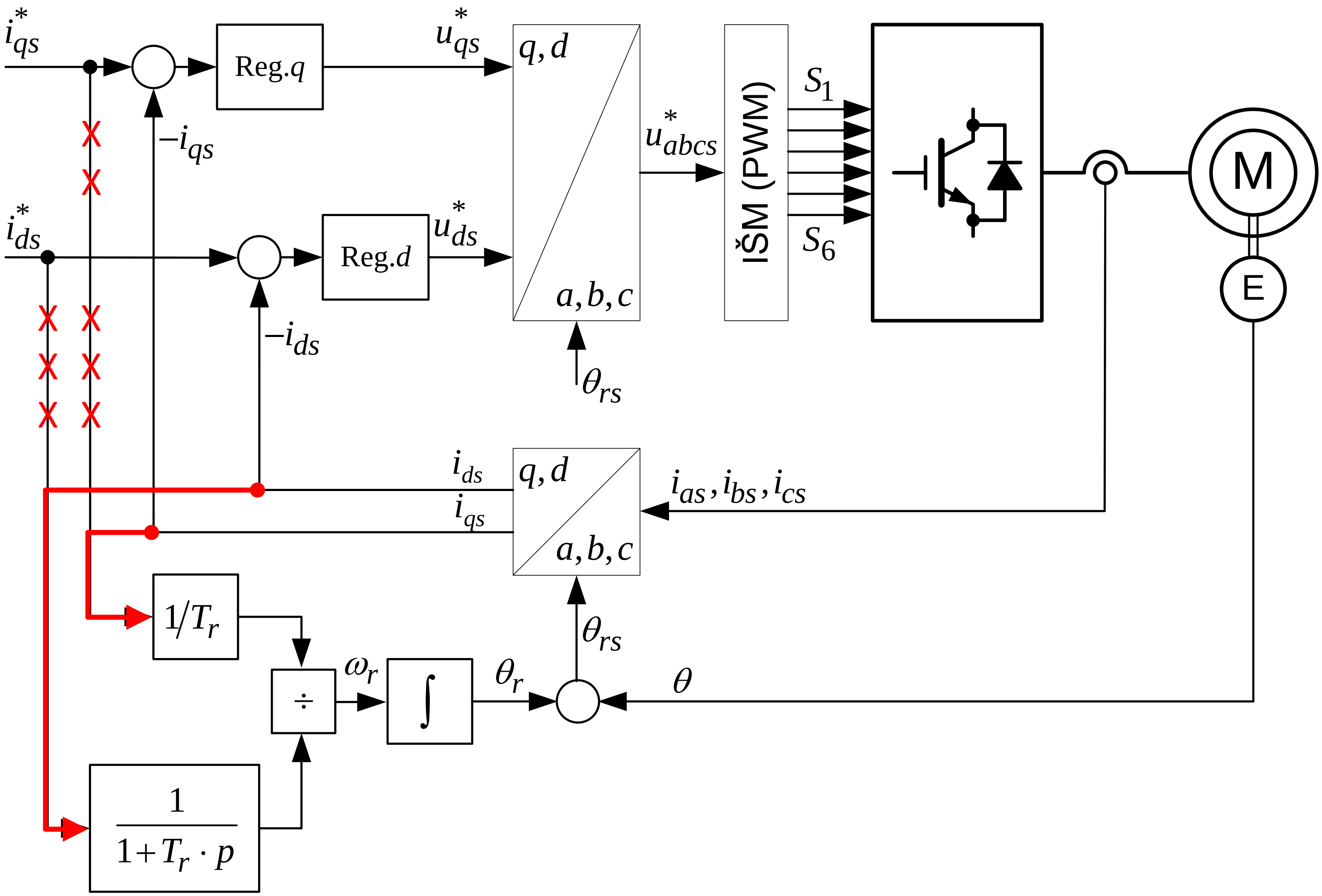
Prikaz rada histerezisnog regulatora struje



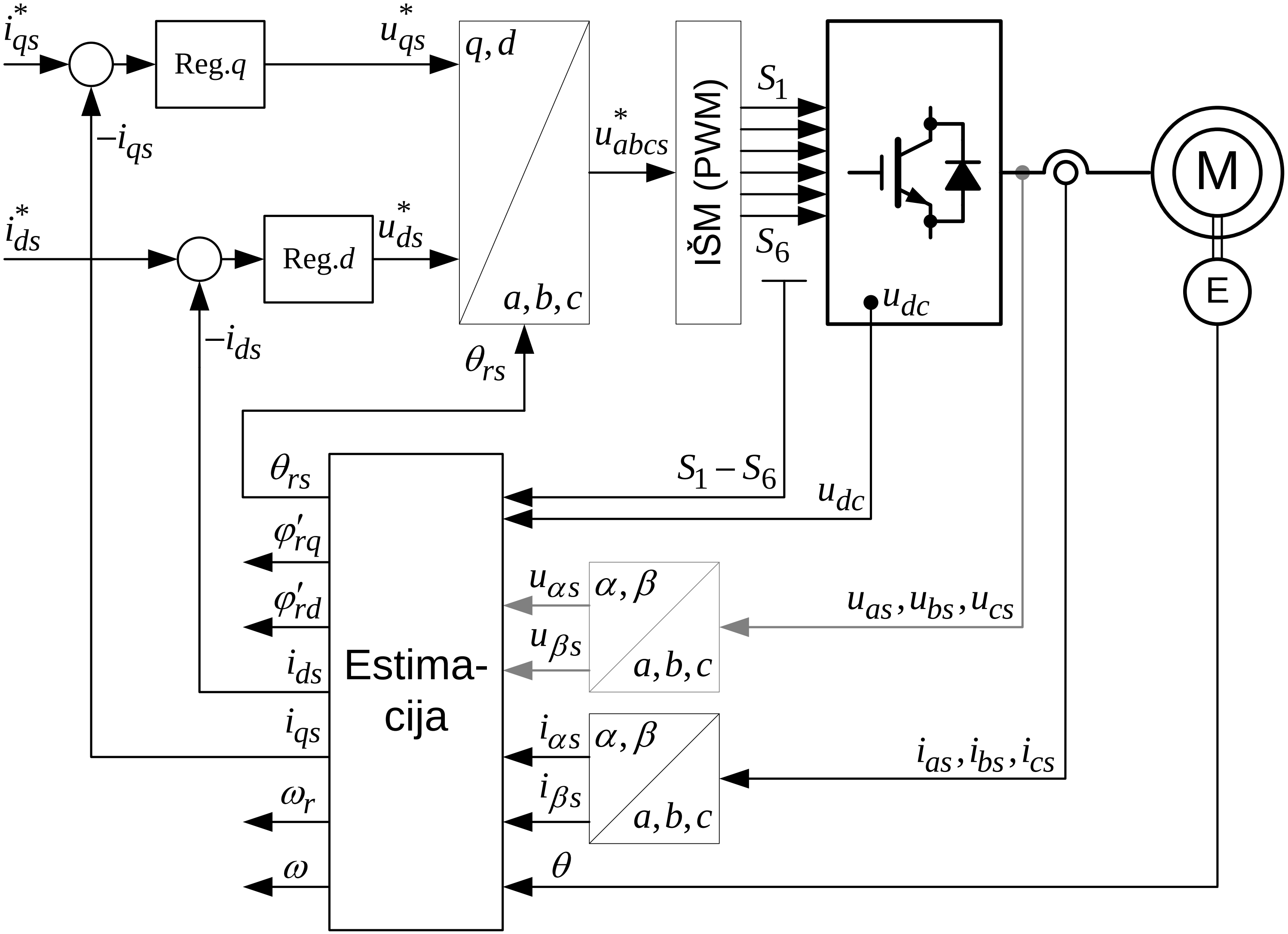
Indirektno vektorsko upravljanje sa IŠM invertorom i regulacijom struje u sinhrono rotirajućem koordinatnom sistemu



~~Indirektno~~ Direktno vektorsko upravljanje sa IŠM invertorom i regulacijom struje u sinhrono rotirajućem koordinatnom sistemu



Direktno vektorsko upravljanje sa IŠM invertorom i regulacijom struje u sinhrono rotirajućem koordinatnom sistemu



Struktura bloka estimacije u direktnom vektorskom upravljanju (naponski estimator flukseva)

$$\varphi_{\alpha s} = \int_0^t \left(u_{\alpha s} - R_s \cdot i_{\alpha s}\right) dt \qquad \varphi'_{\alpha r} = \frac{L_r}{M} \cdot \varphi_{\alpha s} - \frac{L_r \cdot L_r - M^2}{M} \cdot i_{\alpha s}$$

$$\varphi_{\beta s} = \int_0^t \left(u_{\beta s} - R_s \cdot i_{\beta s}\right) dt \qquad \varphi'_{\beta r} = \frac{L_r}{M} \cdot \varphi_{\beta s} - \frac{L_r \cdot L_r - M^2}{M} \cdot i_{\beta s}$$

$$\cos\theta_s = \frac{\varphi'_{\alpha r}}{\sqrt{\left(\varphi'_{\alpha r}\right)^2 + \left(\varphi'_{\beta r}\right)^2}}$$

$$\sin\theta_s = -\frac{\varphi'_{\beta r}}{\sqrt{\left(\varphi'_{\alpha r}\right)^2 + \left(\varphi'_{\beta r}\right)^2}}$$

Struktura bloka estimacije u direktnom vektorskom upravljanju (strujni estimator flukseva)

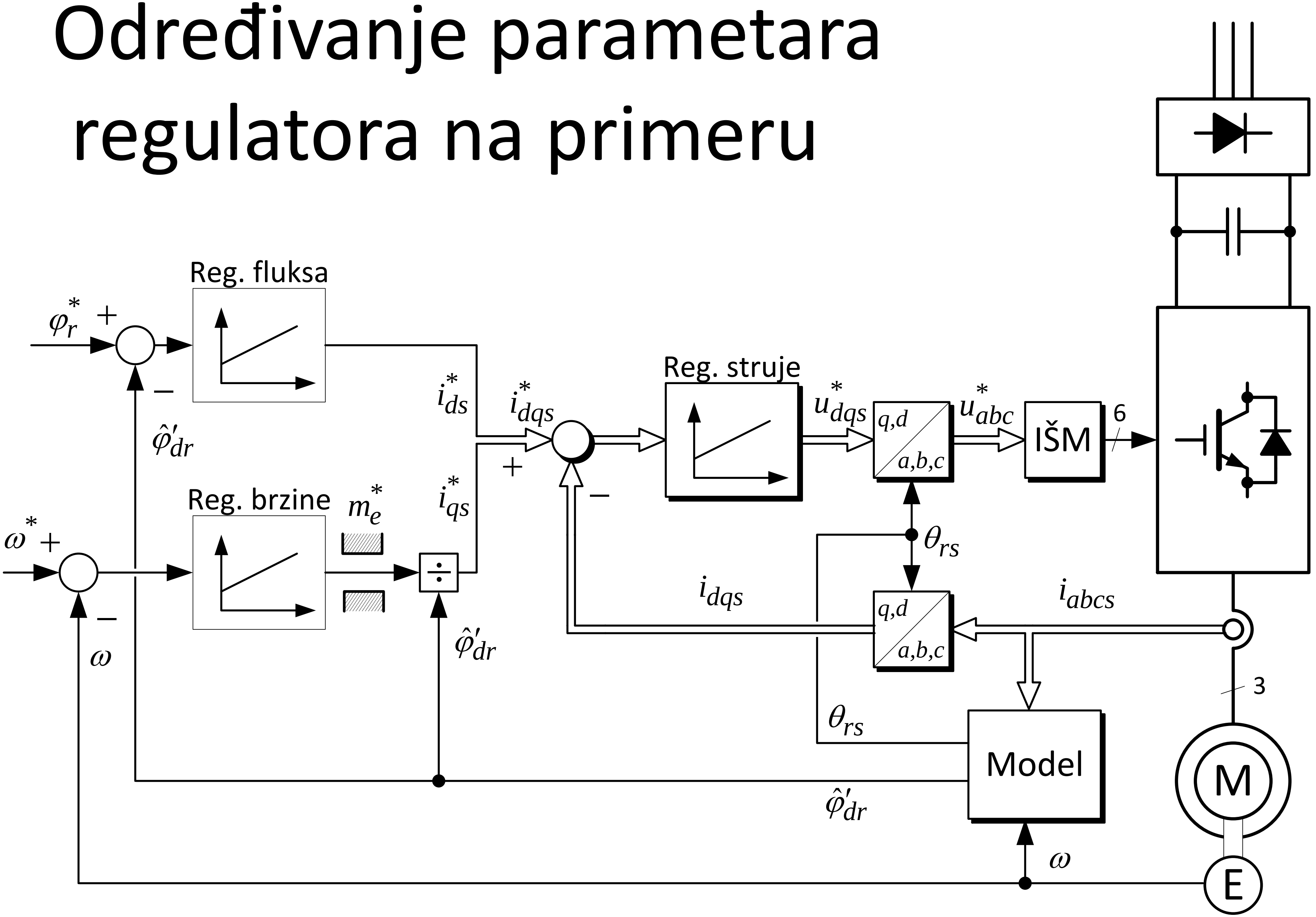
$$\varphi'_{\alpha r} = \int_0^t \left(\frac{R_r}{L_r} \cdot \left(M \cdot i_{\alpha s} - \varphi'_{\alpha r} \right) + \varphi'_{\beta r} \cdot \omega \right) dt$$

$$\varphi'_{\beta r} = \int_0^t \left(\frac{R_r}{L_r} \cdot \left(M \cdot i_{\beta s} - \varphi'_{\beta r} \right) - \varphi'_{\alpha r} \cdot \omega \right) dt$$

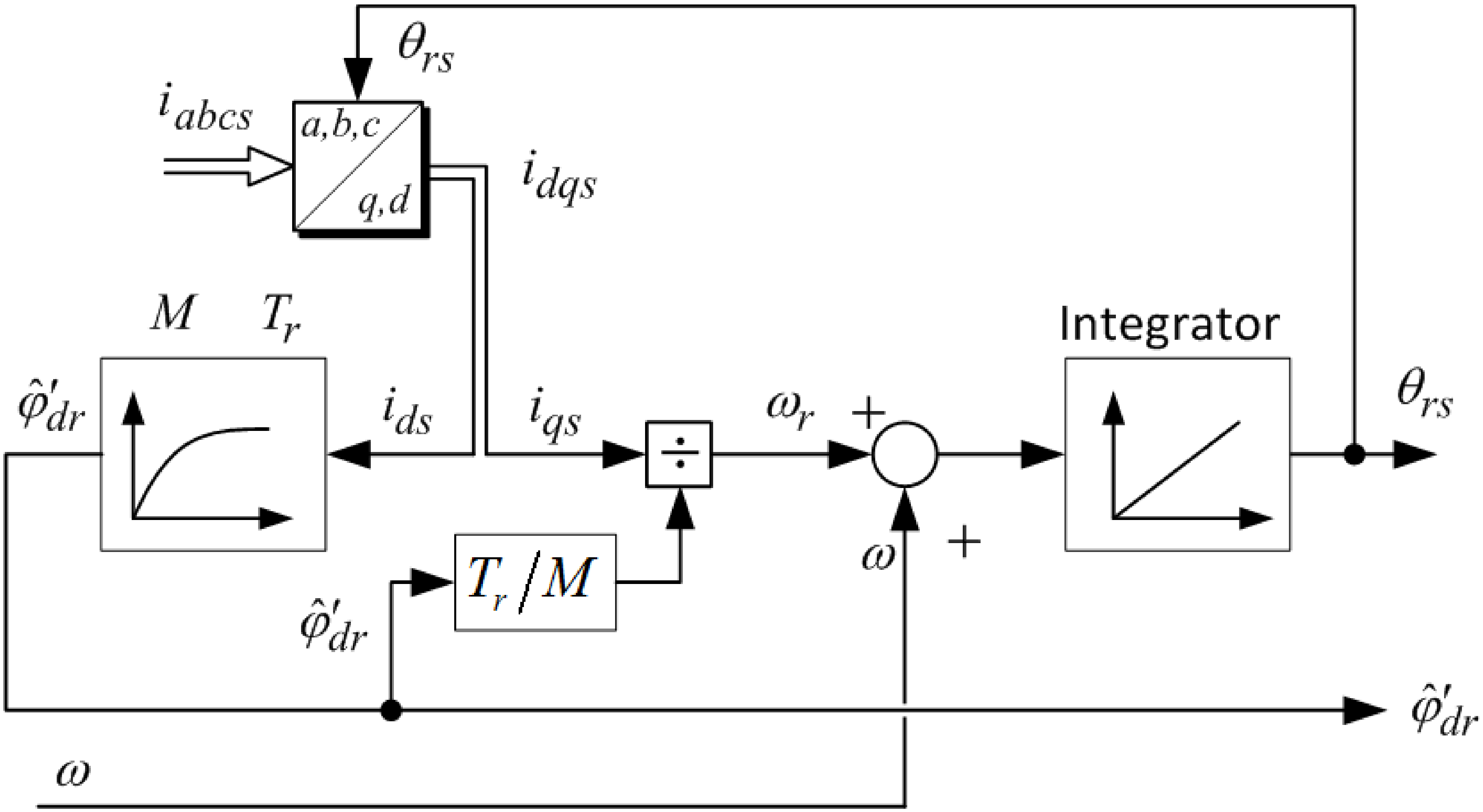
$$\cos\theta_s = \frac{\varphi'_{\alpha r}}{\sqrt{\left(\varphi'_{\alpha r}\right)^2 + \left(\varphi'_{\beta r}\right)^2}}$$

$$\sin\theta_s = -\frac{\varphi'_{\beta r}}{\sqrt{\left(\varphi'_{\alpha r}\right)^2 + \left(\varphi'_{\beta r}\right)^2}}$$

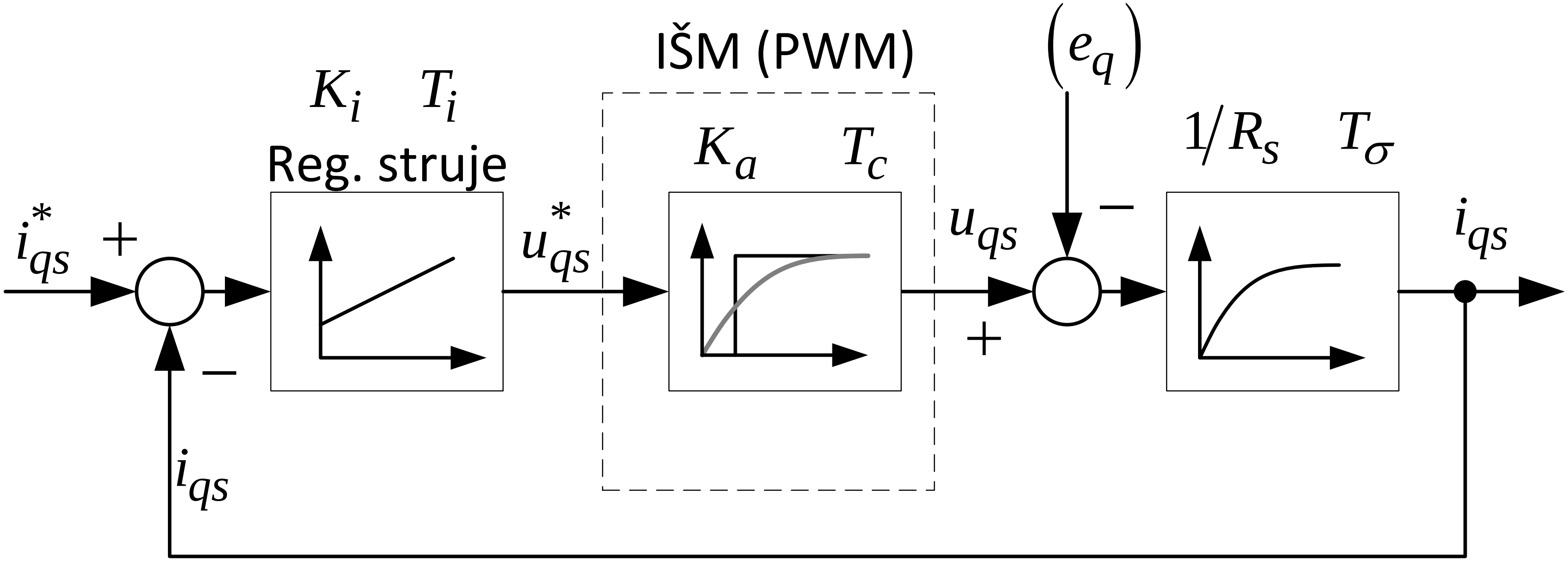
Određivanje parametara regulatora na primeru



Model za izračunavanje (estimaciju) ugla θ_{rs} i rotorskog fluksa $\hat{\varphi}'_{dr}$



Regulacija struje (*q*- osa, *d*-osa)

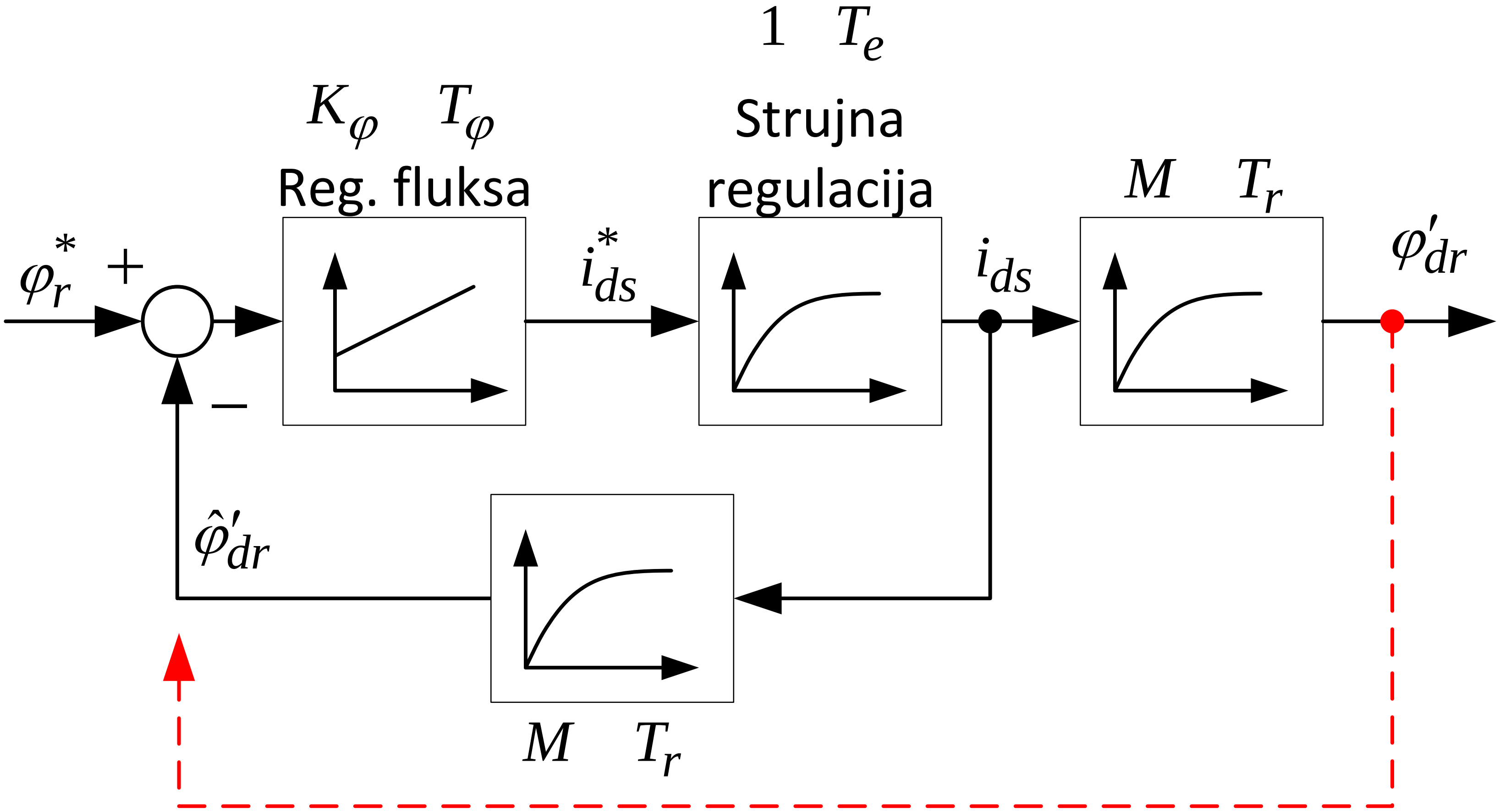


Može se primeniti kompenzacija vremenske konstante i modulni optimum.

$$T_\sigma = \frac{\left(L_s \cdot L_r' - M^2\right)\Big/ L_r'}{R_s}$$

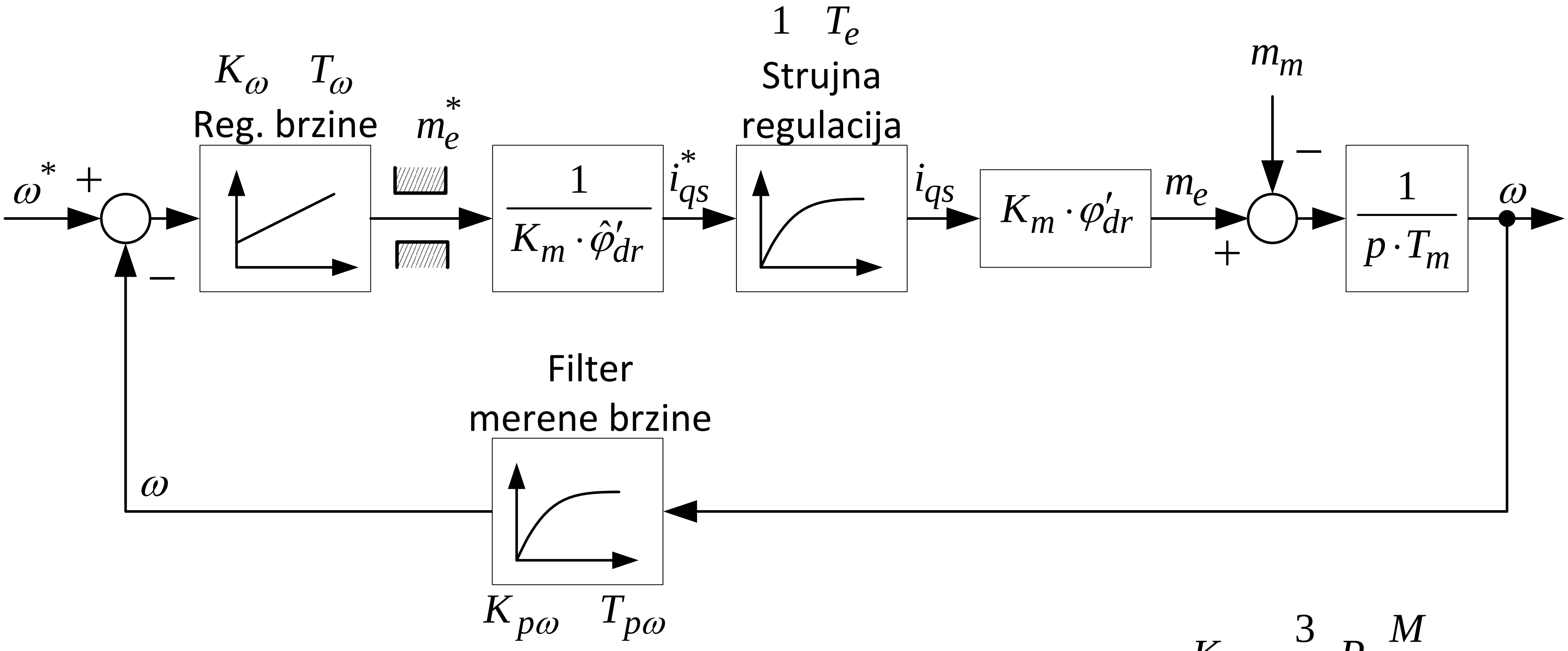
Strujni regulatori u *q* i *d* osi su simetrični, može se koristiti ista struktura i isti parametri regulatora.

Regulacija fluksa



Može se primeniti kompenzacija vremenske konstante i modulni optimum.

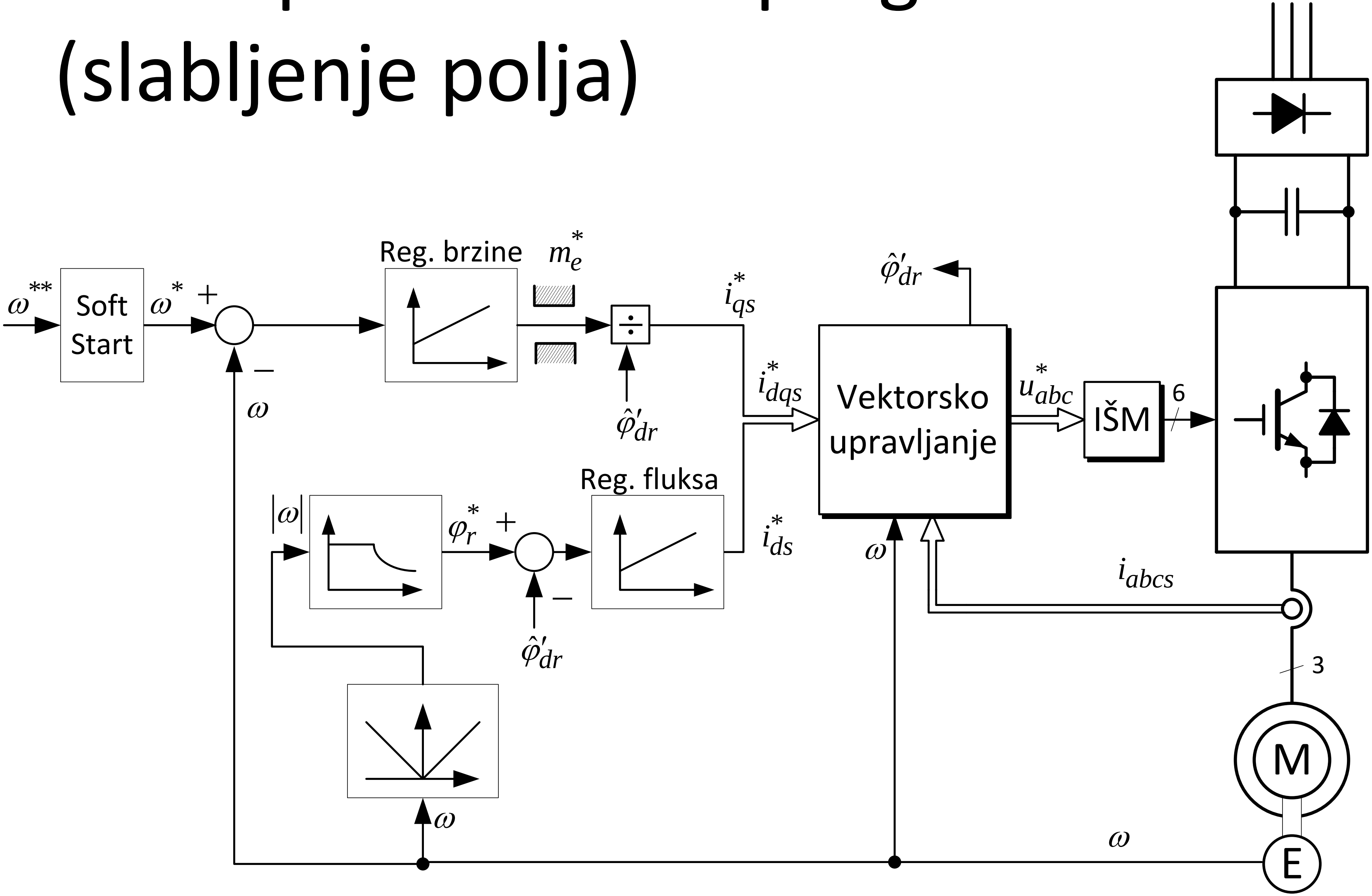
Regulacija brzine



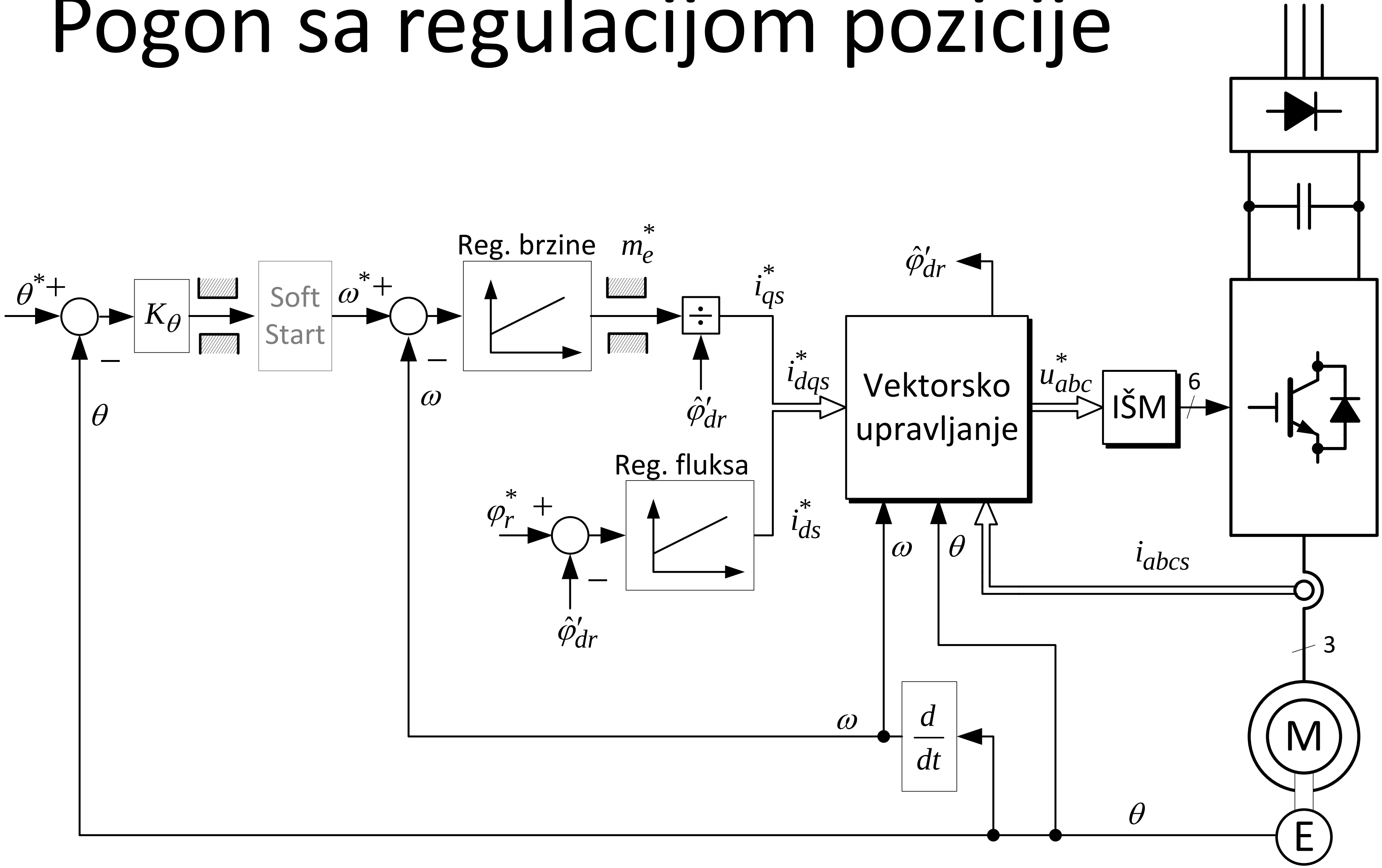
$$K_m = \frac{3}{2} \cdot P \cdot \frac{M}{L'_r}$$

Može se primeniti simetrični optimum.

Rad u proširenom opsegu brzina (slabljenje polja)



Pogon sa regulacijom pozicije



Pregled karakteristika

Prednosti:

- Brz i precizan odziv momenta motora.
- Optimalno iskorišćenje motora.
- Precizna regulacija brzine i pozicije.
- Koristi se isti energetski pretvarač.
- Povećana energetska efikasnost pri opterećenjima manjim od nazivnog.

Nedostaci:

- Potrebno više davača struje (min. 2).
- Potreban davač na vratilu (enkoder, rezolver).
- Potrebno poznavanje parametara motora.
- Zbog složenijeg algoritma koristi se procesor viših performansi.

Prevazilaženje nedostataka

Nedostaci:

• Potrebno više davača struje (min. 2).	✓ Postoji mogućnost da se signali faznih struja motora rekonstruišu iz signala struje jednosmernog međukola. Davačima su pale cene.
• Potreban davač na vratilu (enkoder, rezolver).	✓ Ukoliko su parametri motora tačno određeni i poznati, može se raditi bez davača na vratilu. Još uvek se ne postižu dobri rezultati na malim brzinama (učestanostima).
• Poznavanje parametara motora.	✓ Izuzetno važno pri radu bez davača na vratilu. Parametri motora se određuju veoma precizno prilikom puštanja pogona u rad. U toku rada pogona se vrši kontinualno praćenje parametara motora – auto tuning.
• Koristi se procesor viših performansi.	✓ Procesorima visokih performansi su pale cene. Ipak, ovo je često izgovor za veću cenu pogona.

Za one koji žele više...

- U sledećem terminu
  - Regulisani pogon sa direktnom kontrolom momenta asinhronog motora
- Laboratorijske vežbe – Praktikum
  - **Regulisani pogon sa vektorski upravljanim asinhronim motorom**
  - Primena industrijskih pretvarača učestanosti za upravljanje asinhronim pogonom
- Seminarski rad (uz podršku nastavnika i literature)
- Predmeti:
  - Odabrana poglavlja iz elektromotornih pogona (MS)
  - Energetski efikasni elektromotorni pogoni (MS)
  - **Digitalno upravljanje pretvaračima i pogonima**
- Literatura