4.4 DC-Motor with rectifier

The DC-motor can be supplied from a single-phase contact line through a rectifier, push-pull or diode bridge. The motor is very similar as which one controlled by chopper, without all sophisticated devices in direct motor. In the first built vehicles, the rectifier is fixed and the voltage is controlled by a tapped transformer (BLS: Re 4/4, SNCF: BB 16500). In braking, the rectifier provides the excitation voltage – lower than voltage in traction – and the motor armature gives current to a fixed braking resistance (CFR: 060-EA).

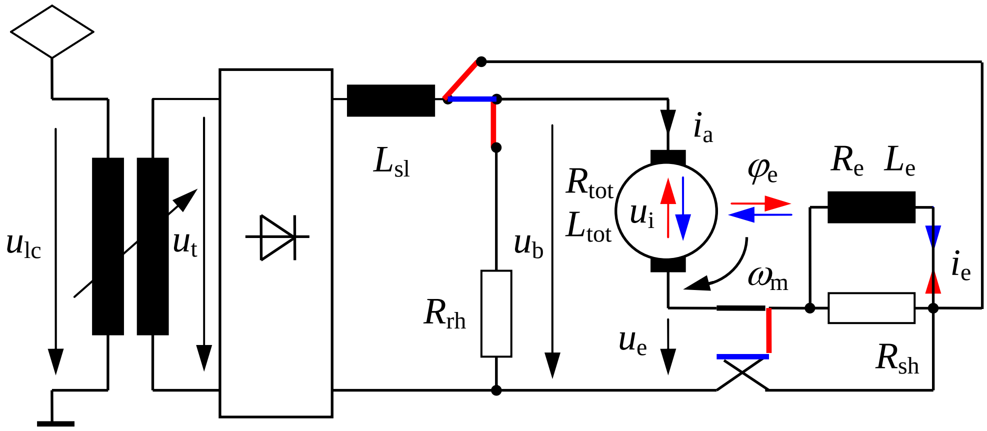

Fig. 4.112 DC-motor with rectifier: traction.
Fig. 4.119 DC-motor with rectifier: rheostatic braking with separate excitation.

The current in the transformer is in phase with the voltage and in approximately rectangular form if the motor inductivity is high. The characteristics deformation at low speed is not present as on a direct motor.

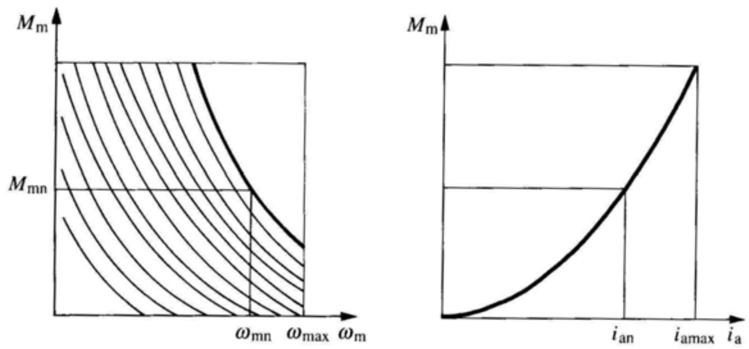

Fig. 4.118 DC-motor with rectifier in traction: characteristics versus current and speed.

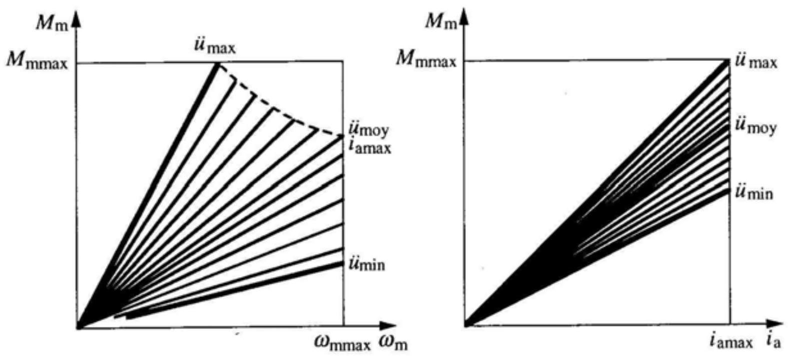

Fig. 4.121 DC-motor with rectifier in rheostatic braking: characteristics versus current and speed.

The development of semi–conductors allowed to build controlled rectifiers, the output voltage is determined by the opening angle of thyristors. The work-point can be changed without discontinuity. The bridge can be full-controlled (CFF Ee 3/3 16502) or half-controlled (SNCF CC 21000). Le rapport du transformateur est alors fixe. En freinage, le redresseur règle le courant d'excitation (RAG : EA1000).

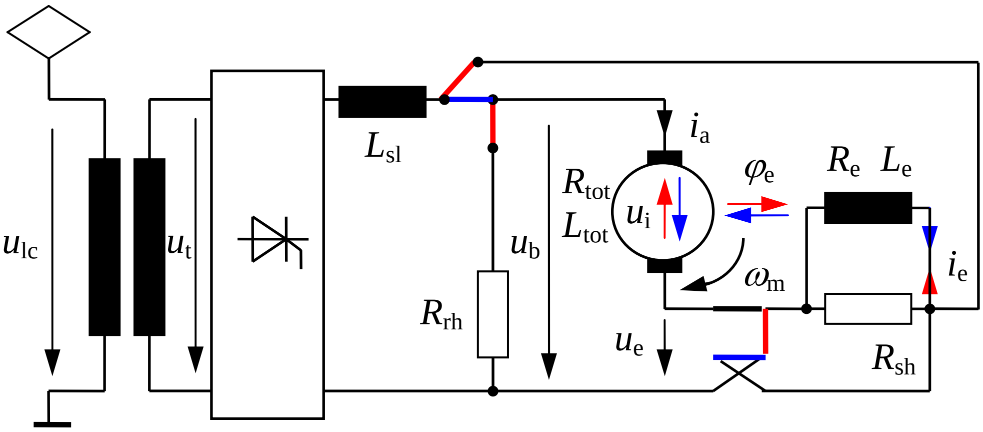

Fig. 4.122 DC-motor with controlled rectifier: traction.
Fig. 4.133 DC-motor with controlled rectifier: rheostatic braking with separate excitation.

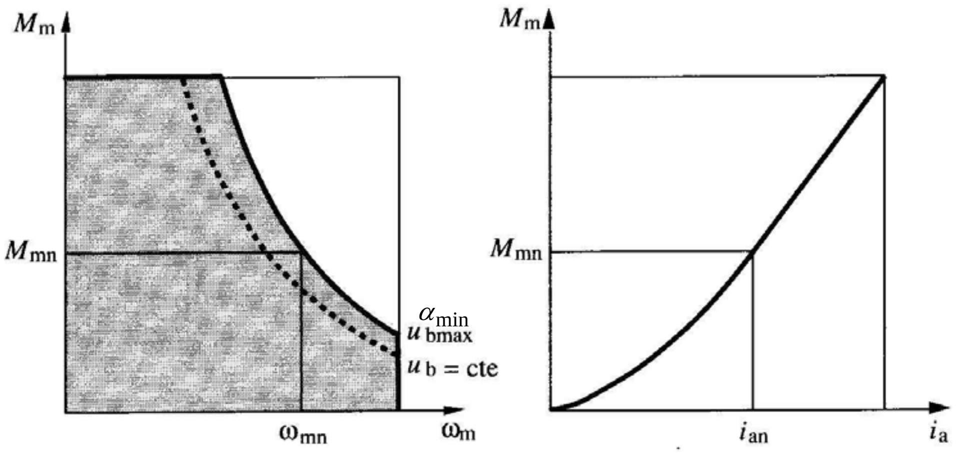

Fig. 4.129 DC-motor with controlled rectifier in traction: characteristics versus current and speed.

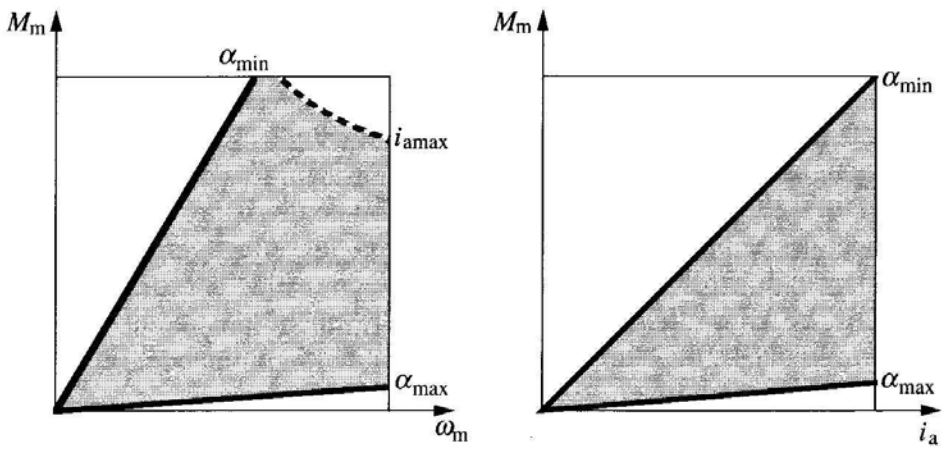

Fig. 4.136 DC-motor with controlled rectifier in rheostatic braking: characteristics versus current and speed.

The simple rectifiers as used in the first vehicles are shown below. More complex mounting will be presented further, with the target to reduce reactive power and harmonics in the contact line.

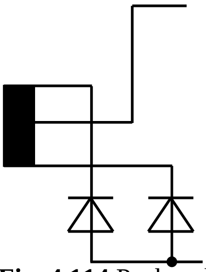

Fig. 4.114 Push-pull.

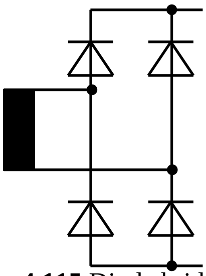

Fig. 4.115 Diode bridge.

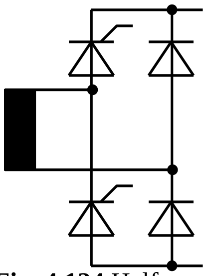

Fig. 4.124 Half-controlled.

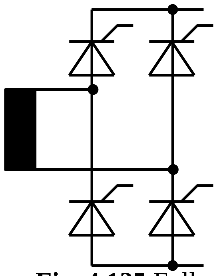

Fig. 4.125 Full-controlled.

A full-controlled bridge can drive a regenerative braking. (CFF : Ee 3/3 II).

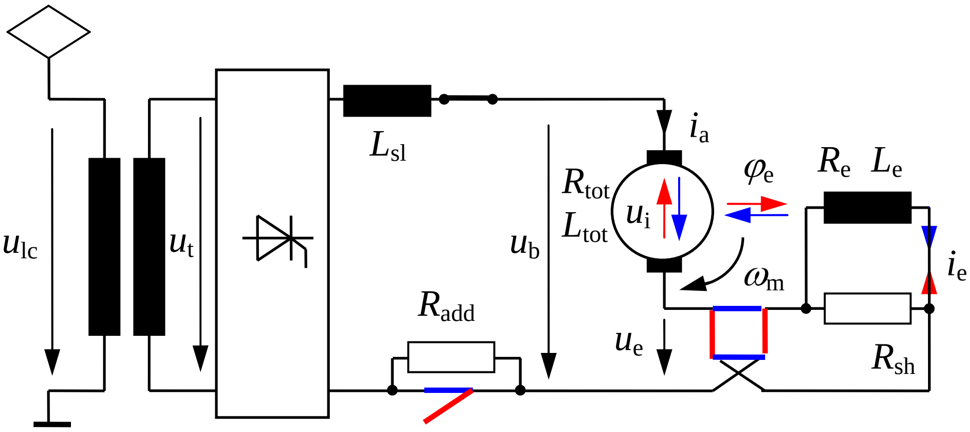

Fig. 4.122 DC-motor with controlled rectifier: traction.
Fig. 4.130 DC-motor with controlled rectifier: regeneration braking with series excitation.

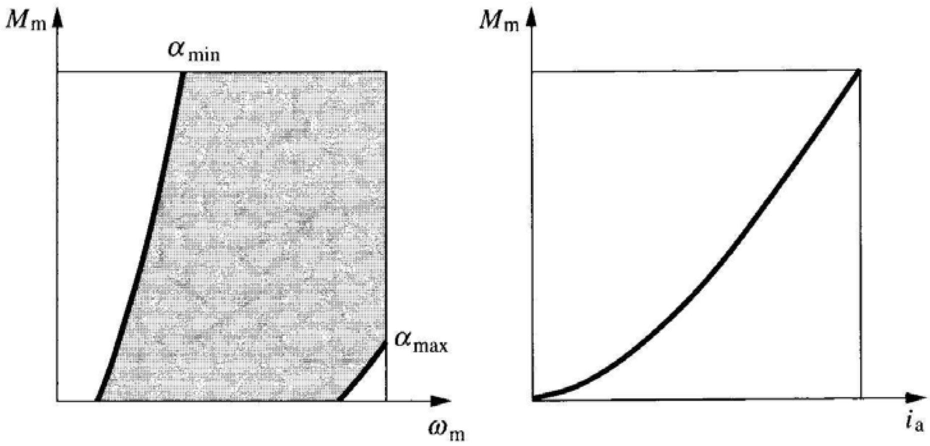

Fig. 4.132 DC-motor with controlled rectifier in regenerative braking: characteristics versus current and speed.

To limit the effects on supply network, bridges in cascade were adopted with two levels (Fig. 4.139), 3 levels (Fig. 4.139A) or 4 levels (Fig. 4.140). In these solutions, the control of par triggering angle is only present on one (bridge I), the other are blocked or full opened. As for motors supplied from continuous voltage, the field weakening can be used to extend their working area. (Fig. 4.142). One solution uses auxiliary thyristors T_{sh} which are triggered during the conducting phase of the main bridge.

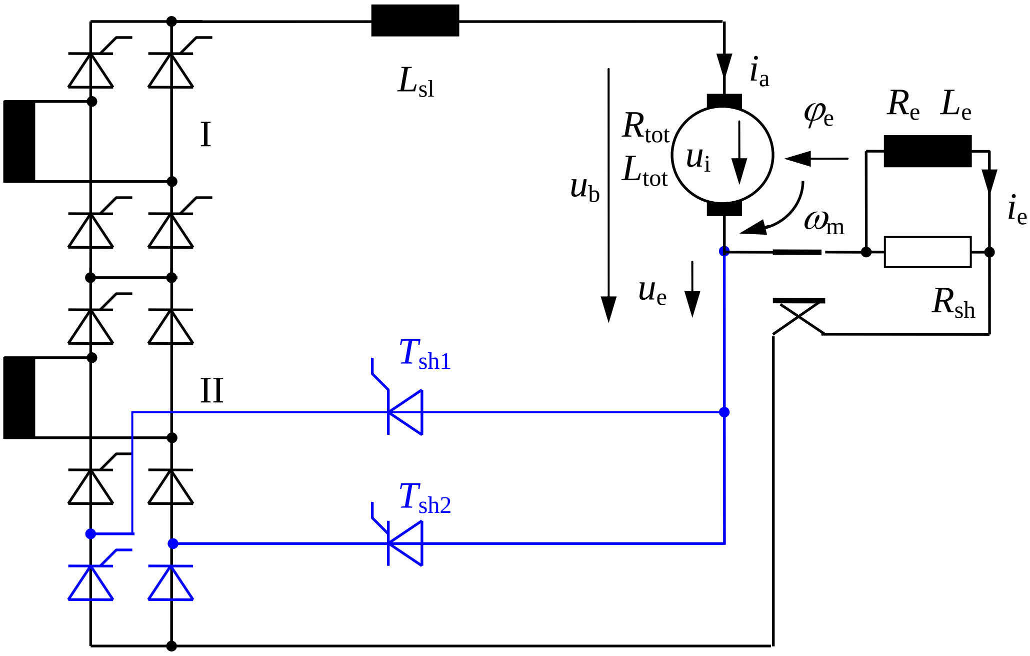

Fig. 4.139 Two bridges in cascade.
Fig. 4.142 Two bridges in cascade with field weakening (SNCF : BB 15000).

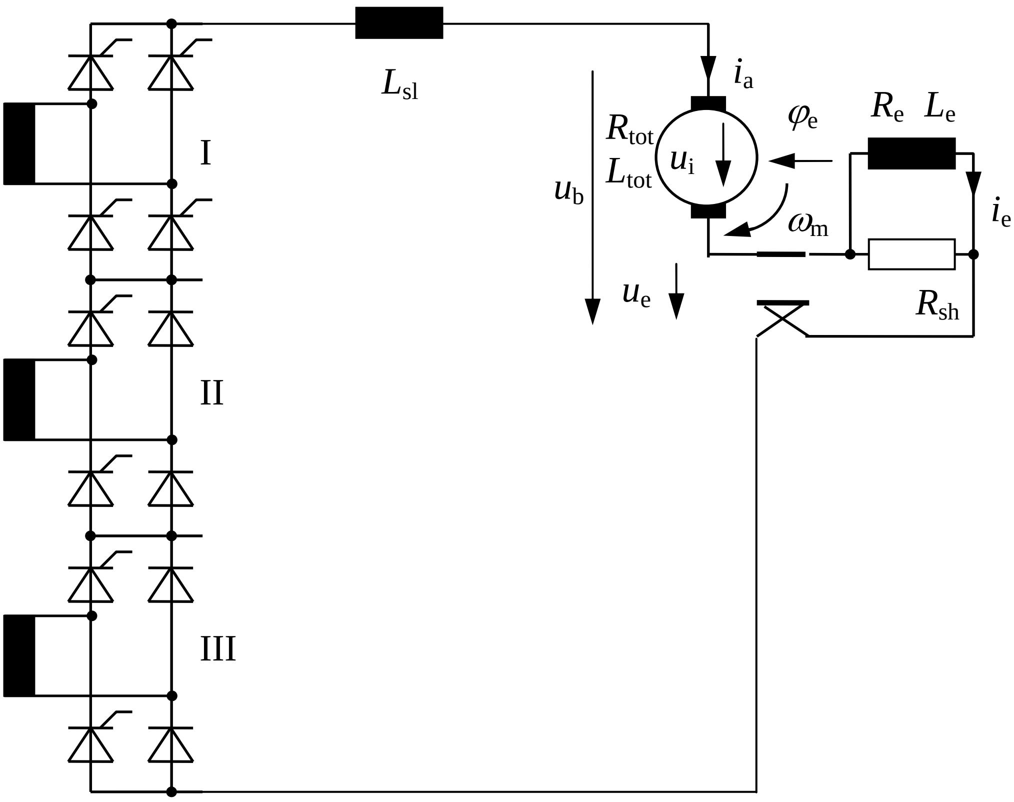

Fig. 4.139 A Three bridges in cascade. (SJ : Rc 1).

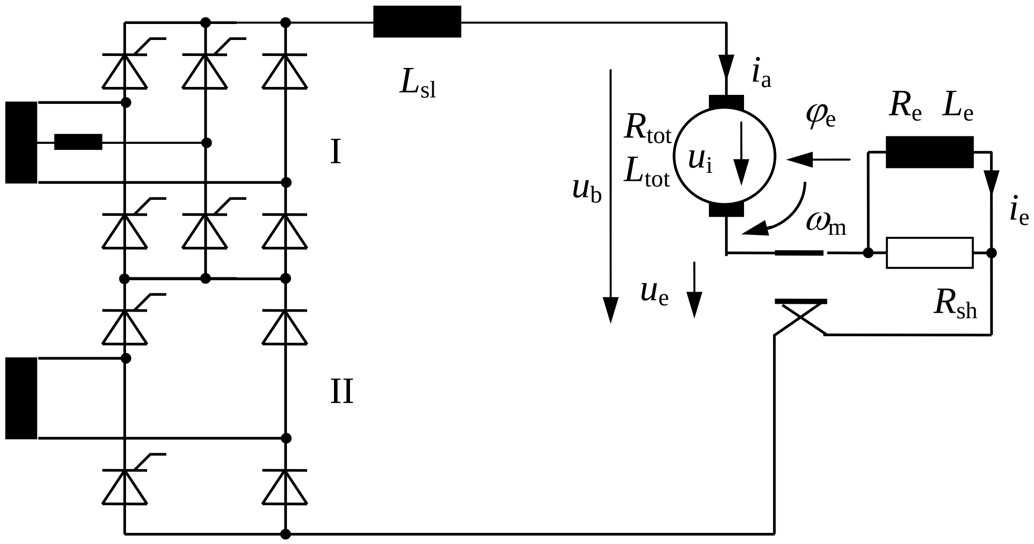

Fig. 4.140 Four bridges in economical mounting (ÖBB : 1044).

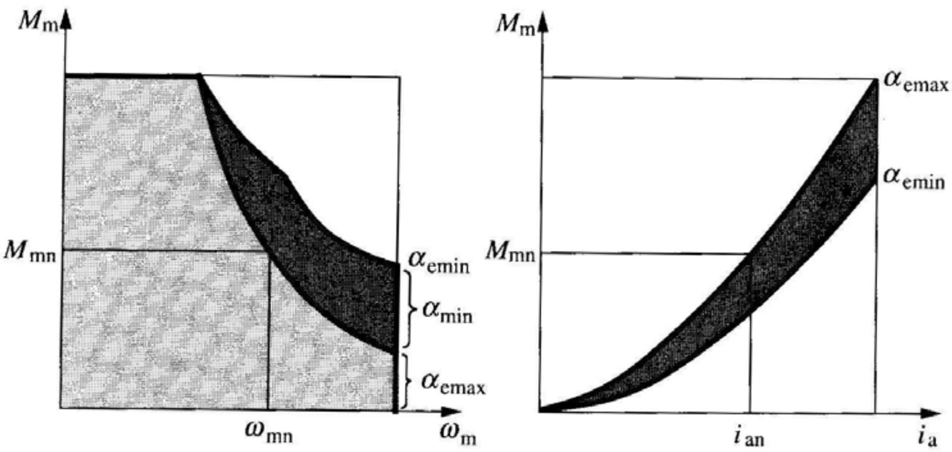

Fig. 4.143 Characteristics in traction with field weakening.

In traction and in braking, separate excitation can be provided by a dedicated secondary of transformer and another rectifier (Fig. 4.145). The excitation rectifier can be controlled (II) in order that the current i_e which produces field follows armature current until full opening of main bridge (I), in this case, it is called simulated-series-motor (RhB : Be 4/4). The torque characteristic is presented above (Fig. 4.143). With the same circuit, a constant induction current can be chosen until full opening of main bridge (SJ : X1) (Fig. 4.143A, p. 4.4-7). In both cases, the field weakening is obtained by increasing of triggering angle at bridge II. In braking, the main bridge I is controlled as inverter and the bridge II controls the excitation current to maintain a sufficient induced voltage at low speed.

The motor can also have two excitation windings: one in series and the other powered by a separate bridge. It is called *compound excitation* (CFF : RBDe 4/4). At minimal field, only the series winding receives the armature current, the bridge II is blocked (fig. 4.148, p. 4.4-10).

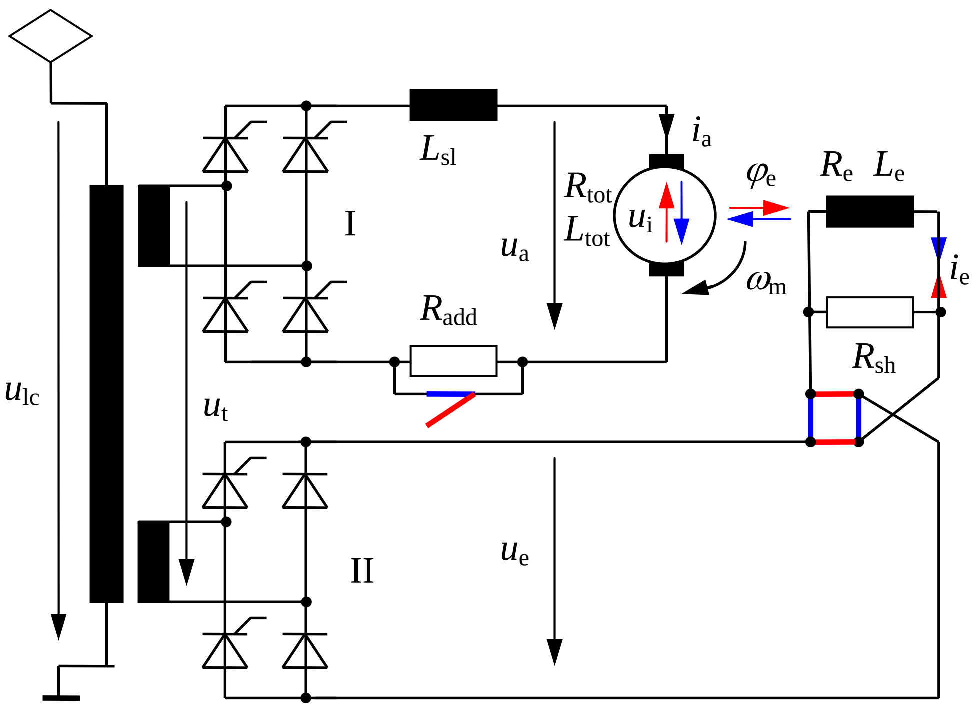

Fig. 4.145 DC-motor with controlled rectifier with separate excitation: in traction and in regeneration braking.

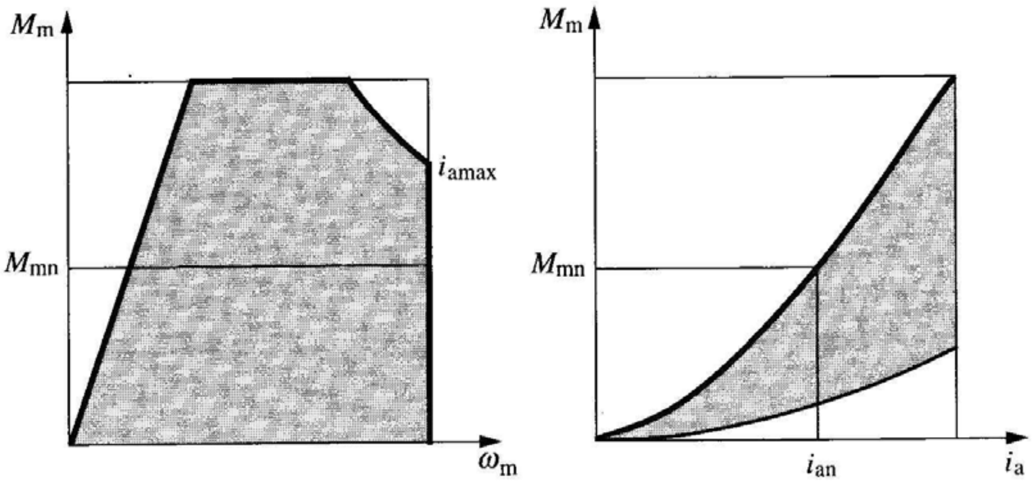

Fig. 4.147 DC-motor with controlled rectifier with separate excitation: characteristics versus current and speed.

The rectifier, as the chopper (sect.4.3) has to be computed for the maximal motor power and not the nominal power (see p. 4.4-11).