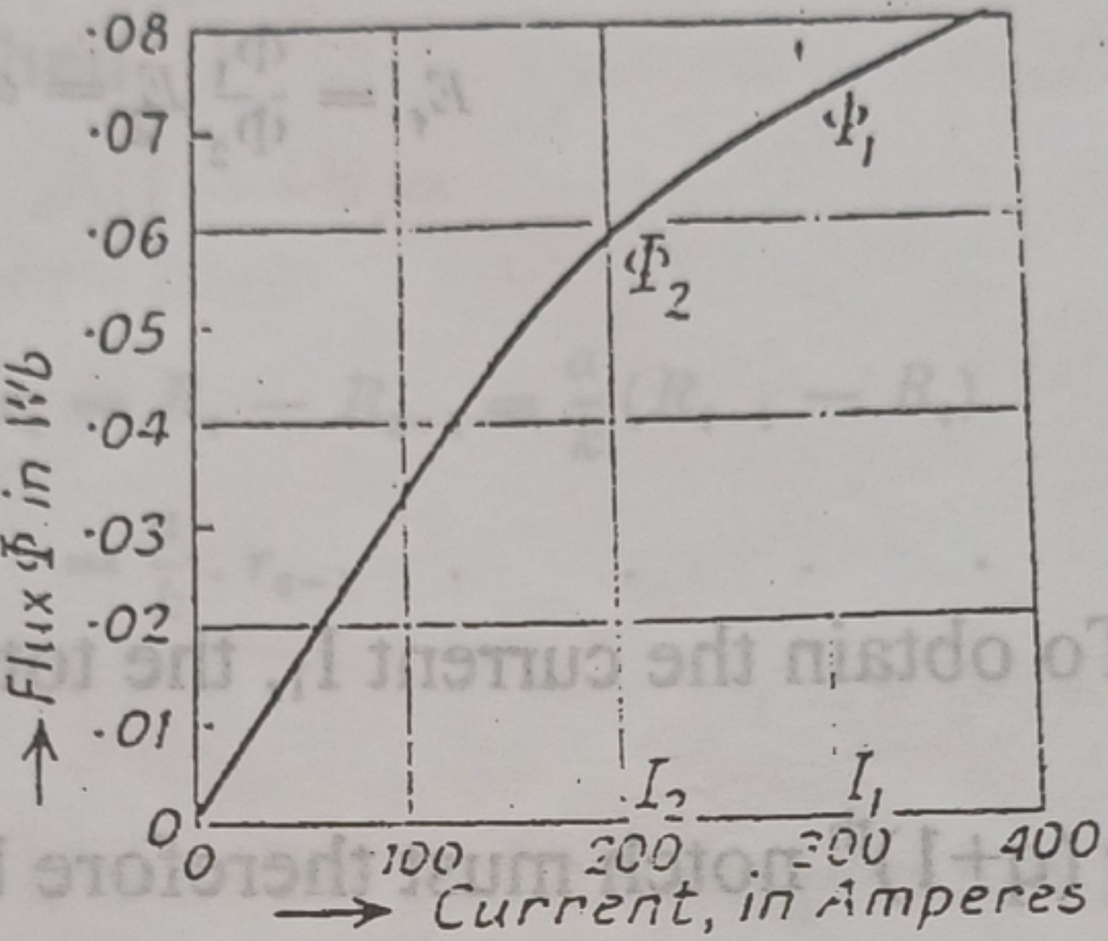
Grading starting resistance for dc series motor

The flux varies with the armature current is shown in fig.



Let φ_1 and φ_2 respectively be the flux established when the current is I_1 and I_2.

Let $\varphi_1/\varphi_2 = a$

Then , dealing with the q^{th} and $(q+1)^{th}$ studs

when the current is I_2

$$E_2 = V - I_2 R_q$$

If notching up then takes place, and the current

at once rises to the value I_1

$$E_1 = \frac{\Phi_1}{\Phi_2} E_2 = aE_2$$

To obtain the current I_1, the total resistance in circuit

on the $(q+1)^{th}$ notch must therefore be

$$R_{q+1} = \frac{V - E_1}{I_1} = \frac{V - a(V - I_2 R_q)}{I_1}$$

$$= R_1(1 - a) + \frac{a}{k} R_q \quad . \quad . \quad . \quad . \quad .$$

The current ratios are the same on all notches

$$k = I_1 / I_2$$

Hence by substituting q-1 for q

$$R_q = R_1(1 - a) + \frac{a}{k} R_{q-1} \quad .$$

The value of the resistance element between the q^{th} and $(q+1)^{th}$ stud is then

$$r_q = R_q - R_{q+1} = \frac{a}{k}(R_{q-1} - R_q)$$

$$= \frac{a}{k} \cdot r_{q-1} \quad . \quad . \quad . \quad . \quad . \quad .$$

The common ratio is now

$$b = \frac{a}{k} = \frac{\Phi_1}{\Phi_2} \times \frac{I_2}{I_1}.$$

The total resistance in the circuit at starting may be expressed

$$R_1 = r_1 + r_2 + \ldots + r_n + r_m$$

$$= r_1(1 + b + b^2 + \ldots b^{n-1}) + r_m$$

$$= r_1 \times \frac{1 - b^n}{1 - b} + r_m \quad . \quad . \quad . \quad .$$

The value of r_1 is obtained

$$r_1 = R_1 - R_2 = R_1 - \left\{R_1(1-a) + \frac{a}{k}R_1\right\}$$

$$= aR_1\left(\frac{k-1}{k}\right)$$

$$= \dot{o}(k-1)R_1$$

If the magnetization curve is a straight –line

$$a = k = \frac{\Phi_1}{\Phi_2} = \frac{I_1}{I_2} \text{ and } \dot{o} = 1$$

Under this conditions all the resistance element have exactly the same value

$$r_1 = \dot{o}R_1(a-1) = (a-1)R_1$$

$$r_1 = \frac{R_1 - r_m}{n}$$

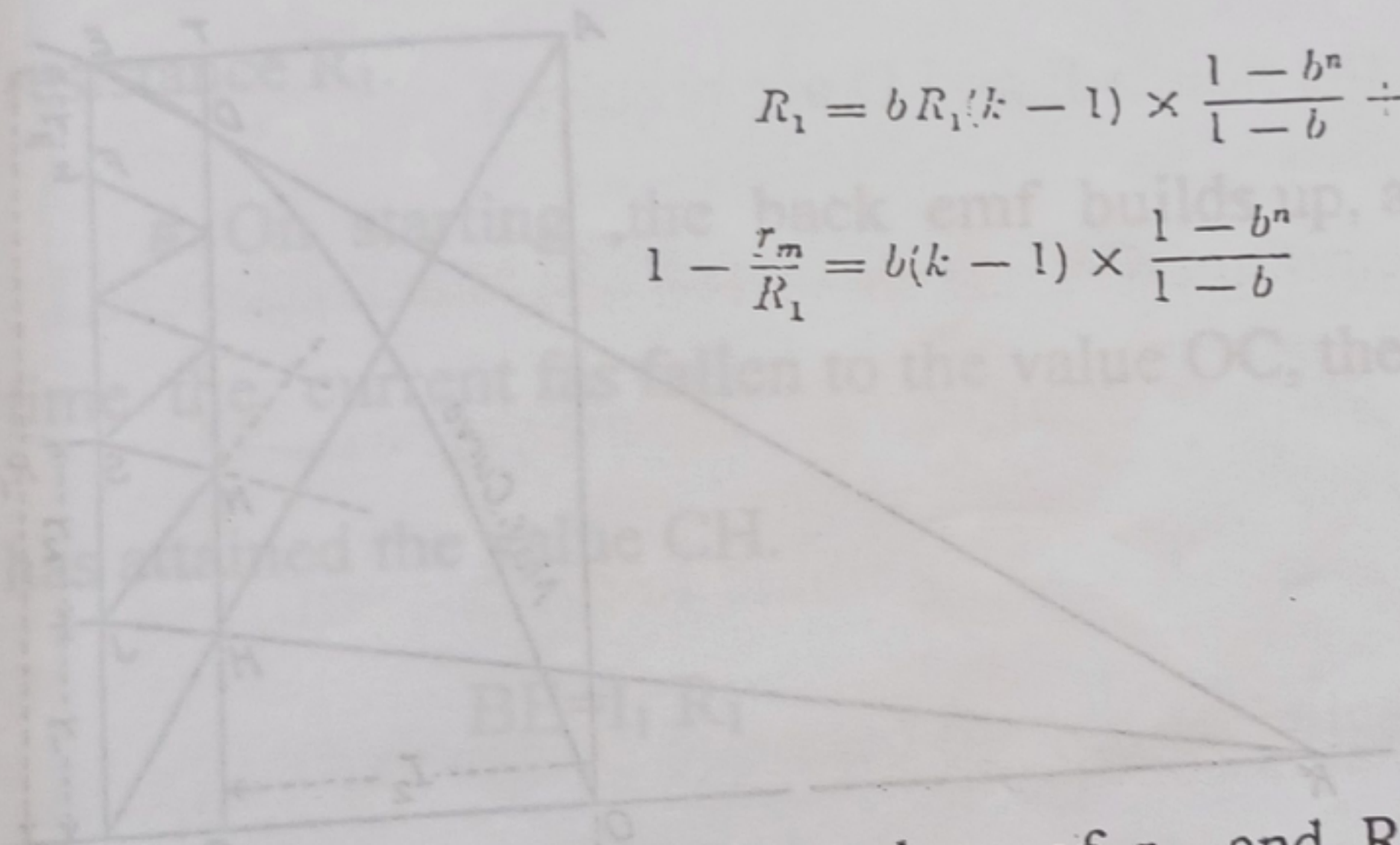
The ratio of the current obtained by equating these two expression for r_1 becomes

$$a = 1 + \frac{1}{n}\left(1 - \frac{r_m}{R_1}\right)$$

For the general case

$$R_1 = bR_1(k-1) \times \frac{1-b^n}{1-b} \div r_m$$

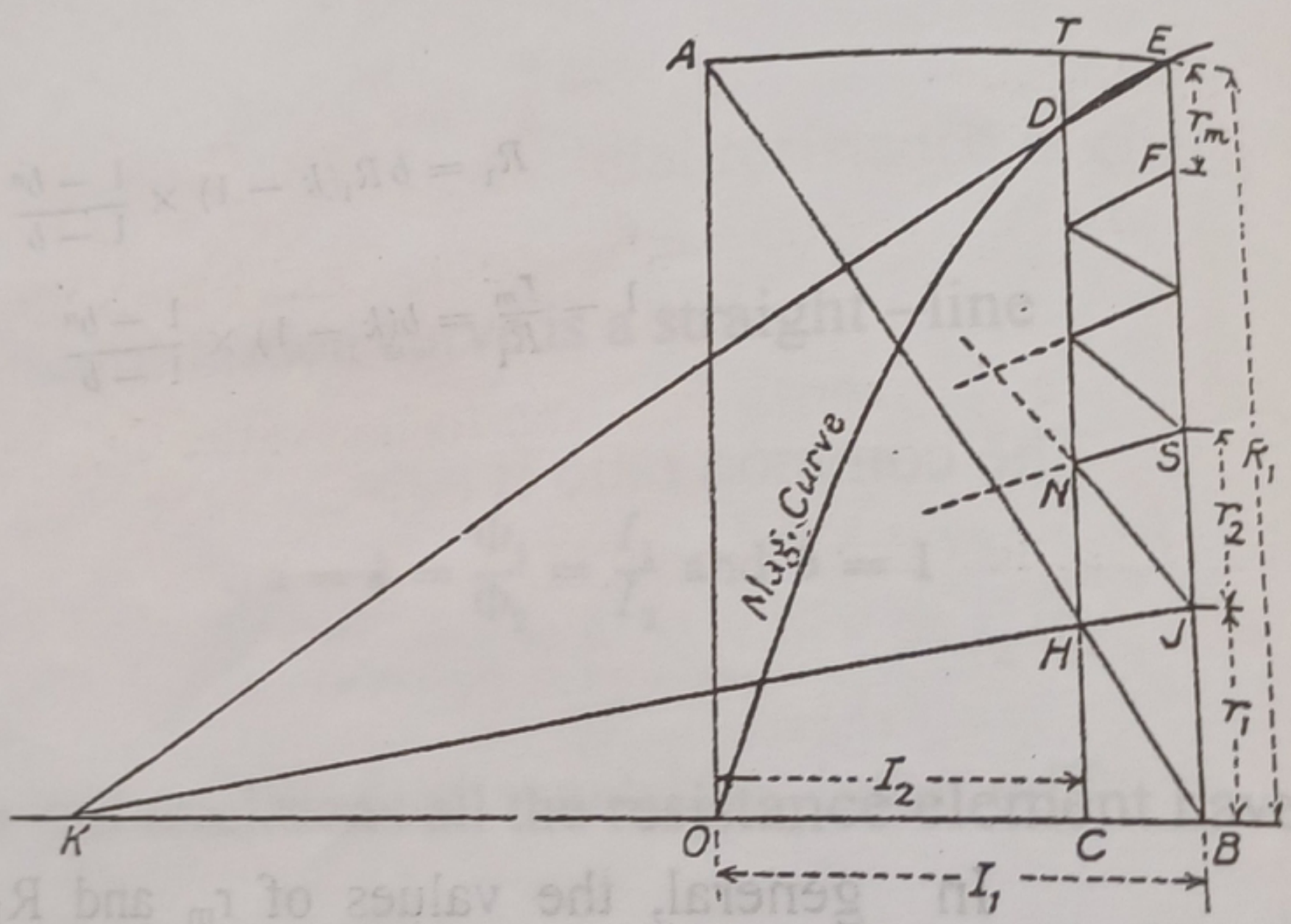
$$1 - \frac{r_m}{R_1} = b(k-1) \times \frac{1-b^n}{1-b}$$



In general, the values of r_m and $R_1=V/I_1$ will be known, and n., the number of resistance sections, given.

Graphical constructions for determining grading of starting resistance of dc series motor

If the ratio I_1 / I_2 and φ_1/φ_2 be assumed known, construction can be made as shown



The magnetization curve is shown as ODE

OB represents the maximum current I_1 and OC represents the current I_2.

The fluxes at these two currents are represented by BE and CD respectively.

BE represents the supply voltage and the total resistance R_1.

On starting ,the back emf builds up, and by the time the current fas fallen to the value OC, the back emf has attained the value CH.

$$BE = I_1 R_1$$

$$HT = I_2 R_1$$

On notching up emf at once increases in the ratio φ_1/φ_2 from CH to BJ.

The resistance R_2 is represented by JE

BJ represents the elemental resistance r_1.

CH and CN represent the values of the back emf on notches 1and 2, BJ and BS represent their values on notches 2 and 3.

EF represents the resistance of the motor circuit r_m.

The complete magnetization curve need not be drawn, only the points E and D are required.

AUTOMATIC STARTERS

An automatic starter is one where the starting sequence is not controlled by the operator.

Automatic starter is more expensive than manual starter.

The advantages of automatic starters

1) They ensure a correct starting operation irrespective of loading.

2) They can be operated by non-technical personal

3) Adjustment of timing for cutting on and out of resistance steps ensures smoothing acceleration.

4) Overload protection is provided. This is usually under voltage and over current protection.

5) If required electric braking may be incorporated relatively easily.

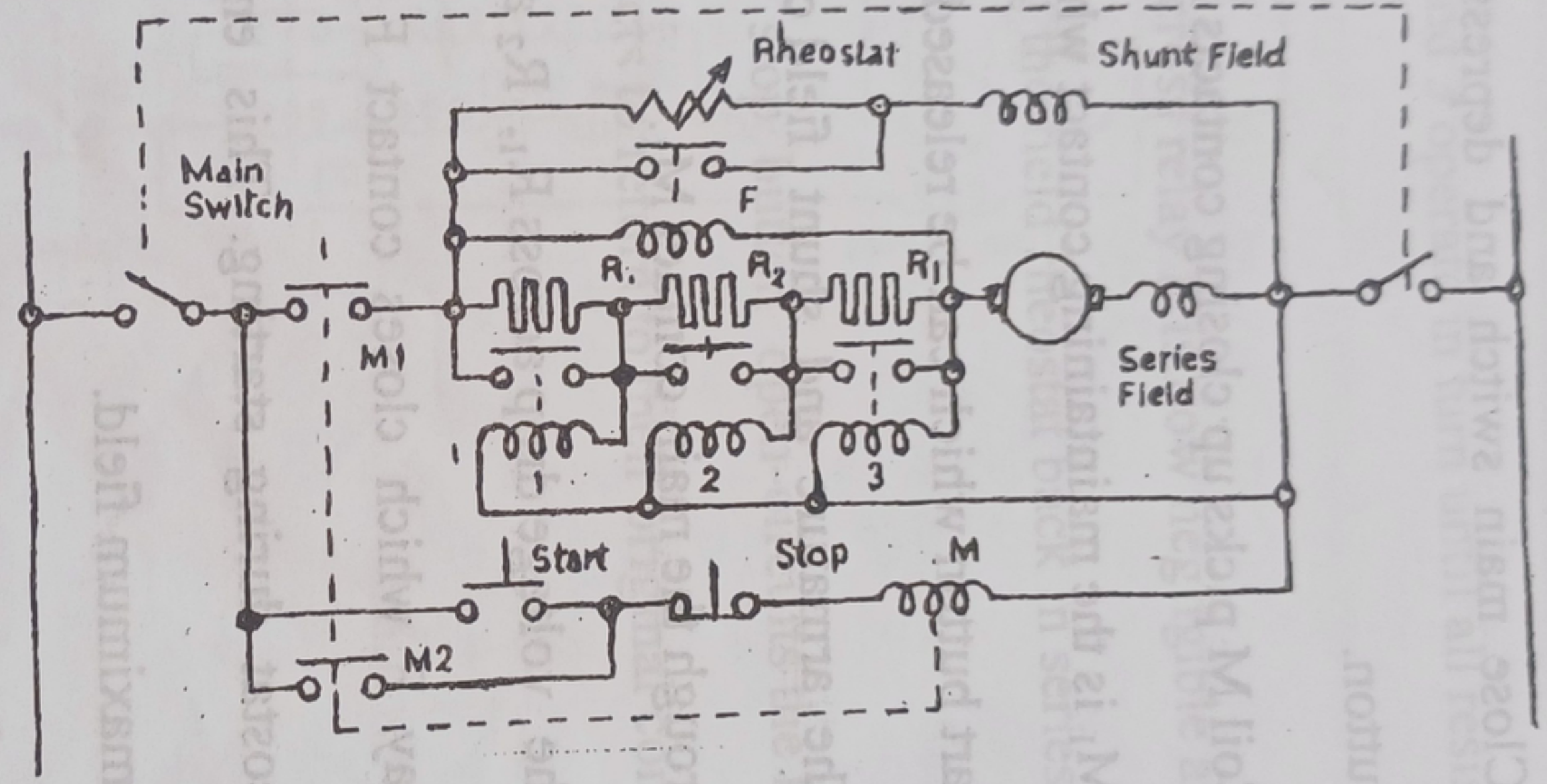
The automatic sequencing of the starting operation of a starter can be effected by any of three methods.

a) Back emf starter

This type of starter is used with small and medium sized dc shunt and compound motors having high starting torque.

It is push button operated with a field rheostat which may be present to give the speed required on load.

The starter relay are set to operate at various predetermined values of back emf and an overload relay operates above a predetermined current value.


Rheostat
Shunt Field
Main Switch
F
R1
R2
R3
M1
Series Field
1
2
3
Start
Stop
M
M2

The operation of the starter is as follows:

1) Close main switch and depress spring-loaded start button.

2) Coil M picks up closing contacts M_1 and M_2.

3) M_1 is the maintaining contact which short circuits the start button which can be released.

4) The armature and shunt field circuits are energized through the main contact M_1.

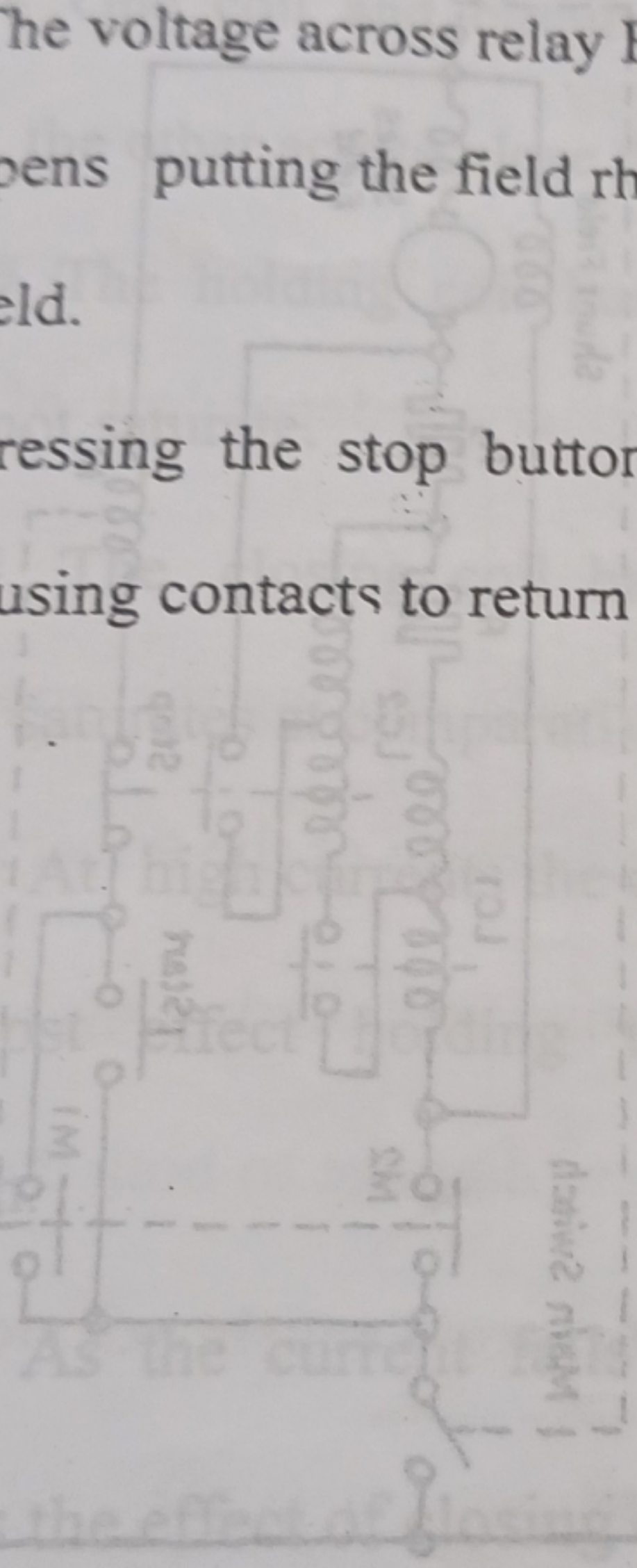
5) The voltage drop across R_1, R_2 and R_3 energize field relay F which closes contact F to short circuit the rheostat during starting. This ensure the motor starts on maximum field.

6) As the motor accelerates E_b builds up and when the voltage drop across contactor 1 falls to a certain value the contactor operates and the contacts short circuit the section of the staring resistance R_1.

7) As the motor accelerates E_b continues to rise and contactors 2 and 3 operate in turn until all resistance is short out.

8) The voltage across relay F is now negligible and relay opens putting the field rheostat back in series with the field.

9) Pressing the stop button open-circuits the line to M causing contacts to return to their original condition.



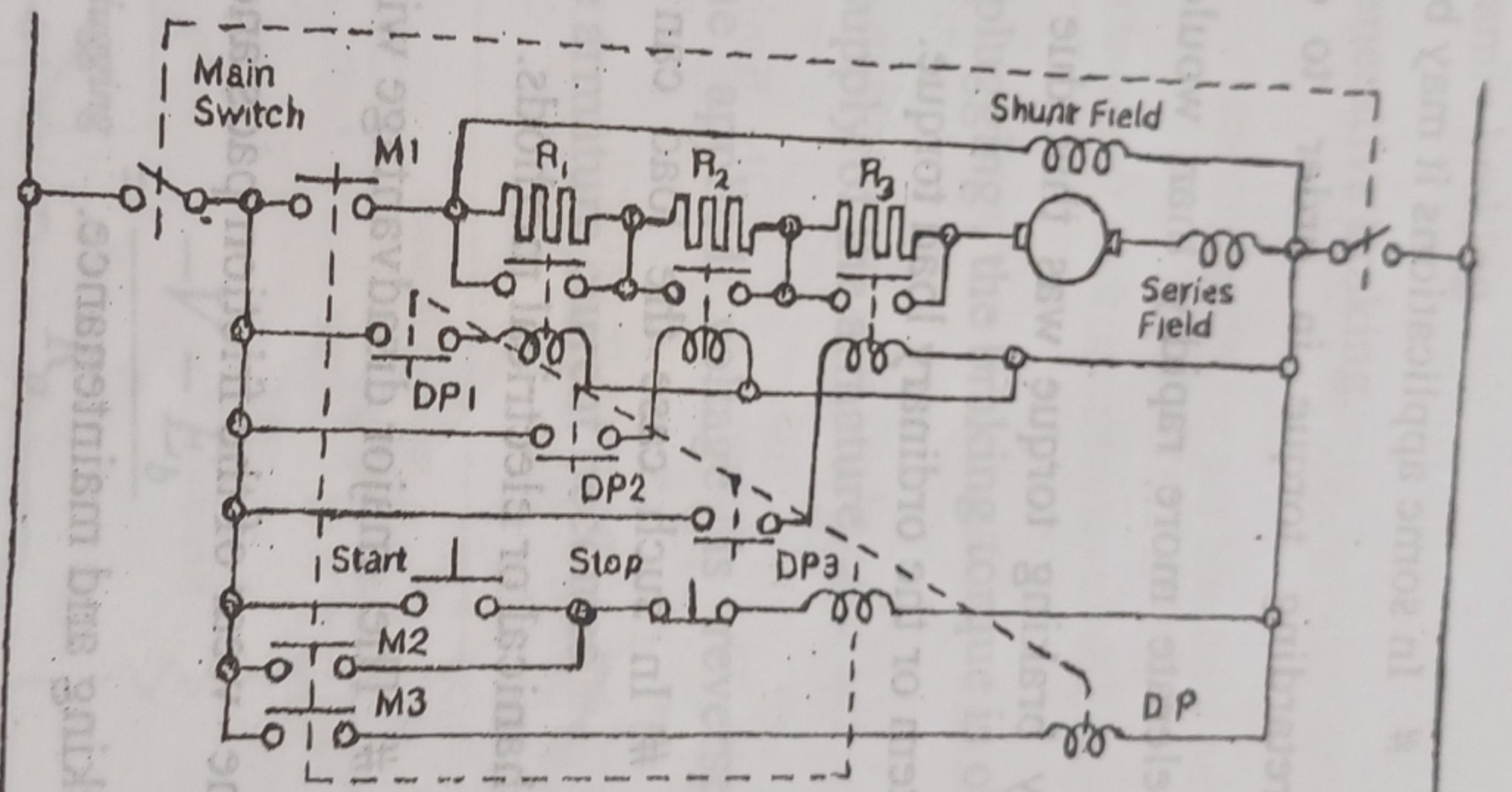
Below a predetermined value the tractive force of the closing coil has the most effect and the contactors closes.

c) Time limit starter

In this type of starter the starting sequence is controlled by timing devices independent of the motor starting conditions.

As a consequence, the starting sequence proceeds without reference of acceleration of the armature and will proceed even if the armature is stalled.

As this could cause damage to both the starter and the machine , some over current sensing device should be incorporated in the circuit.


Main
Switch
M1
R1
R2
R3
Shunt Field
Series
Field
DP1
DP2
DP3
Start
Stop
M2
M3
D P

ELECTRIC BRAKING OF DC MOTORS

In some applications it may be necessary to apply a retarding torque in order to cause a machine to decelerate more rapidly than would be the case if the only braking torque was that due to the friction of the system or the ordinary load torque.

In such case the load can be braked by either mechanical or electrical methods.

The major disadvantage with mechanical braking is the wear of the friction pads and the need for constant checking and maintenance.

The better method is to use electrical braking systems where the braking torque is obtained electrically.

The electrical braking are:

1) Plugging

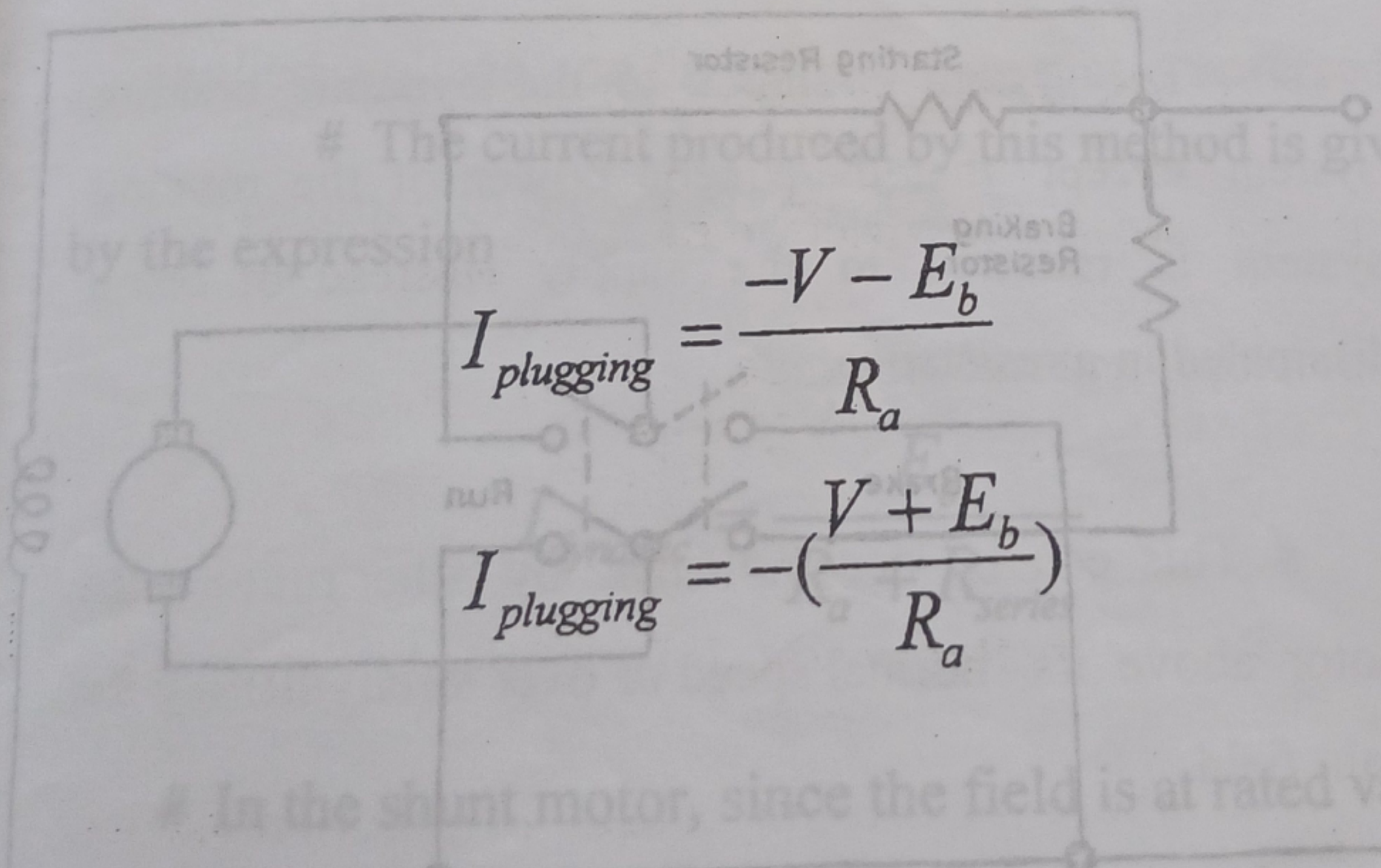
2) Dynamic braking

3) Regenerative braking.

1) Plugging

With the plugging , the braking torque is obtained by reversing the supply of the armature.

When the applied voltage is reversed , the expression for the armature current becomes



$$I_{plugging} = \frac{-V - E_b}{R_a}$$

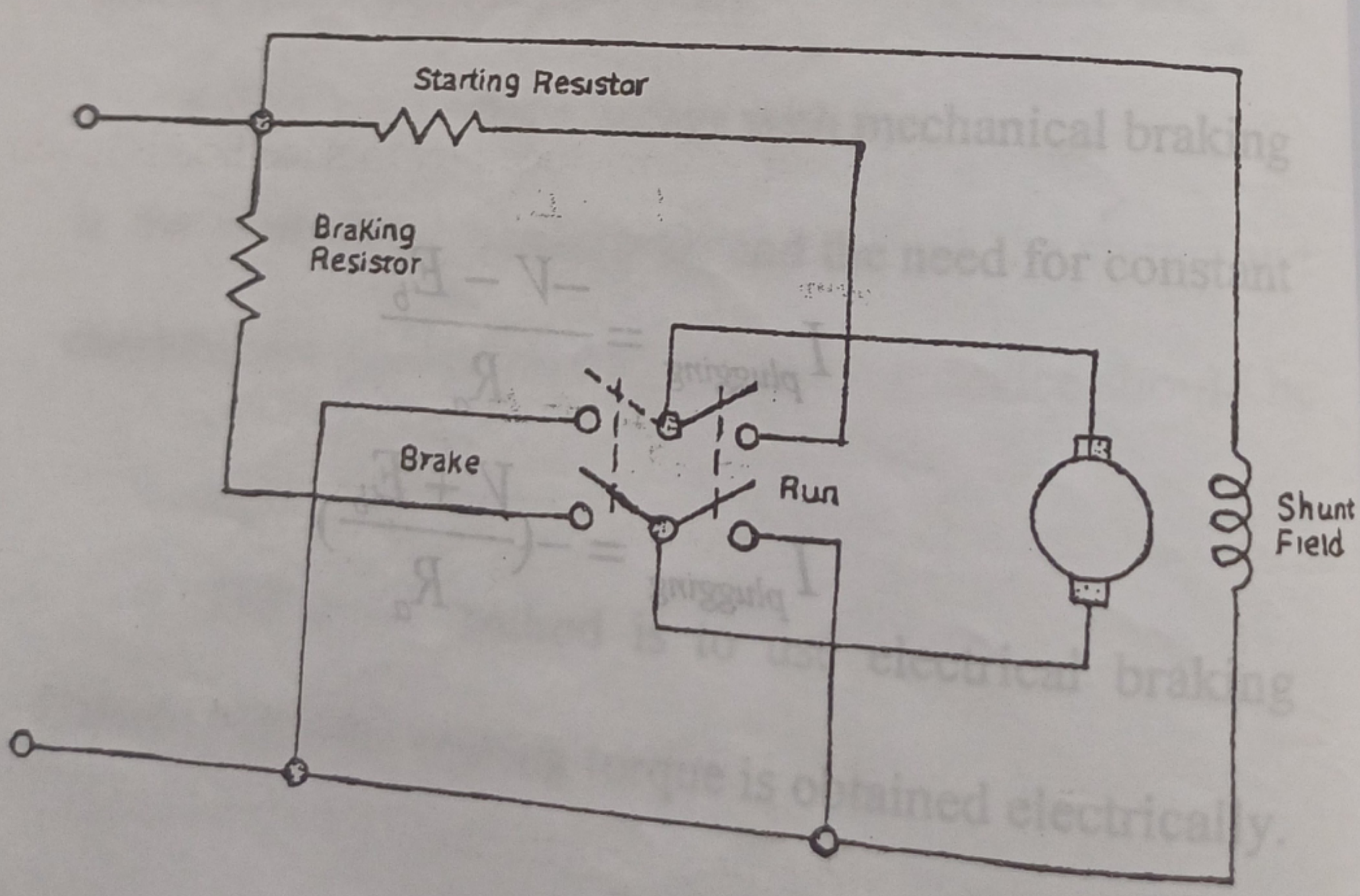
$$I_{plugging} = -\left(\frac{V + E_b}{R_a}\right)$$

The negative sign indicates that the current is in the reverse to the normal direction.

The torque produced opposes the internal torque of the load and the rotating system.

However, since the reversal of the supply to the armature results in the emf action on the armature circuit being the sum of the terminal voltage and the back emf ,

The current is usually limited during braking operations by a series resistor.



2) Dynamic braking

In dynamic braking the motor is disconnected from the supply and a low resistance is connected across its terminals.

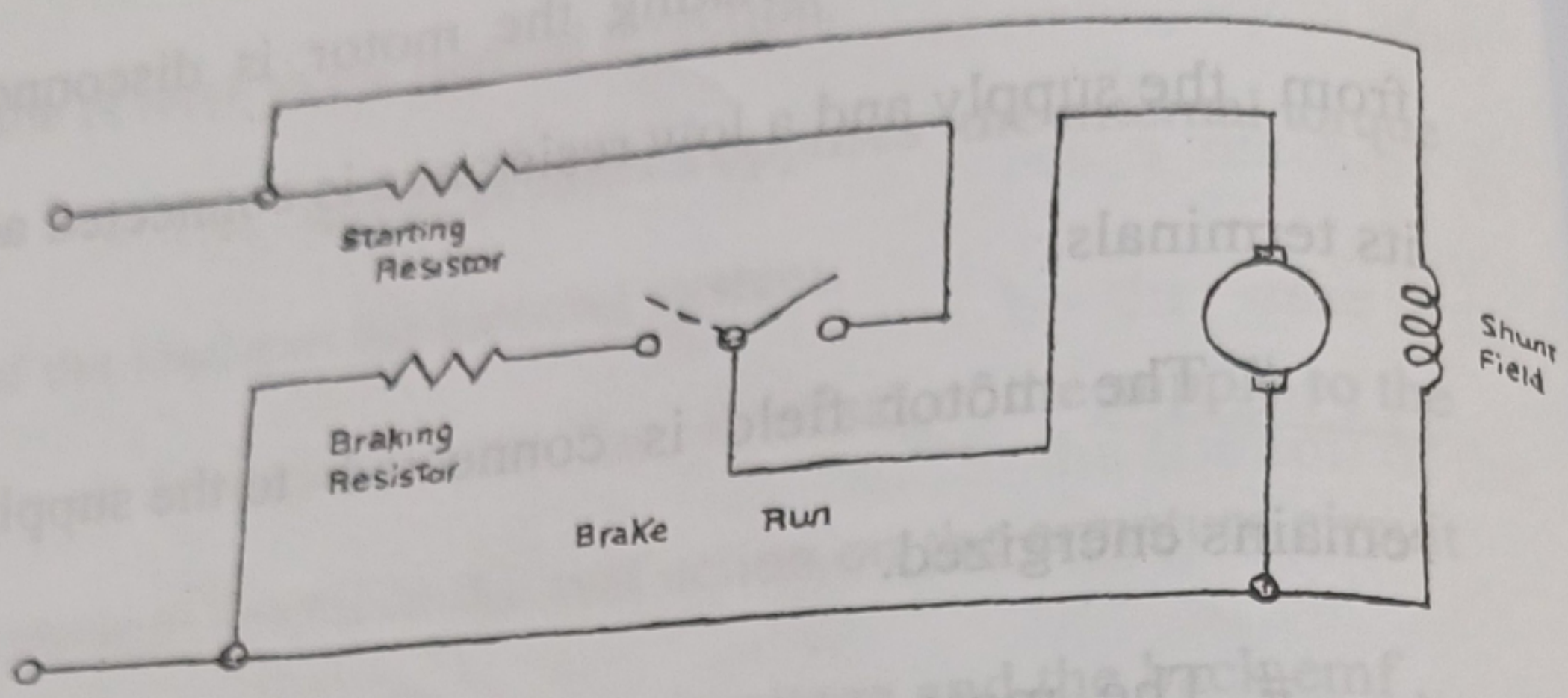
The motor field is connected to the supply and remains energized.

The motor will now act as a generator supplying energy to the resistance, until all the kinetic energy in the armature has been dissipated as I^2R loss in the resistance.

The current produced by this method is given by the expression

$$I_{dynamic} = \frac{E_b}{R_a + R_{series}}$$

In the shunt motor, since the field is at rated value, the torque is directly proportional to the speed.



3) Regenerative braking

The system is similar to the dynamic braking system except that the kinetic power of the rotating system is returned to the supply instead of being dissipated in a resistance.

This can be accomplished by either running the motor above its normal speed or over strengthening the main field.

A typical application is its use for electric traction system, where there are long downhill runs.

No braking resistor is used with this method and initial braking current is given by

$$I_{reg} = \frac{E_b - V}{R_a}$$

As the speed increases above the normal speed, the back emf increases and become greater than the applied voltage, so the armature current is reversed and returned to the supply.

LOADING OF DC GENERATORS

$ The types of loads will be considered are resistive load , charging battery and combination of them.

$ In dealing with generators where the terminal voltage varies with the load, it is difficult to use mathematical equations to calculate current flowing.

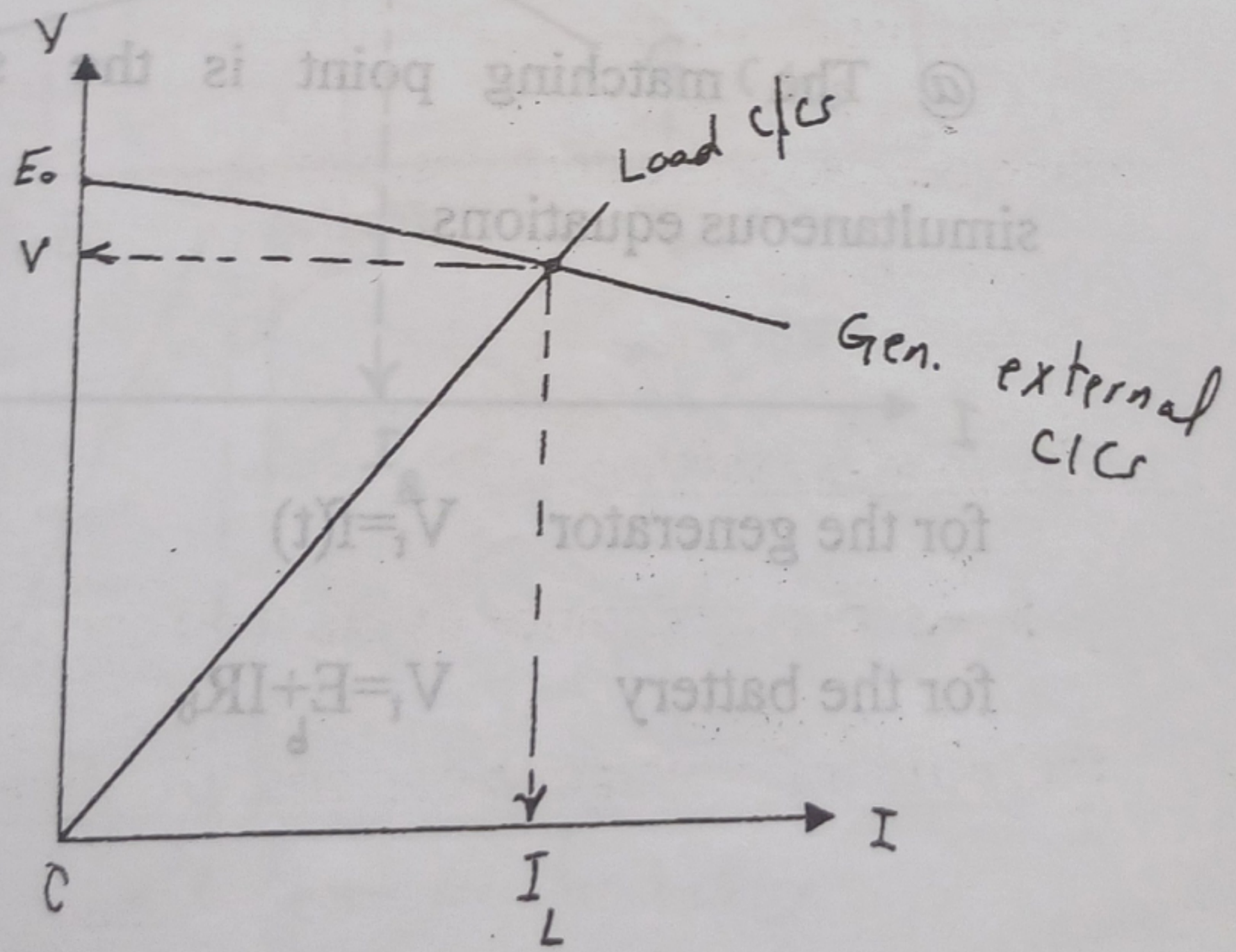
@ It is easier to apply a graphical method.

& This method involves superimposing the external characteristic of the generator and voltage current characteristic of the load to find the load conditions where the two characteristics intersect.

a)The load is resistor

$ As the resistance of the load can be expressed as the ratio of voltage to current, load line can be drawn

as a straight line on the graph and where this line crosses the external characteristic of the generator, the voltage and current for that equivalent load resistance can be obtained.



b) The load is charging battery

When it is required to find the charging current delivered by a generator to a battery the procedure is similar.

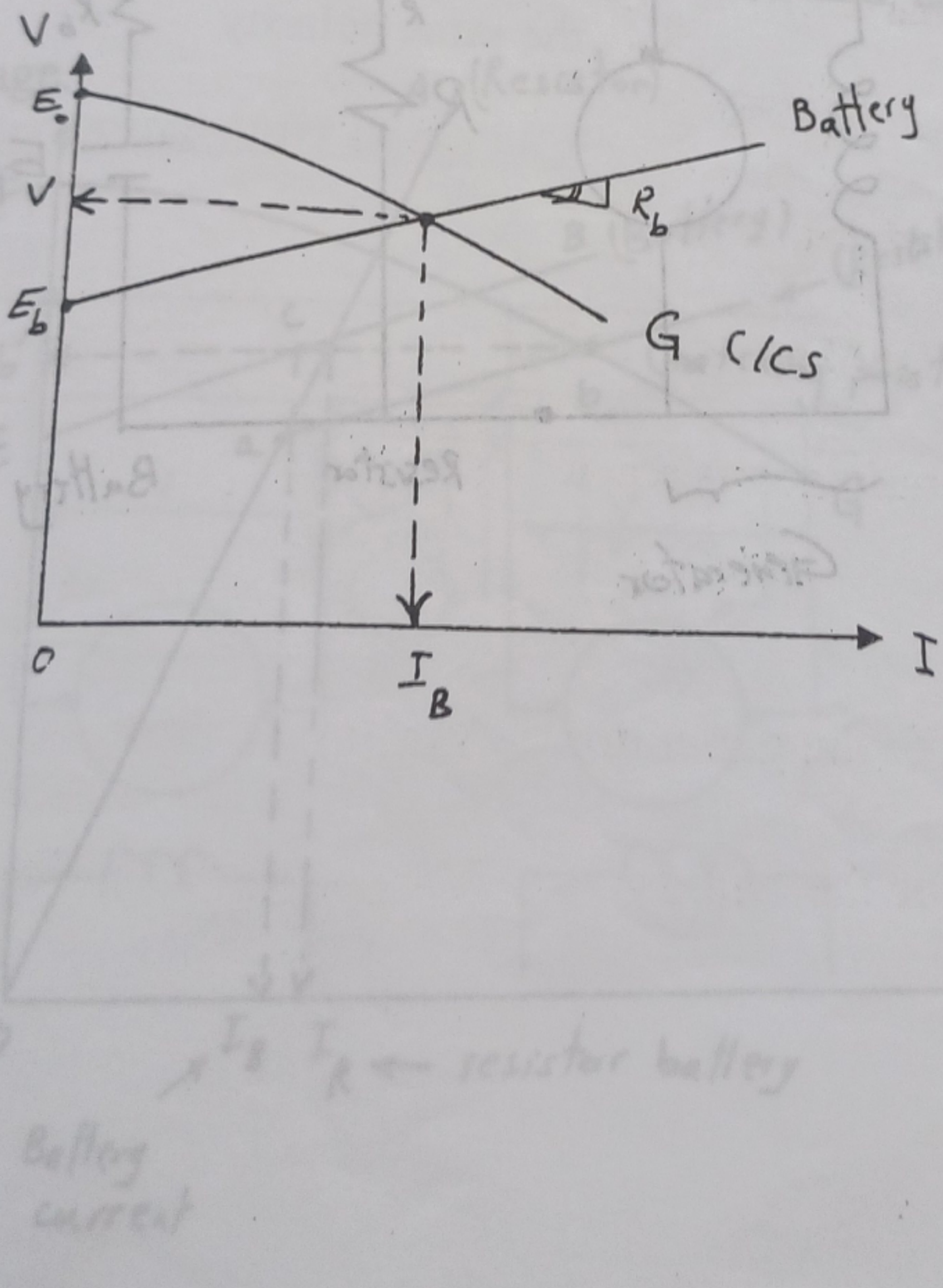
$ The battery characteristic is obtained so that it can be drawn on the same graph as the external characteristic of the generator.

& Where the two characteristics cross this give the load point.

@ The matching point is the solution to the simultaneous equations.

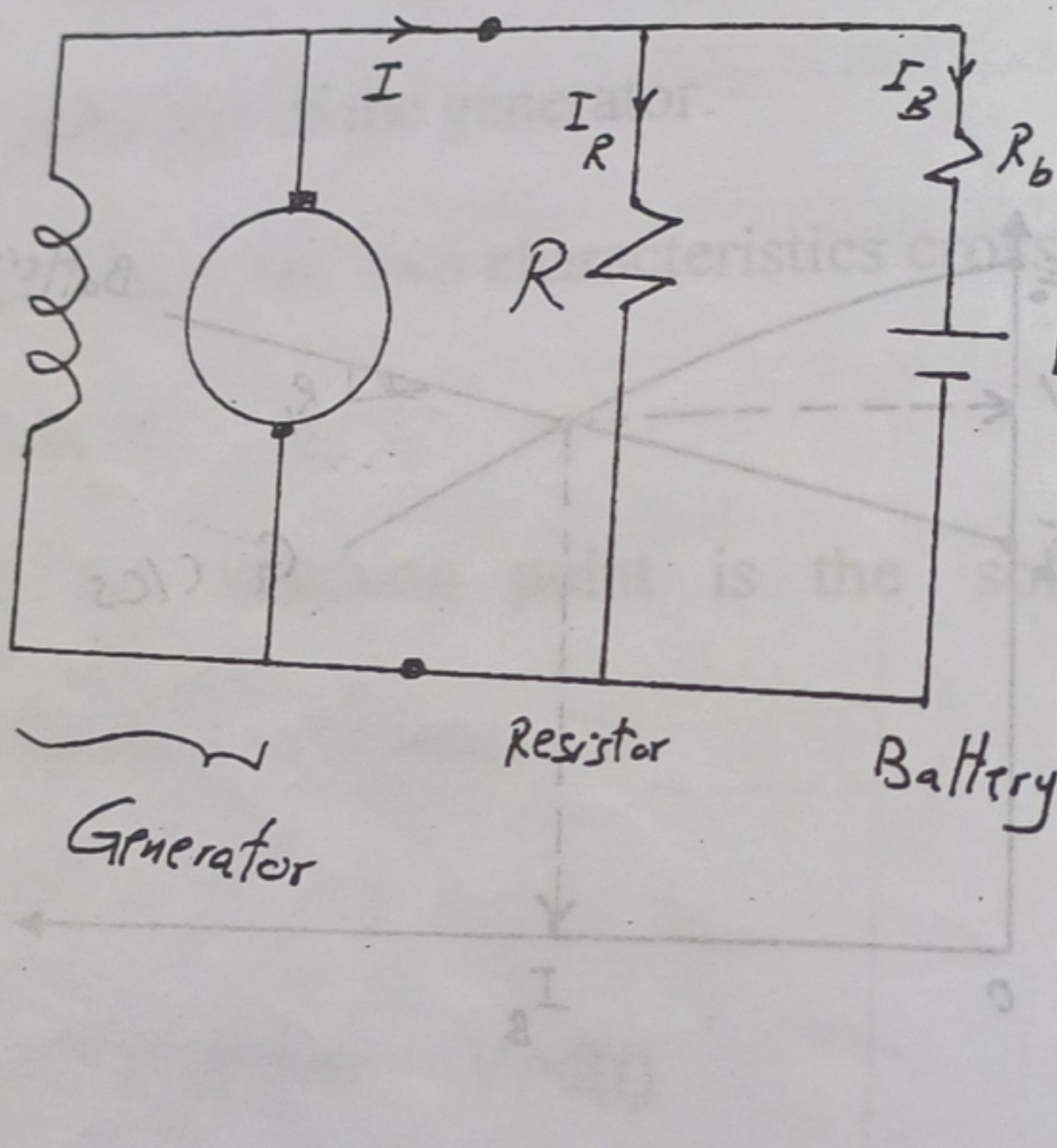
for the generator $V_t = f(t)$

for the battery $V_t = E_b + IR_b$


V
E_0
V
E_b
R_b
Battery clcs
G clcs
0
I_B
I

c) The load is resistor and charging a battery in parallel

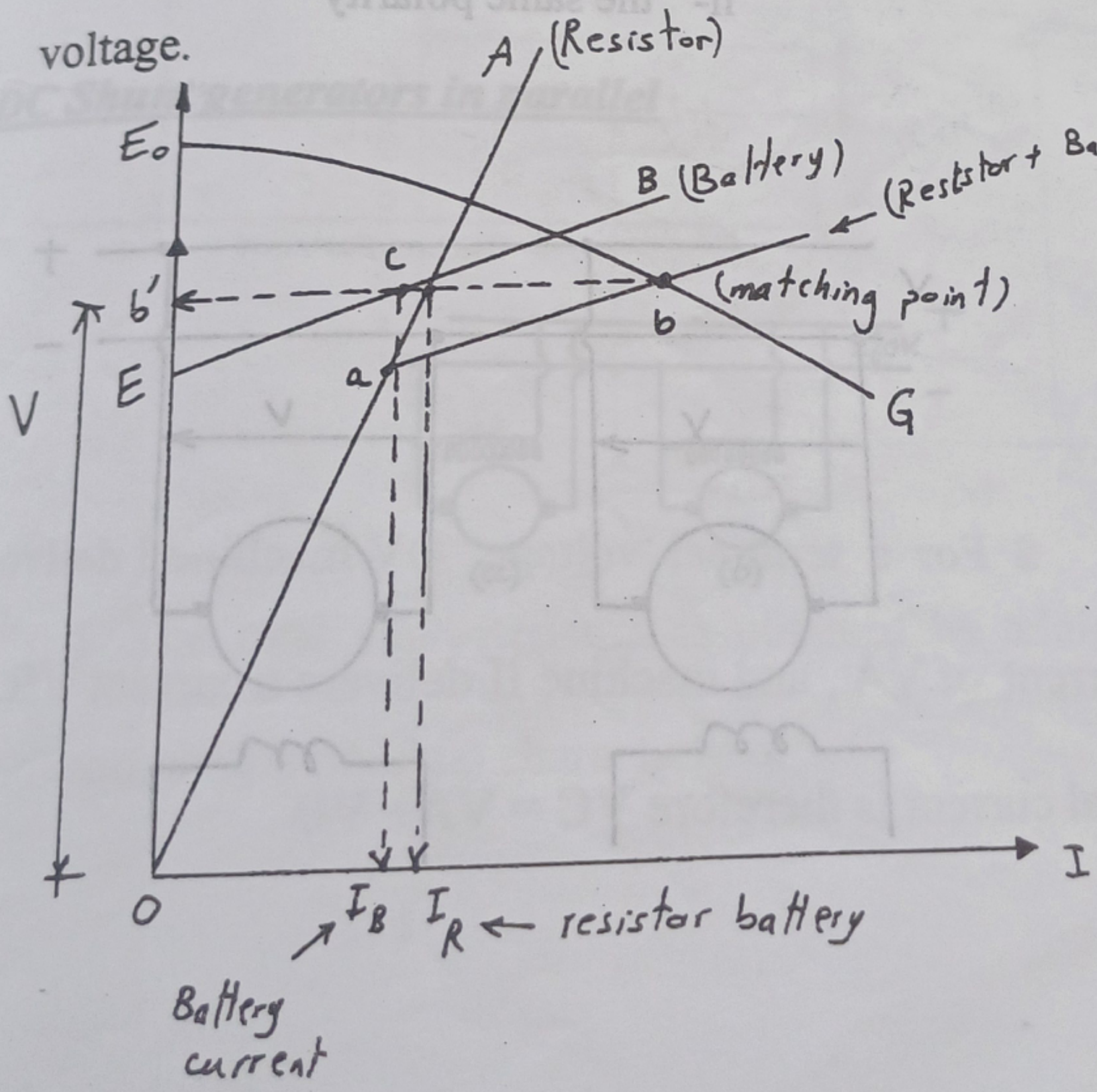
$ As the loads are connected in parallel the voltage across both battery and resistor is the same and the current will divide between them.



The total characteristics of the load (OA and EB) are taken at constant voltage.

@ The intersect of the total characteristics of the load (o a b) with external characteristic of the generator E_oG determines the load point (b).

$ From point "b" draw a horizontal line (b b'), the intersect of this line (b b') with OA and E B determines the current in each load and the load voltage.



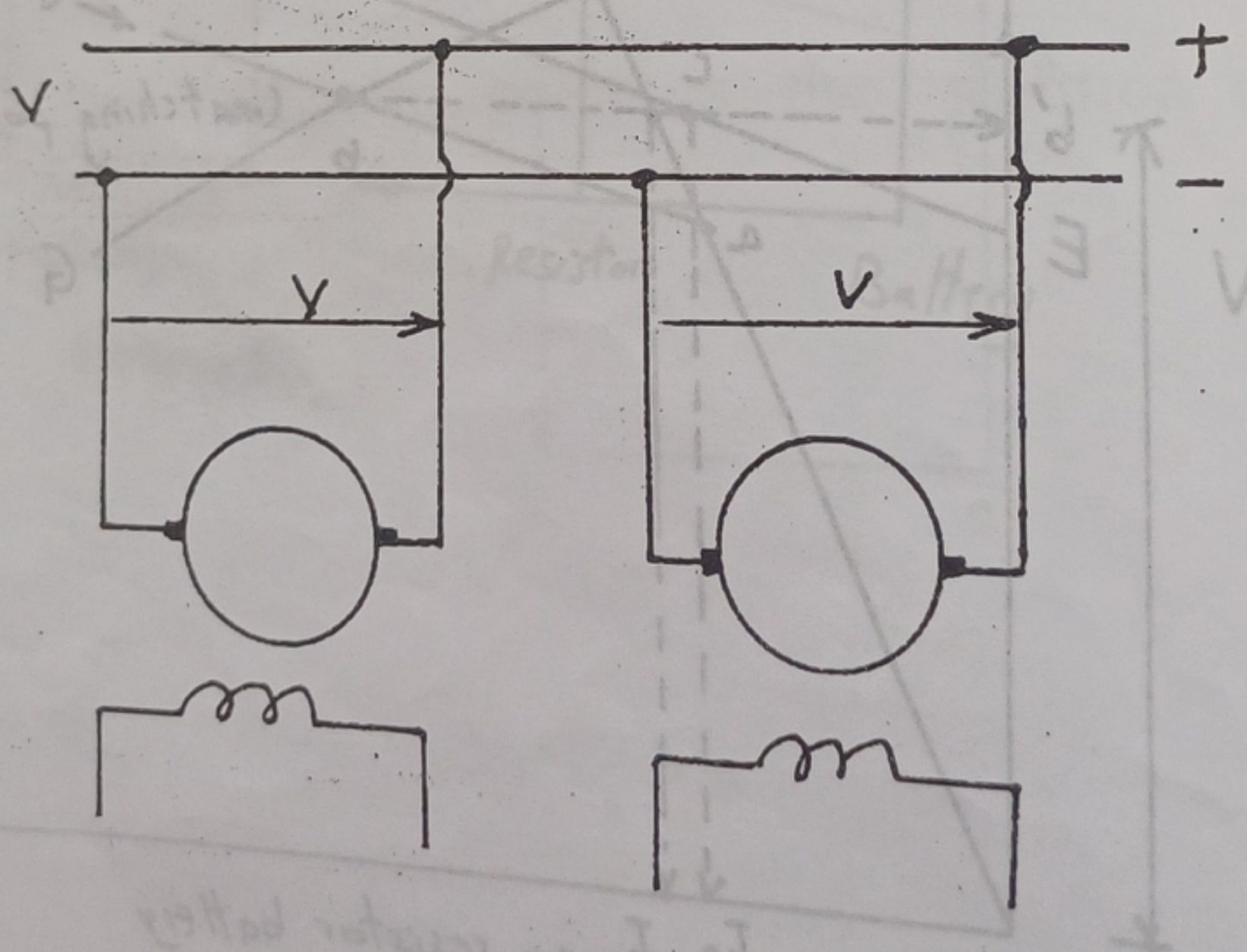
PARALLEL OPERATION OF DC GENERATORS

@ In some situations it is necessary that generators be connected and operate in parallel as the output of one machine is insufficient for a given load.

@ The conditions for parallel operation:

i- the same terminal voltage

ii- the same polarity

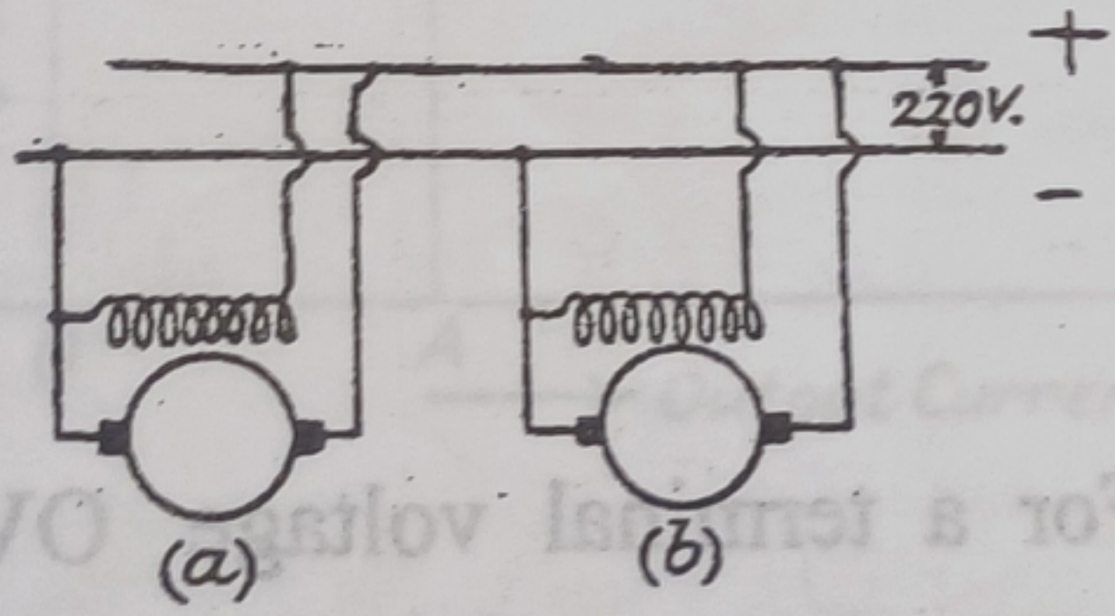


@ To determine how the load is shared it is necessary to construct a combined load characteristics.

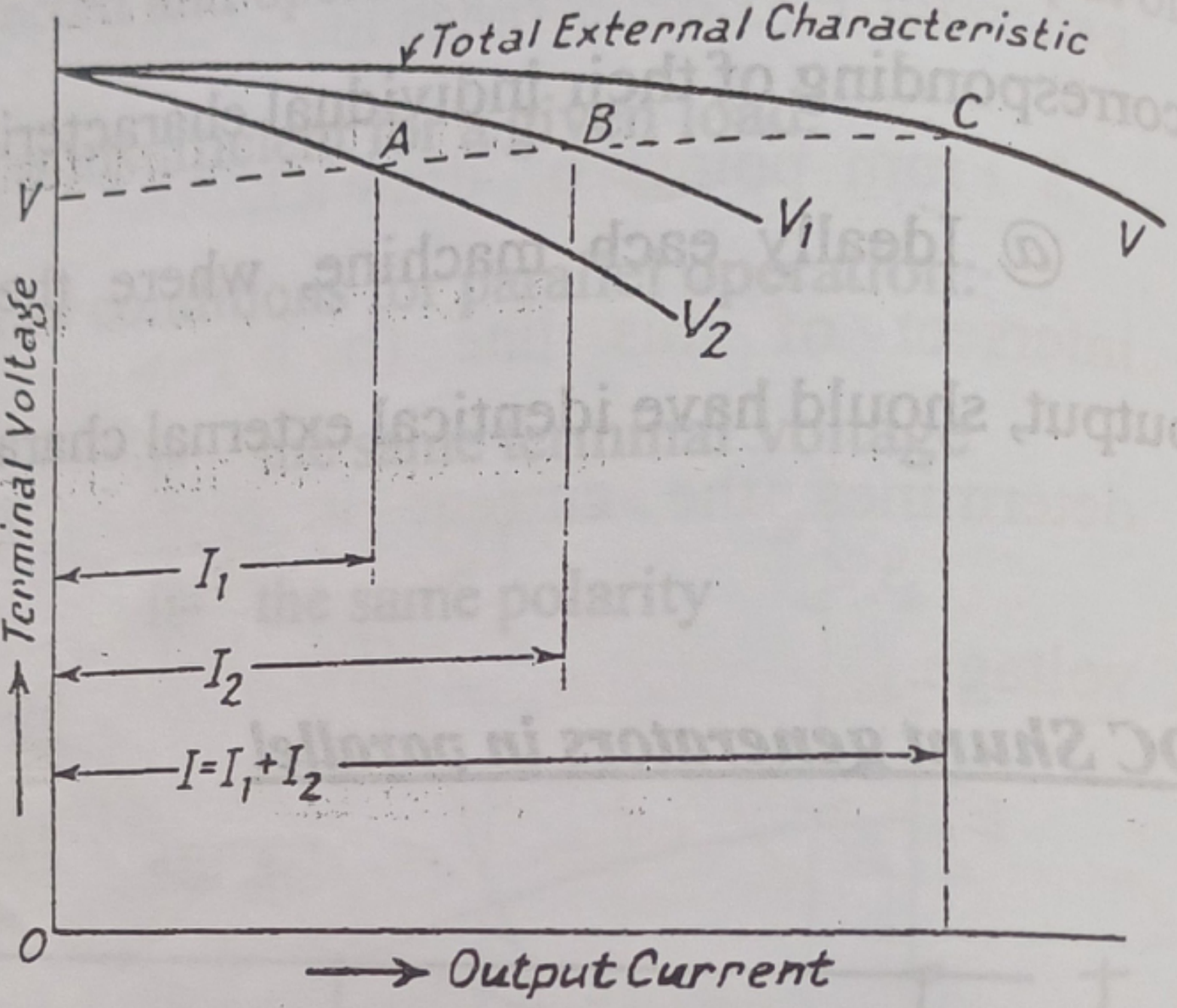
@ The total external characteristic for a number of machines in parallel is obtained by summing corresponding of their individual characteristic.

@ Ideally each machine, where they are identical output, should have identical external characteristic.

DC Shunt generators in parallel



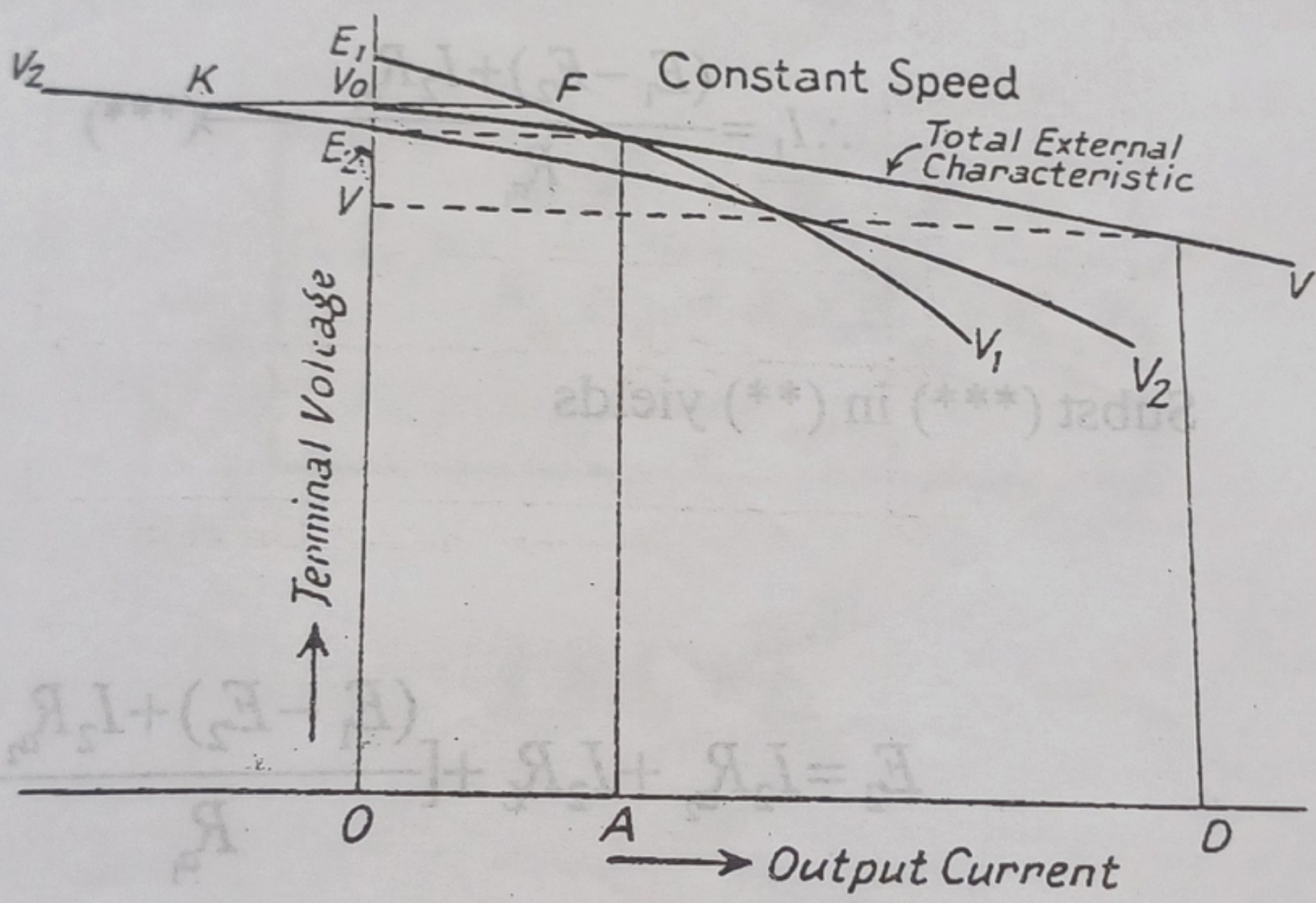
$ The following figure gives the external characteristics of two dc shunt generators, excited so as to give exactly the same emf on open circuit.



$ For a terminal voltage OV machine I delivers a current of VA , and machine II delivers a current VB, the total current is therefore VC = VA+ VB

$ The machine with the more dropping characteristic takes the smaller share of the load.

$ Dealing now with machines excited so that their emf^{s} on open circuit are not equal.



$ The total characteristics is obtained by adding corresponding individual characteristic.

$$V=(I_1+I_2)R_L$$

$$E_1=I_1R_{a_1}+(I_1+I_2)R_L \longrightarrow (*)$$

$$E_2=I_2R_{a_2}+(I_1+I_2)R_L \longrightarrow (**)$$

Subtracting (**) from (*) yields

$$E_1-E_2=I_1R_{a_1}-I_2R_{a_2}$$

$$\therefore I_1=\frac{(E_1-E_2)+I_2R_{a_2}}{R_{a_1}} \longrightarrow (***)$$

Subst (***) in (**) yields

$$E_2=I_2R_{a_2}+I_2R_L+\left[\frac{(E_1-E_2)+I_2R_{a_2}}{R_{a_1}}\right]R_L$$

$$E_2=I_2\left(R_{a_2}+R_L+\frac{R_{a_2}R_L}{R_{a_1}}\right)+\frac{(E_1-E_2)}{R_{a_1}}R_L$$

$$\therefore I_2 = \frac{E_2 R_{a_1} - (E_1 - E_2) R_L}{R_{a_1}(R_{a_2} + R_L) + R_{a_2} R_L}$$

$$\therefore I_2 = \frac{E_2 R_{a_1} + (E_2 - E_1) R_L}{R_{a_1} R_{a_2} + R_L (R_{a_1} + R_{a_2})}$$

Subst. the value of I_2 in (***) yields

$$\therefore I_1 = \frac{E_1 R_{a_{21}} + (E_1 - E_2) R_L}{R_{a_1} R_{a_2} + R_L (R_{a_1} + R_{a_2})}$$

$$I = I_1 + I_2$$

$$\therefore I = \frac{E_1 R_{a_2} + E_2 R_{a_1}}{R_{a_1} R_{a_2} + R_L (R_{a_1} + R_{a_2})}$$

The terminal voltage is

$$V = IR_L$$

$$\therefore V = \frac{E_1 R_{a_{21}} + E_2 R_{a_1}}{\frac{R_{a_1} R_{a_2}}{R_L} + (R_{a_1} + R_{a_2})}$$

When the load is open,(where $R_L = \infty$) the voltage becomes

$$\therefore V_{oc} = \frac{E_1 R_{a_{21}} + E_2 R_{a_1}}{(R_{a_1} + R_{a_2})}$$

On short circuit, (where $R_L = 0$) the current is

$$\therefore I_{sc} = \frac{E_1 R_{a_{21}} + E_2 R_{a_1}}{R_{a_1} R_{a_2}}$$

$$I_{sc} = \frac{E_1}{R_{a_1}} + \frac{E_2}{R_{a_2}}$$

$ At very light loads the machine having the smaller open circuit emf delivers a negative current, it actually receives current and acts as a motor.

$ From the figure, when the main circuit is open circuit the terminal voltage of the generators is OV_o.

$ The one machine generates V_oF ampere and other receives V_oK ampere.

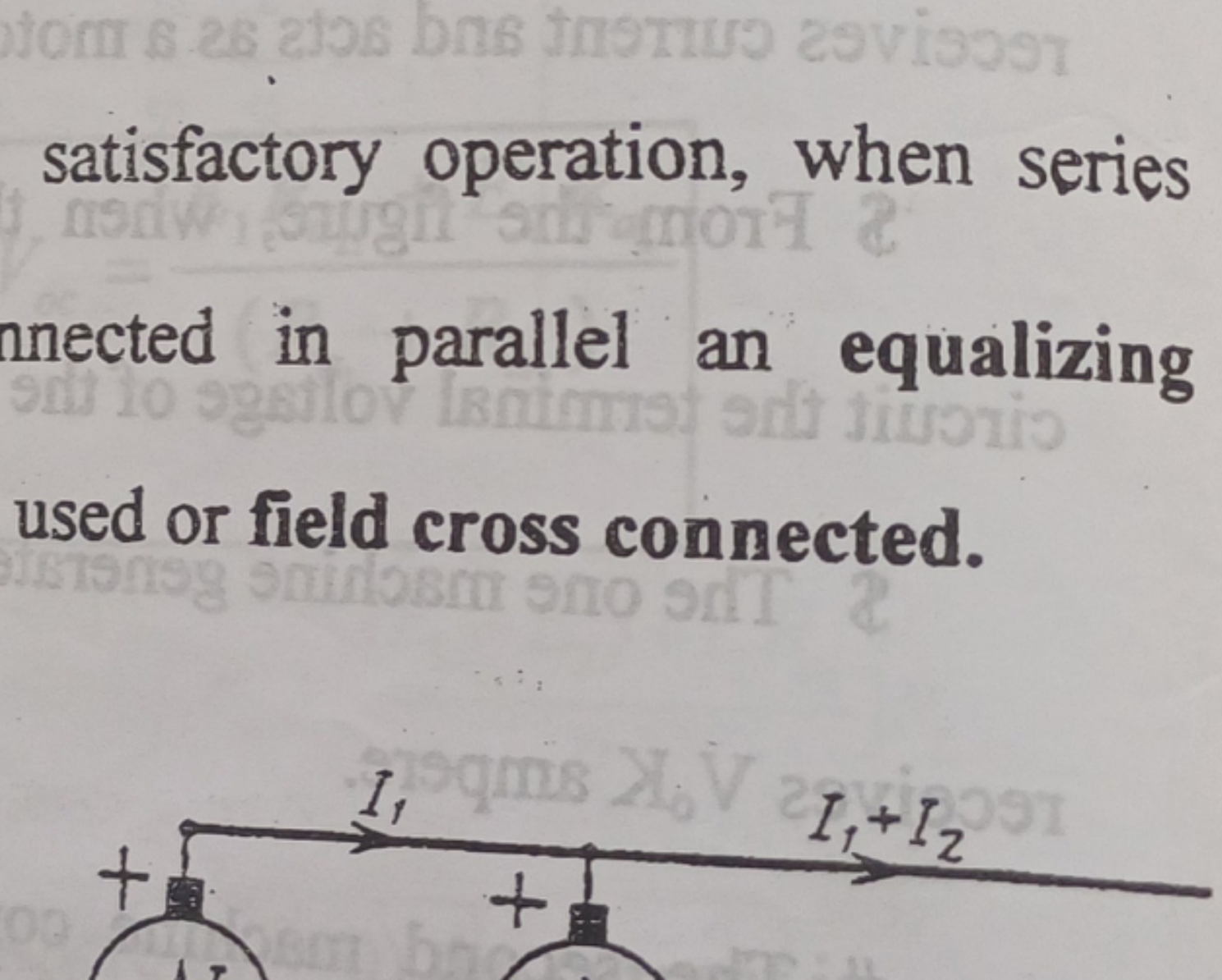
The second machine continues to function as a motor until the load current reaches OA ampere, at which point machines II just floats.

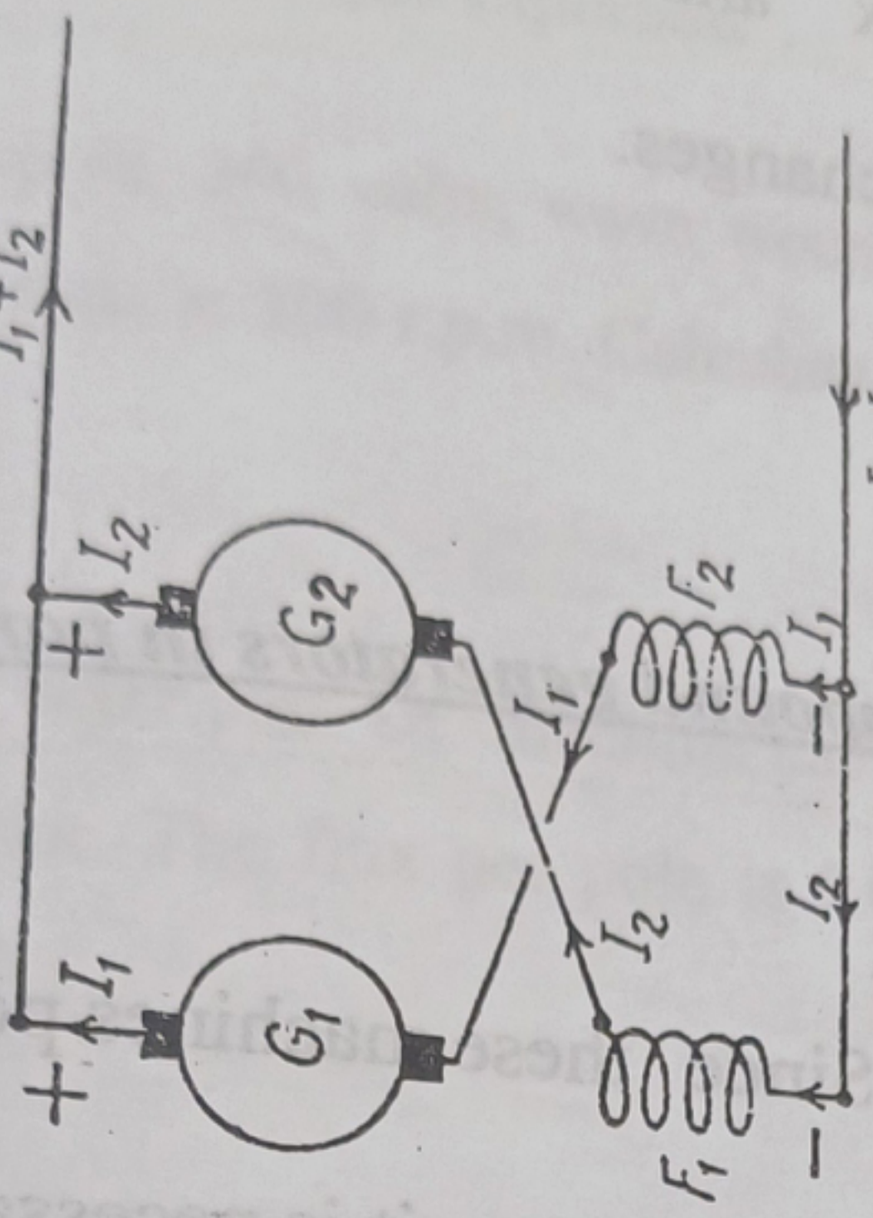
Beyond this load, both machines share the load, machine I taking the greater part until the load OD is attained, after which machine II carries the greater share.

DC Series generators in parallel

DC Series machines are not normally used as generators.

To ensure satisfactory operation, when series generators are connected in parallel an **equalizing connection** must be used or **field cross connected.**





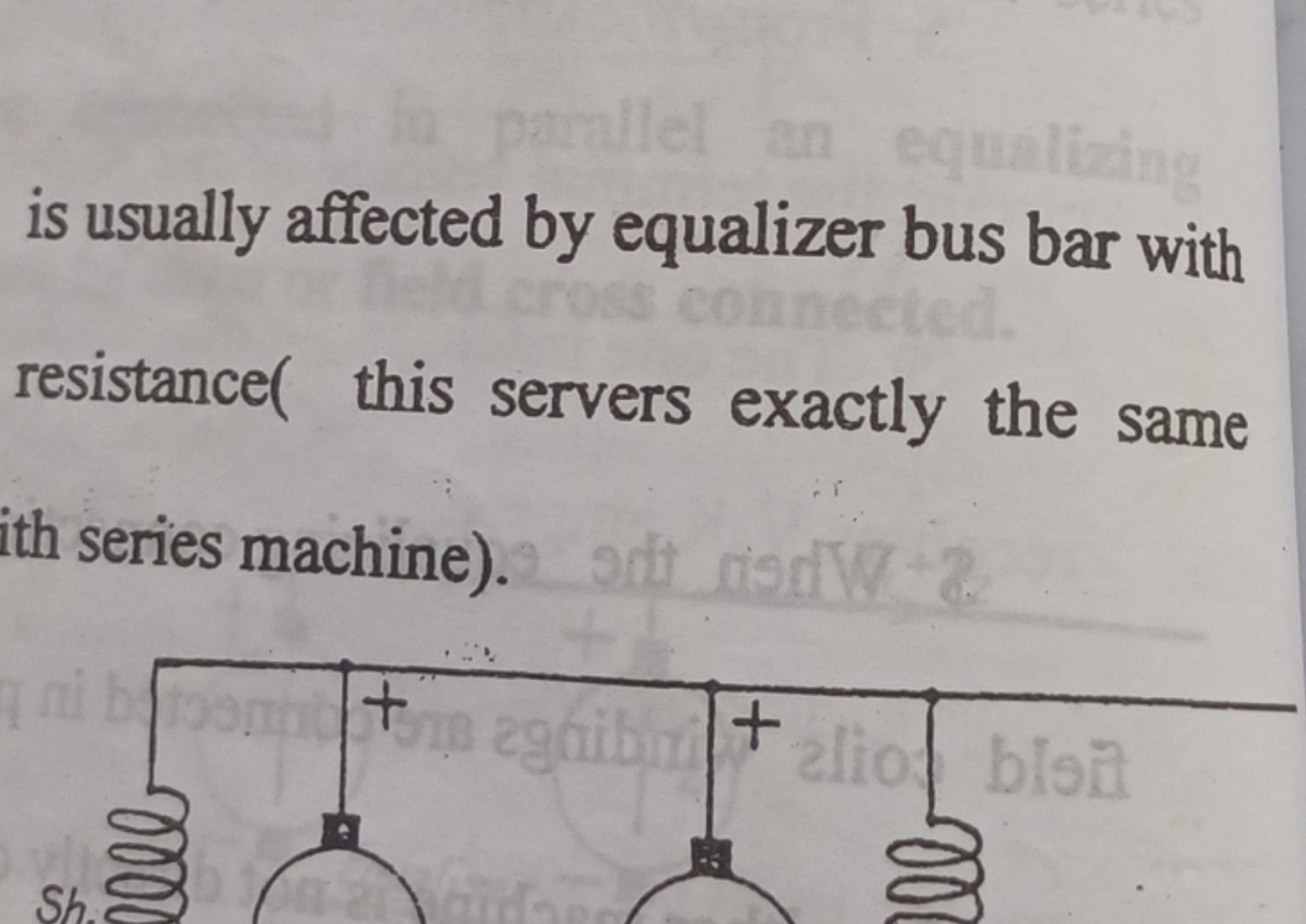
$ When the equalizing connection is used, the two field coils windings are connected in parallel, so that the flux for either machine is not directly dependent upon its own armature current.

Without the equalizing connection ,the value of the flux and induced emf varies when the armature current changes.

DC Compound generators in parallel

@ Since these machines possess windings in series with the armature , it is necessary to equalize their field currents.

This is usually affected by equalizer bus bar with very small resistance(this servers exactly the same purpose as with series machine).



SHEET (1)
EMF & Torque Equation

1) The armature of a 2-pole, 200 volts, wave wound DC machine has 400 conductors and runs at 300 r.p.m. Calculate the useful flux per pole.

2) A 400 volts, 8-poles, 600 r.p.m DC machine has 100 slots. Each slot contains 40 conductor. The flux per pole is 0.01 weber. What type of winding is used ?

3) A 4-pole dc machine has a simplex lap winding, and the armature winding has 96 coils of two turns each, the voltage per turn is 2.5 volts. The resistance per conductor is 0.002Ω.

Calculate: i-the generated voltage ,

ii-the armature resistance.

4) A four pole lap wound dc machine has a 970 conductors. If the flux per pole is 0.06 webers and the armature current is 48.6 amp. Calculate the torque developed.

SHEET(2)

Characteristic of DC Motor

1) A separately excited DC motor is rotated at 1000rpm, The variation of armature terminal voltage as a function of field current is measured under no-load conditions and tabulated below:

I_f	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
V_t	0	30	60	85	102	115	124	130	134

The field winding supply V_f=24V and the field resistance is adjustable. The armature winding resistance RA=0.2Ω and the armature terminal voltage V_t=130V.

a. Calculate the field current if the motor is operated with no-load at 1000 rpm
b. The motor drives a load at 1200 rpm. Calculate the armature voltage at 1200 rpm if the field resistance RF=60Ω
c. Calculate the torque for the above condition

2) A series DC motor has combined armature and field resistance of $R_a + R_s$ =1.2Ω. When connected to a supply of V_t=48V at standstill, the motor develops a torque of 1500Nm.

a. Calculate the armature current at standstill and combined motor constant k_t.
b. Calculate the torque when the speed is 500 rpm
c. Calculate the output power and efficiency when operating at 500 rpm (neglect mechanical losses)

3) A series motor has a terminal voltage of 250 volts, an armature resistance of 0.023 ohms and has a rated full load speed at 1200 r.p.m where the armature current is 62 amp. Calculate the speed when the armature current is 10 amp.

4)120 HP, 550 volts, shunt motor has 4-poles and wave connected armature winding with 492 conductors. The flux is 0.0055 weber per pole and full load efficiency 90 %. The resistance of the armature and shunt field are 0.08 and 250 Ohms respectively. Calculate the motor speed.

SHEET (3)

Speed Control of DC Motor

1) The speed of 500 v shunt motor is to be raised from 700 rpm to 1000 rpm by field weakening the total torque remaining unchanged, the armature and the shunt field resistance are 0.8Ω ,750 Ω respectively and the supply current at lower speed is 12 A, calculate the additional shunt field resistance required assuming the magnetic circuit to be unsaturated.

2) A 500v, 10 HP. shunt motor has full load efficiency of 85% .for the same torque it is desired to reduce its speed by 30% by insertion of resistance in the armature circuit assuming that all the losses except copper losses vary directly with speed, calculate the value of the inserted resistance and the efficiency of the motor when running at the reduced speed ,the resistance of the field and armature are 400 Ω and 0.25 Ω respectively.

3) A dc series motor connected to a 440v supply, runs at 600 rpm when taking a current of 50 A, calculate the value of the series resistance which inserted in series with the motor to reduce the speed to 400 rpm and the gross torque is half its previous value, self resistance of motor is 0.2 Ω.

4) A 220 V shunt motor has armature and field resistance of 0.2 Ω and 220 Ω respectively. The motor is driving a constant load torque and running at 1000 rpm drawing 10 A current from the supply. Calculate the new speed and armature current if an external armature resistance of value 5 Ω is inserted in the armature circuit. Neglect armature reaction and saturation.

5) A 220 V shunt motor has armature and field resistances of 0.2 Ω and 220 Ω respectively. The motor is driving load torque, $T_L \propto n^2$ and running at 1000 rpm drawing 10 A current from the supply. Calculate the new speed and armature current if an external armature resistance of value 5 Ω is inserted in the armature circuit. Neglect armature reaction and saturation.