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EXERCISE 2

Design and control of a DC electrical drive

Exercise text

1.Find the design parameters of a DC independent excited motor that moves a tramway vehicle

Characteristics of machine

Quantity	**Symbol**	**value**	**u.o.m**
Motor rated voltage	V_n	600	V
Motor rated speed	W_n	314	rad/s
Efficiency	η	0.9	
Armature circuit time constant	Ʈa	10	ms
Excitation rated voltage	Ven_n	120	V
Excitation rated current	Ien_n	1	A
Excitation time constant	Ʈe	1	s
Acceleration time	t_acc	25	s
Tramway mass	M_tram	10000	Kg
Reached speed	V_reac	60	km/h
Total people	peo_tot	80	/
People mass	M_peo	80	Kg

The tramway should accelerate from 0 to 60 km/h in 25 s. The tramway mass is 10 T and you should consider 200 people as the tramway trainload with a standard weight of 80 kg.

The friction force is proportional to the speed and at rated speed (60 km/h or 314 rad/s) is ⅓ of traction force.

2. Design and simulate a DC electrical drive with speed and current control in order to cover a 10 km track considering the following data.
NB : the slope is defined as s% =100*tanφ

Track (km)	Slope %	Speed (Km/h)
0-1	0	35
1-3	0	60
3-4	5	60
4-6	0	75
6-8	0	60
8-9	-5	60
9-10	0	35

Development

Required specifics:

1. Armature time constant = 10 ms;
2. Excitation time constant =1 s;
3. Acceleration to reach 60 Km/h from 0 Km/h in 25 seconds.

Parameter Identification

Considering the system and the energy balance is possible to define :

Name	**Symbol**	**Equation**	**Computation**	**Value**	**U.O.M**
Total mass	M_t	M_tram+M_peo*peo_tot	(100000 + 200*80)	26000	kg
Max Linear Speed	Vmax		60/3.6	16.7	Km/h
Average acceleration	a_ave	Vmax/t_acc	16.7/25	0.668	m/s^2
Traction force	F_traction	M_t*a_ave	26000*0.668	17333	N
Traction power	P_traction	F_traction*Vmax	17333*16.7	288.9	kW
Friction Force	F_friction	F_traction/3	17333/3	5777.7	N
Friction power	P_friction	F_friction*Vmax	5777.7*16.7	96.5	kW
Total Power	P_tot	P_traction+P_friction	288.9+96.5	385.4	kW
Armature Nominal current	Ian_n	P_tot/(η*V_n)	385.4/(0.9*600)	713.306	A
Nominal torque	T_n	P_tot/W_n	385.4/314	1226	N*M
Torque coefficient	K	T_n/(Ian_n*Ien_n)	1226/(713.306*1)	1.7189	A
Armature Resistance	Ra	((1-η)*V_n)/Ian_n	(0.1*600)/713.306	0.084	Ω
Armature Inductance	La	Ra*Ʈa	0.084*10	841	µH
Excitation Resistance	Re	Ven_n/Ien_n	120/1	120	Ω
Excitation Inductance	Le	Re*Ʈe	120/1	120	H

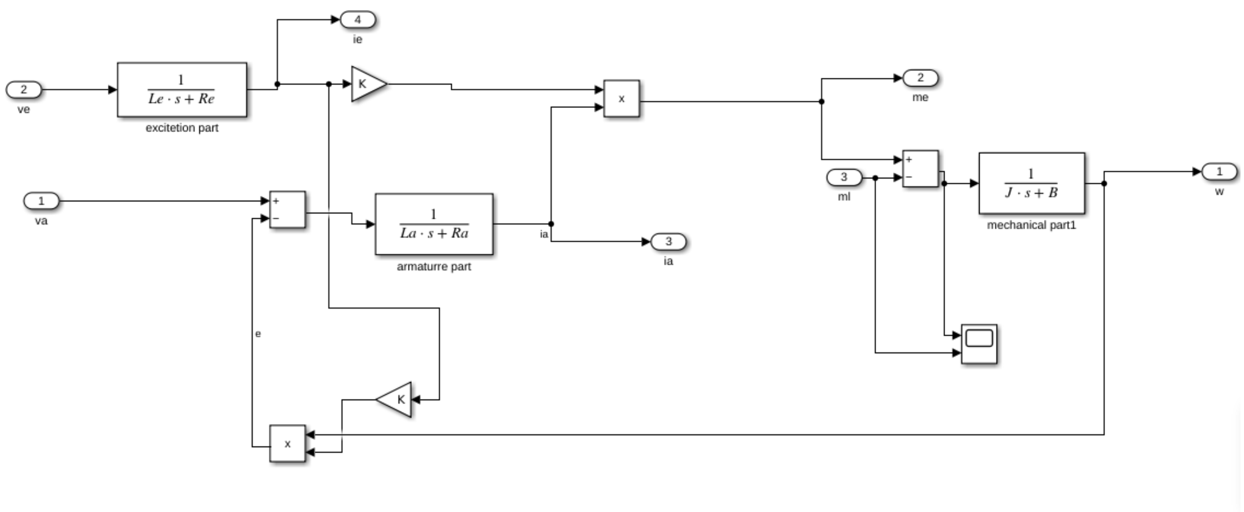
Equivalent Inertia	Jeq	M_t*Vmax^2/W_n^2	260000*16.7^2/314^2	73.174	Kgm^2
Conversion constant rad/s to m/s	C1	/	16.7/314	0.0531	(m/s)/(rad/s)
Conversion constant m/s to rad/s	C2	/	314/16.7	18.8039	(rad/s)/(m/s)
Conversion constant Km/h to rad/s	C3	/	314/60	5.2333	(rad/s)/(Km/h)
Anti Windup	ant_win	/	/	10	/

Simulink Models

-Machine models

They represent the dynamic model of the DC machine.

*Mechanical model



NB: B is used for the frictions

-Control models

The scope of the controller is to generate a control law to follow the system constraint required.

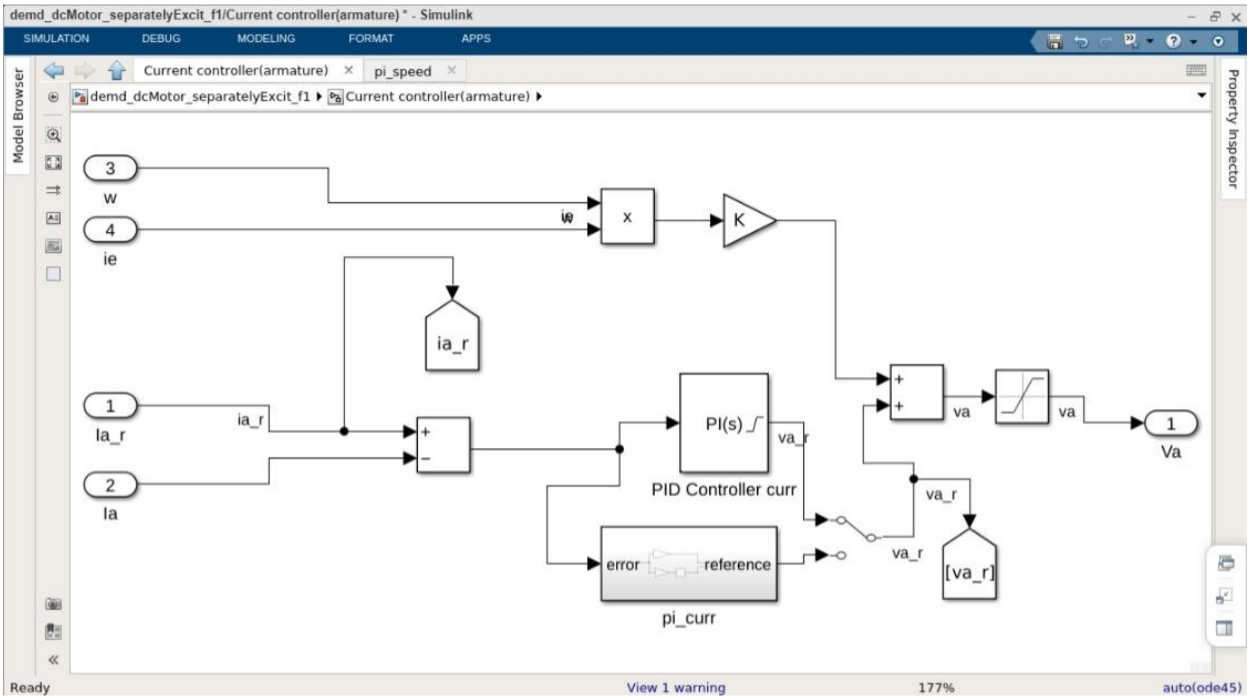
From the theory , it is known that the SE DC machine can be controlled using 2 decoupled regulators, one for the speed and one for the current.

The 2 regulators have 2 different time constants, in particular the speed controller is slower with respect to the current one.

*Current controller

The Frequency transfer function controlled by this regulator is given by 1/(Ra + s*La).

The values considered for the phase margin and the band frequency are:



Name	symbol	value	U.O.M
Frequency band	B_wia	200	rad/s
Phase_margin	M_phase_ia	75	degree

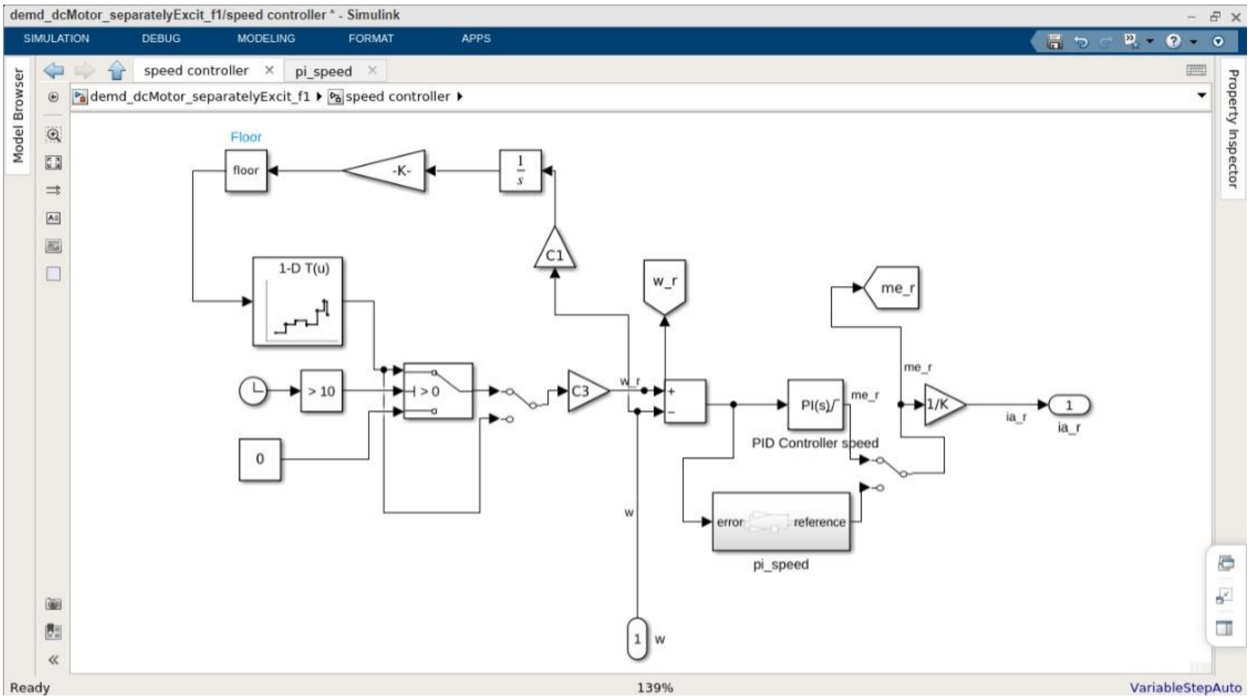
So, it is possible to define for the PI controller the following coefficients

Name	symbol	value	U.O.M
Proportional coefficient armature	kp_ia	0.1676	/
Integral coefficient armature	ki_ia	16.7598	/

Remembering that the PI structure is give by

PI = kp + ki/s

*Speed controller



The Frequency transfer function controlled by this regulator is given by 1/(B+ s*Jeq).
The values considered for the phase margin and the band frequency are:

Name	**symbol**	**value**	**U.O.M**
Frequency band speed	B_wm	10	rad/s
Phase_margin speed	M_phase_w	75	degree

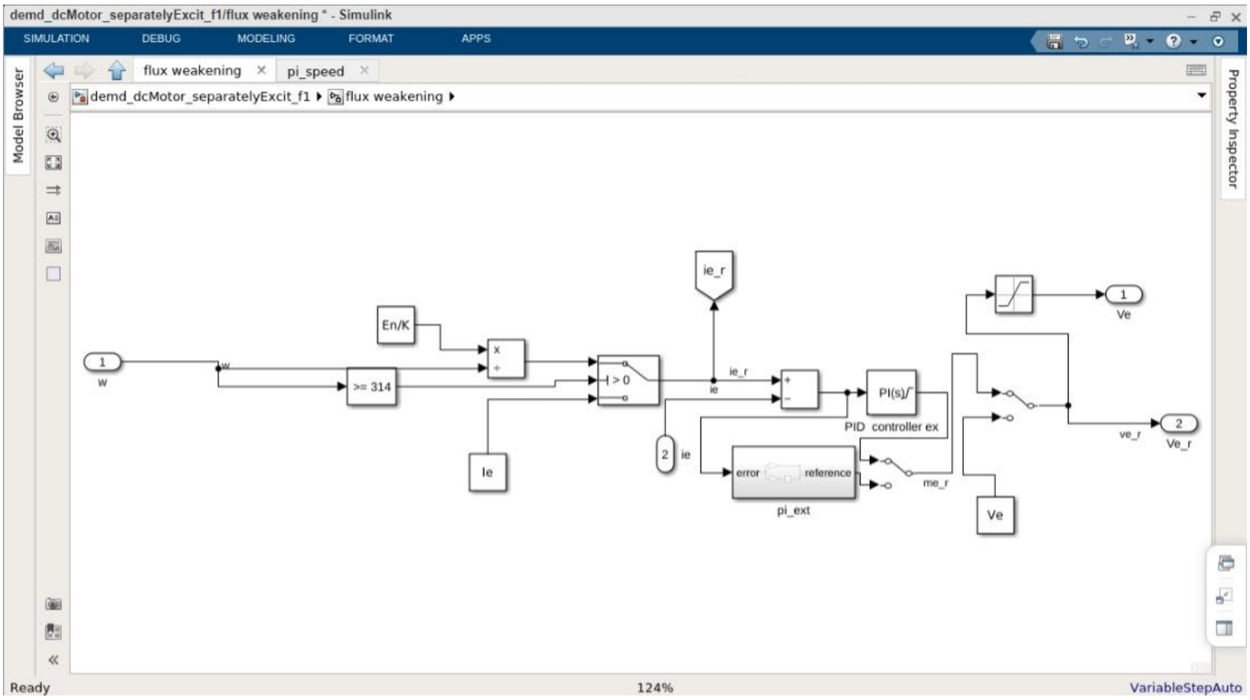
So, it is possible to define for the PI controller the following coefficients

Name	**symbol**	**value**	**U.O.M**
Proportional coefficient speed	kp_w	147	/
Integral coefficient speed	ki_w	2.6000	/

*Flux weakening

It helps us to go above the nominal speed of the machine (=60 km/h). In particular the speed that the tram has to reach is equal to 75 km/h.
So, to do that , for speed > 60 Km/h, the excitation current considered will be En/(Ω*K) , where En = V_n*η = 540 V. Doing this the power for speed greater of 60 Km/h (Ωb) the power remains constant equal to Te*Ωm, because Te decreases proportional to 1/Ωm. It is important for that point to add an excitation controller

*Excitation controller



The frequency transfer function that this controller has to control is given by
1/(Re + s*Le).
The values considered for the phase margin and the band frequency are:

Name	**symbol**	**value**	**U.O.M**
Frequency band excitation	B_wie	1	rad/s
Phase_margin excitation	M_phase_ie	75	degree

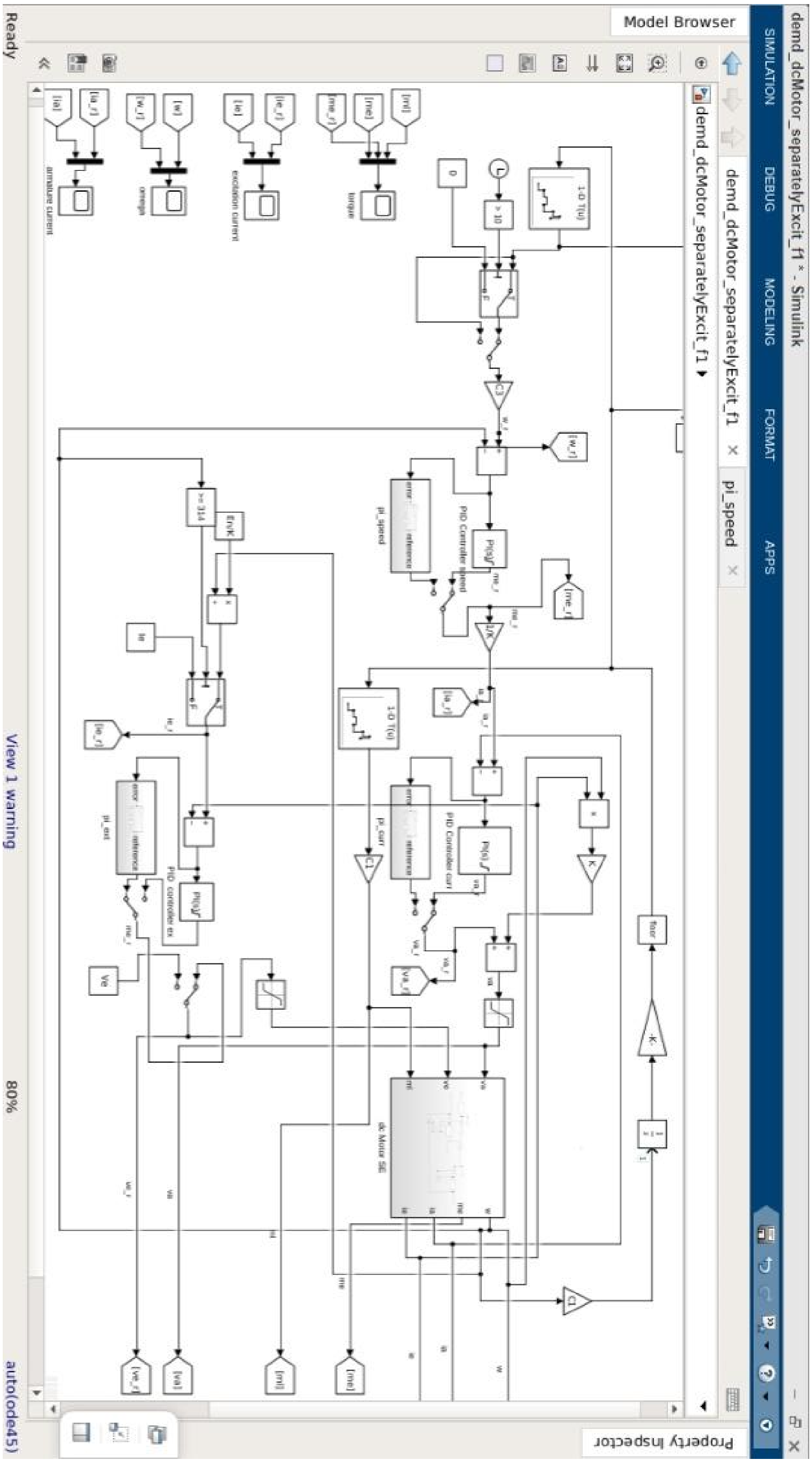
So, it is possible to define for the PI controller the following coefficients

Name	symbol	value	U.O.M
Proportional coefficient excitation	kp_ie	2400	/
Integral coefficient excitation	ki_ie	2400	/

NB: The anti windup regulator has the saturation limits equal to:

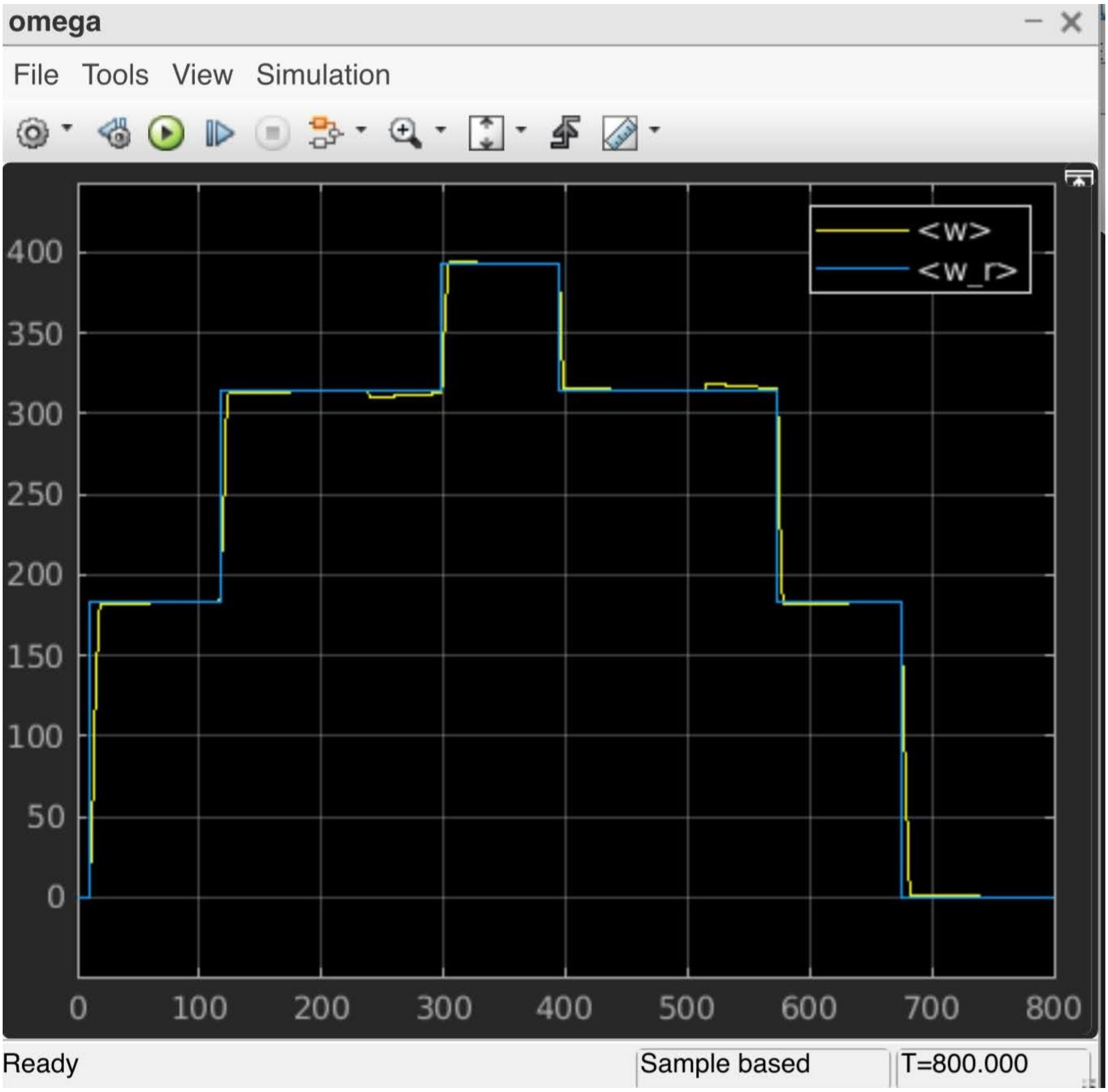
Name	symbol	value	U.O.M
Minimum Excitation Voltage	Ve_min	0	V
Maximum Excitation Voltage	Ve_max	Ve_n	V

-Complete scheme



Results

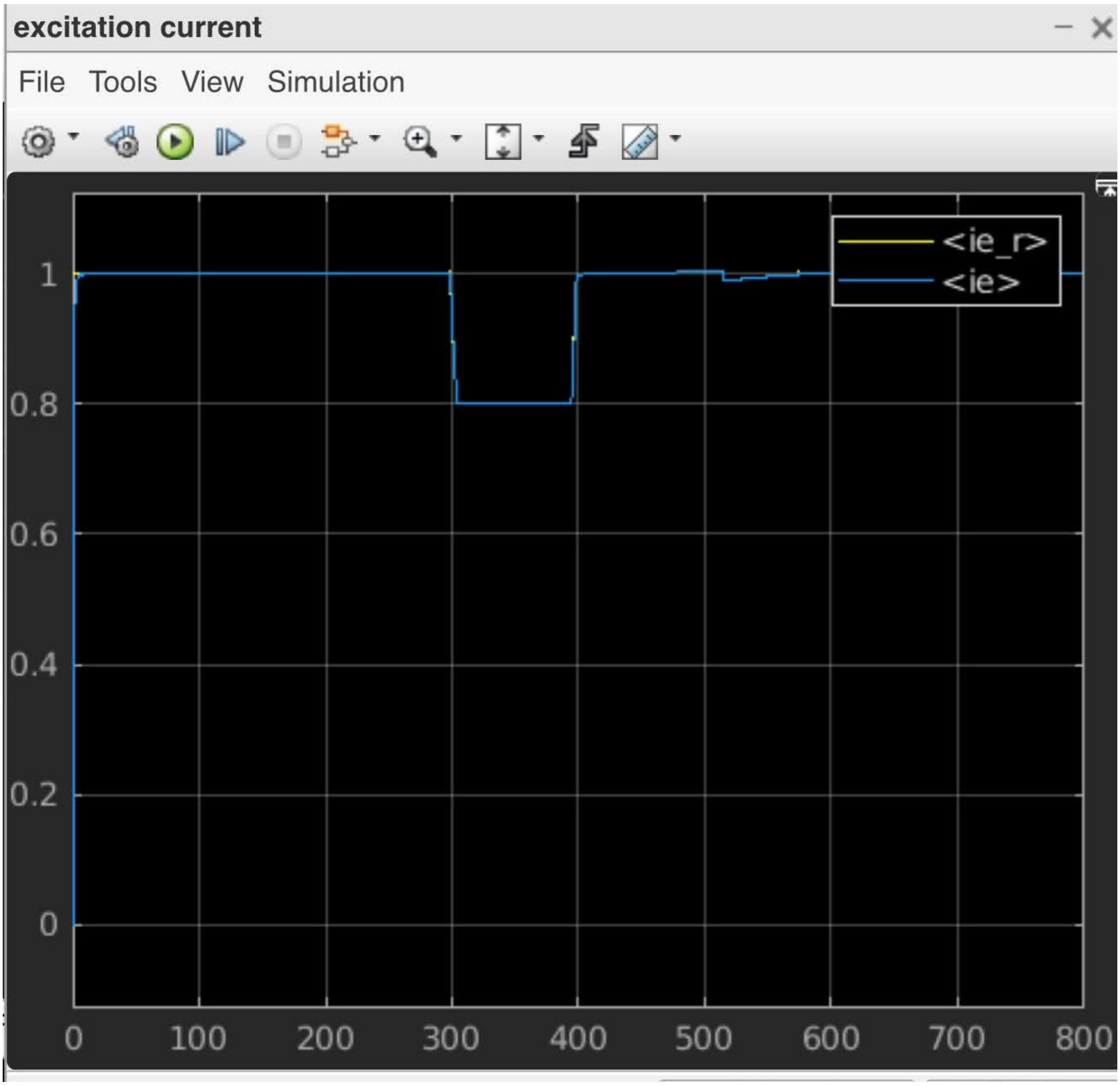
-Speed behaviour



Remark

It is possible to notice that the control unit permits the machine to follow with a high accuracy the speed given as reference. The peak is reached thanks to the flux weakening because the value of the speed in that point is greater than the base speed.

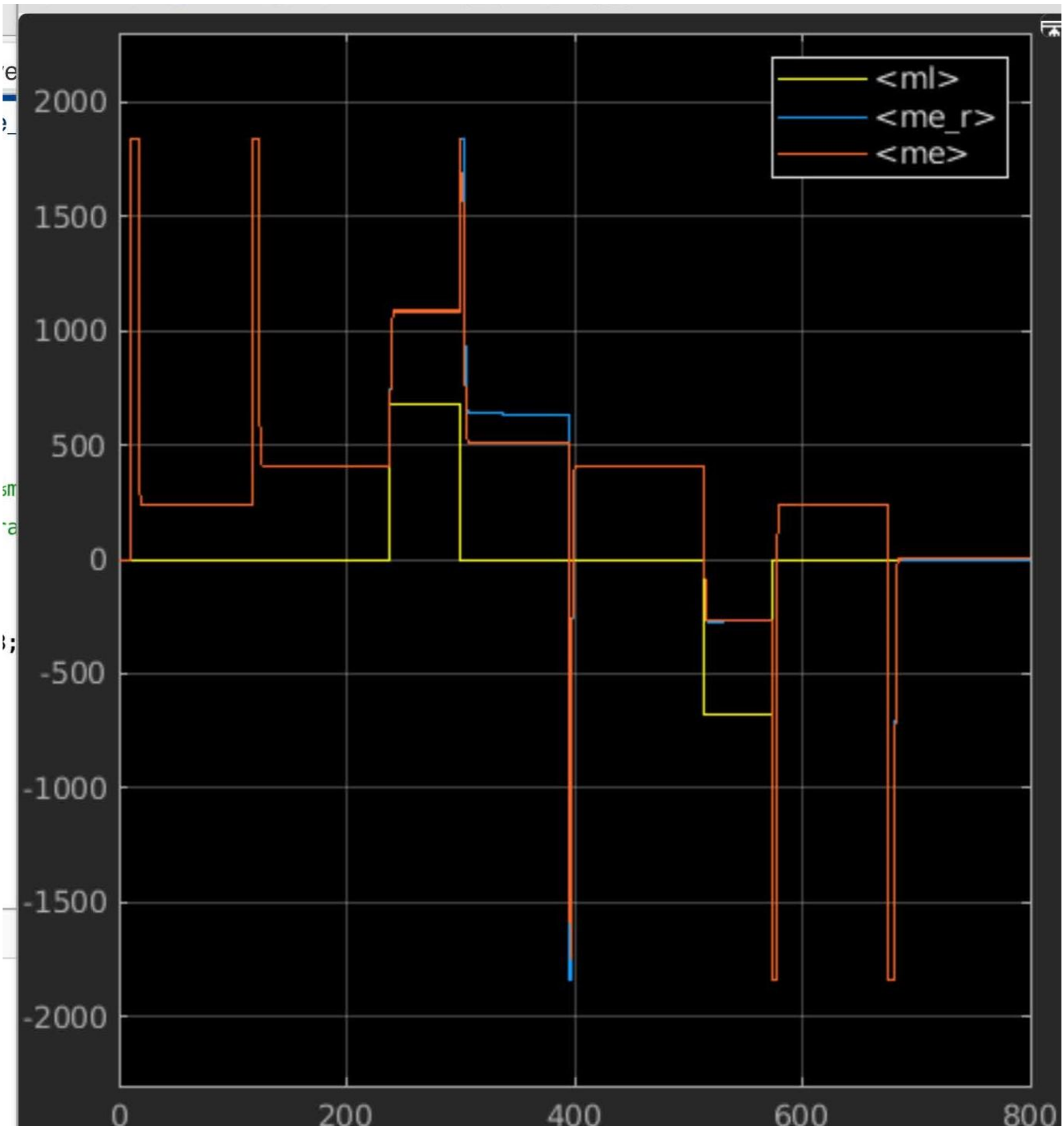
-Excitation behaviour



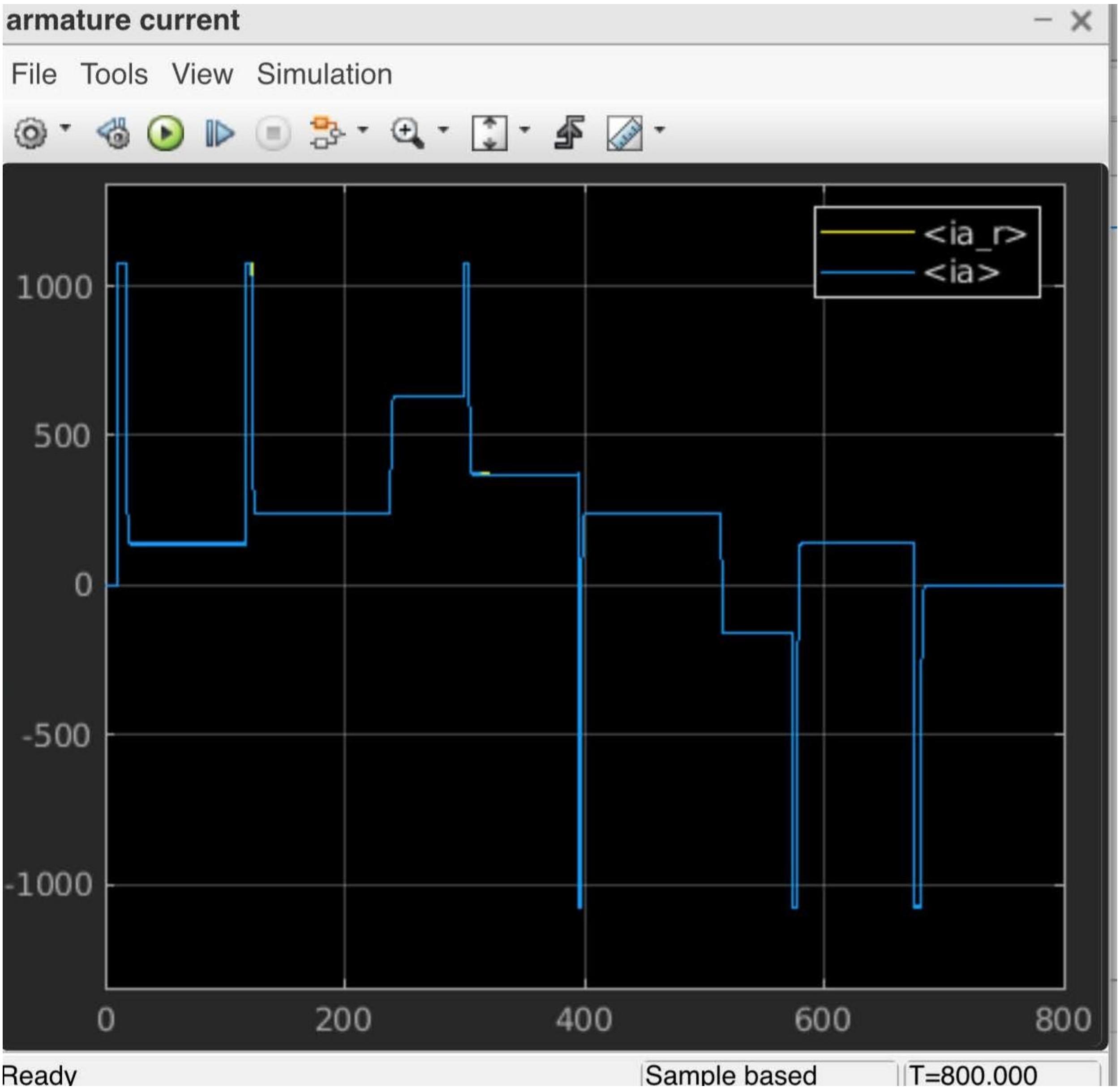
Remark

It is possible to notice a decrease of the excitation current due to the flux weakening, that helps to go above the base speed.

-Torque behaviour



-Armature behaviour



Remark

It is possible to notice that the torque and the armature current have the same behaviour, this is correct because the torque is directly depending on the armature current.

These quantities change with respect to the need of the machine to accelerate, maintain the same speed or decelerate.