Actuators

Lab 5.
DC drive PWM converters

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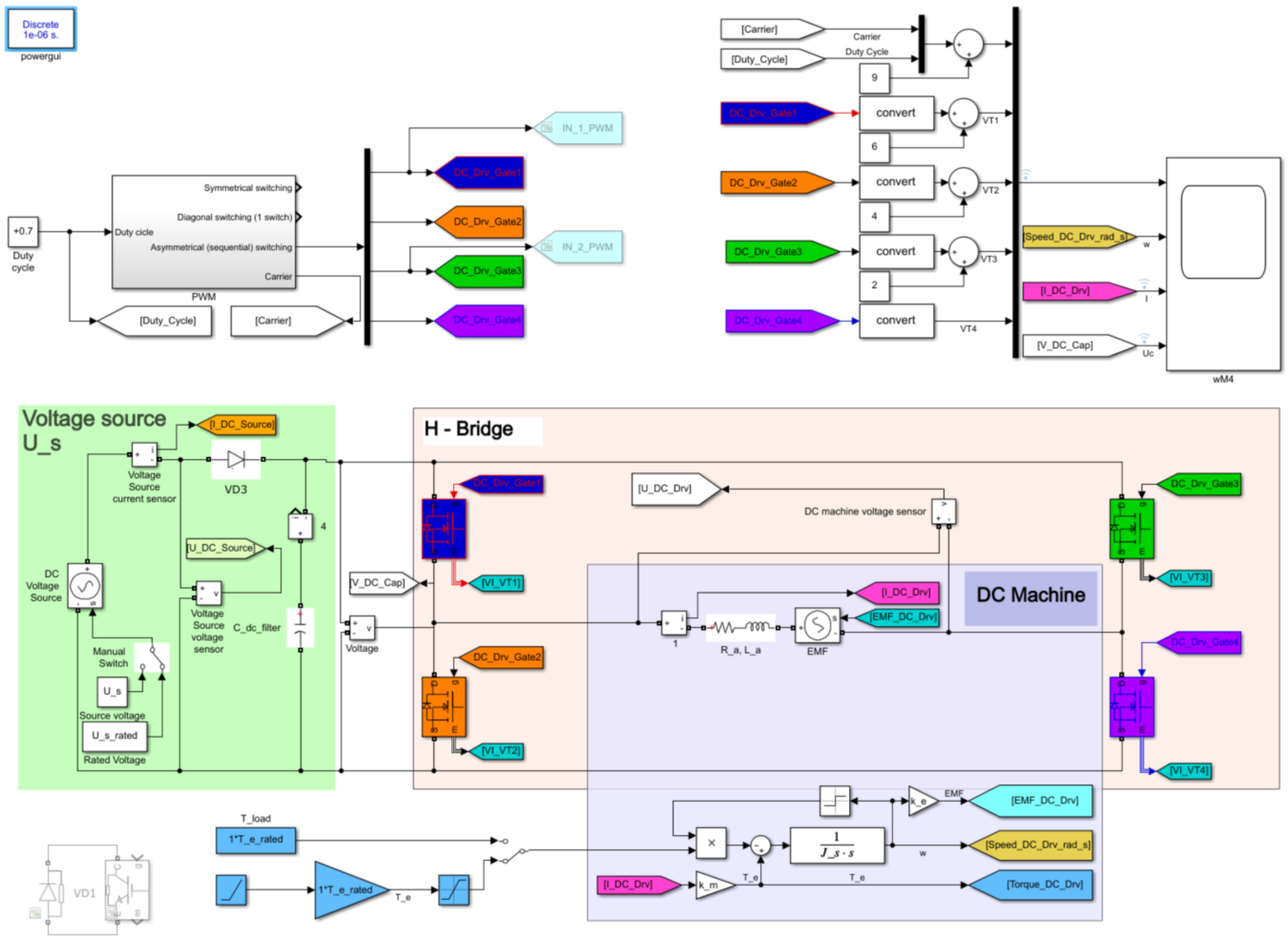
Efficiency analysis of DC drive with PWM converter

https://clck.ru/34SRNH



Deadline is the 9th of April (Beijing 23:59 GMT+8)

09/ 04 /2024

Step 1.

Lab 3. Research on DC drive PWM converters

Student name: ____________________ Date of submission______________

HDU ID ____________________ Student ITMO ID______________

Part 1. Evaluate missing parameters

Open **Actuators_Lab3_PWM_R202__.slx** model and **Actuators_Lab3_R202__.mlx**

Drive parameters

$U_{s\_rated}=$ - Rated source voltage, V;

$n_{rated}=$ - Rated rotating speed, rpm;

$f_{sw}=$ - PWM frequency, Hz;

$R_a=$ - Resistance of DC machine winding, Ω;

$L_a=$ - Armature inductance, H;

$J_S=$ - Moment of inertia, $kg \cdot m^2$;

$I_{a\_rated}=$ - Anchor rated current of DC machine, A;

$k_{lim}=\frac{T_{e\_max}}{T_{e rated}}=$ - Maximum current limit, A.

Evaluations:

$P=U_{s\_rated}\cdot I_{a\_rated}=$ - Power, W;

$I_{a\_sc}=\frac{U_{s\_rated}}{R_a}=$ - Short circuit current, A;

$w_{m\_rated}=\frac{2\cdot\pi\cdot n_{rated}}{60}=$ - Rated rotating speed, rad/s;

$k_e=\frac{(U_{s\_rated}-R_a\cdot I_{a\_rated})}{w_{m\_rated}}=$ - EMF constant, V*s/rad;

$k_m=k_e$ - Electromechanical constant, N · m /A;

$T_{e\_rated}=k_m\cdot I_{a\_rated}=$ - Rated Torque of the DC machine, N · m;

$T_{e\_max}=k_{lim}\cdot T_{e\_rated}=$ - Maximum torque, N · m;

$I_{lim}=k_{lim}\cdot I_{a\_rated}=$ - Maximum current, N · m;

$T_{e\_st}=k_m\cdot I_{a\_sc}=$ - Starting torque, N · m;

$K_{eff\_rated}=\frac{w_{m\_rated}\cdot T_{e\_rated}}{P}\cdot 100\%=$ - Rated efficiency, %;

$\tau_e=\frac{L_a}{R_a}=$ - Electromagnetic time constant, s;

$w_0=\frac{U_{s\_rated}}{k_e}=$ - Idle speed, rad/s;

HDU_ID_XXXXXXXX. Lab 5. Research on DC drive PWM converters

Please unsure yourself that **XXXXXXXX is your HDU ID number**

Use the **Actuators_Lab_5_R20XX.mlx** to evaluate missing parameters.

Drive data should be used from your variant in

Actuators - Bachelor - Automation - Lab 5.xlsx

Automation (bachelor 2021)							Drive parameters									Transistor switch parameters							
Semester 2, Year (2023/2024)							Source rated voltage	Rated rotating speed,	PWM frequency	Resistance of DC machine winding,	Armature inductance	Moment of inertia,	Anchor rated current of DC machine,	Duty cycles	Maximum current limit coefficient	Forward voltage	Forward voltage V at current I_a=I_lim	Snubber capacitance	Snubber resistance	Internal (antiparallel) diode forward voltage Vr	Internal (antiparallel) diode forward voltage Vr at current I_lim,	switch-on (rise) time of the transistor	switch-off (fall) time of the transistor
Course name		Actuators					[V]	[rpm]	[Hz]	[Ω]	[mH]	[kg*m^2]	[A]			[V]	[V]	[nF]	[kΩ]	[V]	[V]	[μs]	[μs]
	No. In ITMO	Surname, First name in Russian	No. In HDU	Surname, First name in English	Surname, First name in Chinese	Gender	U_{s_rated}	n_{rated}	f_{sw}	R_a	L_a	J_s	I_{a_rated}	$gamma_{all}$	k_{i_lim}	V_{f_vt}	$V_{f\_vt\_la}$	C_s	R_s	V_{f_rd}	$V_{f\_rd\_la}$	t_+	t_-

```
U_s_rated    =   220;      % - Rated source voltage, V;
n_rated      =   750;      % - Rated rotating speed, rpm;
f_sw         =   5000;     % - PWM frequency, Hz;
R_a          =   27.20;    % - ResistanCe of DC machine winding (armature), Ω;
L_a          =   0.128;    % - Anchor inductance, H, %tau_e=La/Ra;
J_s          =   0.004;    % - Moment of inertia, kg*m^2;
I_a_rated    =   170/220;  % - Anchor rated current of DC machine, A;
k_lim        =   3.5;      % - Maximum current limit coefficient
```

Part 2. Evaluate parameters of the system with PWM

Transistor switched on circuit parameters

V_{fvt}	=	0	- IGBT Forward voltage V_f at current $I_a \approx 0$, V (For MOSFET may be considered equal to 0);
$V_{fvt_{Ia}}$	=	1.3	- Forward voltage V_f at current $I_a = I_{lim} = I_{a\_rated} \cdot k_{lim}$, V;
$R_{on_{vt}}$	=	$\frac{(V_{fvt_{Ia}} - V_{fvt})}{I_{lim}} =$	- MOSFET / IGBT resistance R_{on} , Ω;

Snubber circuit parameters

C_S	=	330e-9	- Snubber capacitance, F;
R_S	=	1e6	- Snubber resistance, Ω;

Reverse (antiparallel) diode parameters

V_{frd}	=	0.65	- Internal (antiparallel) diode forward voltage V_f at current $I_a \approx 0$, V;
$V_{frd_{Ia}}$	=	0.75	- Internal (antiparallel) diode forward voltage at current I_{lim}, V;
$R_{on_{rd}}$	=	$\frac{V_{frd_{Ia}} - V_{frd})}{I_{lim}} =$	- Internal (antiparallel) diode resistance R_d , Ω;

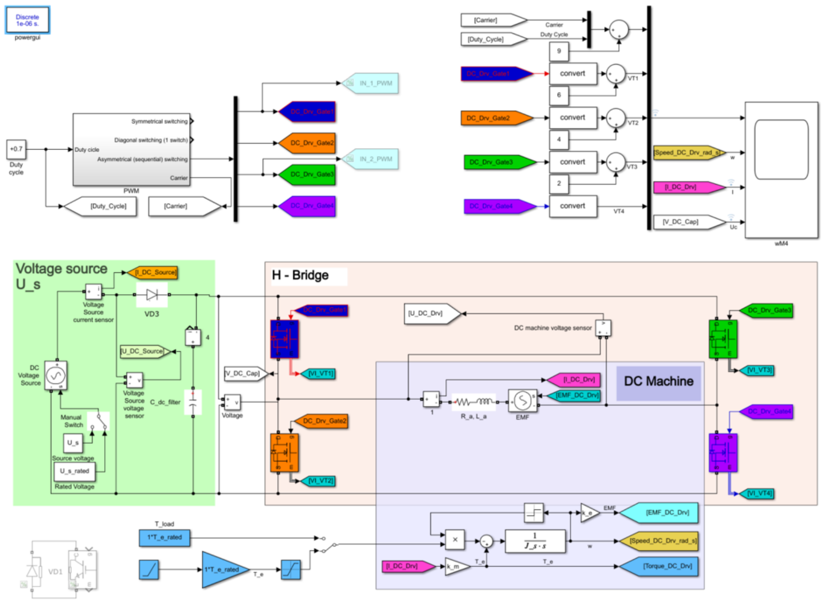


Figure 1 – DC drive system under test

Step 2.

Change the transistor parameters in the section to the new ones from your variant data

Transistor parameters

Transistor switched on circuit parameters

```
Vf_vt        =   0;                       % - Forward voltage Vf (V) (For MOSFET may be considered equal to 0)
Vf_vt_Ia     =   1.3;                     % - Forward voltage Vf at rated current I_lim (V)
R_on_vt      =   (Vf_vt_Ia-Vf_vt)/I_lim;  % - MOSFET / IGBT resistance R_on (Ω)
```

Snubber circuit parameters

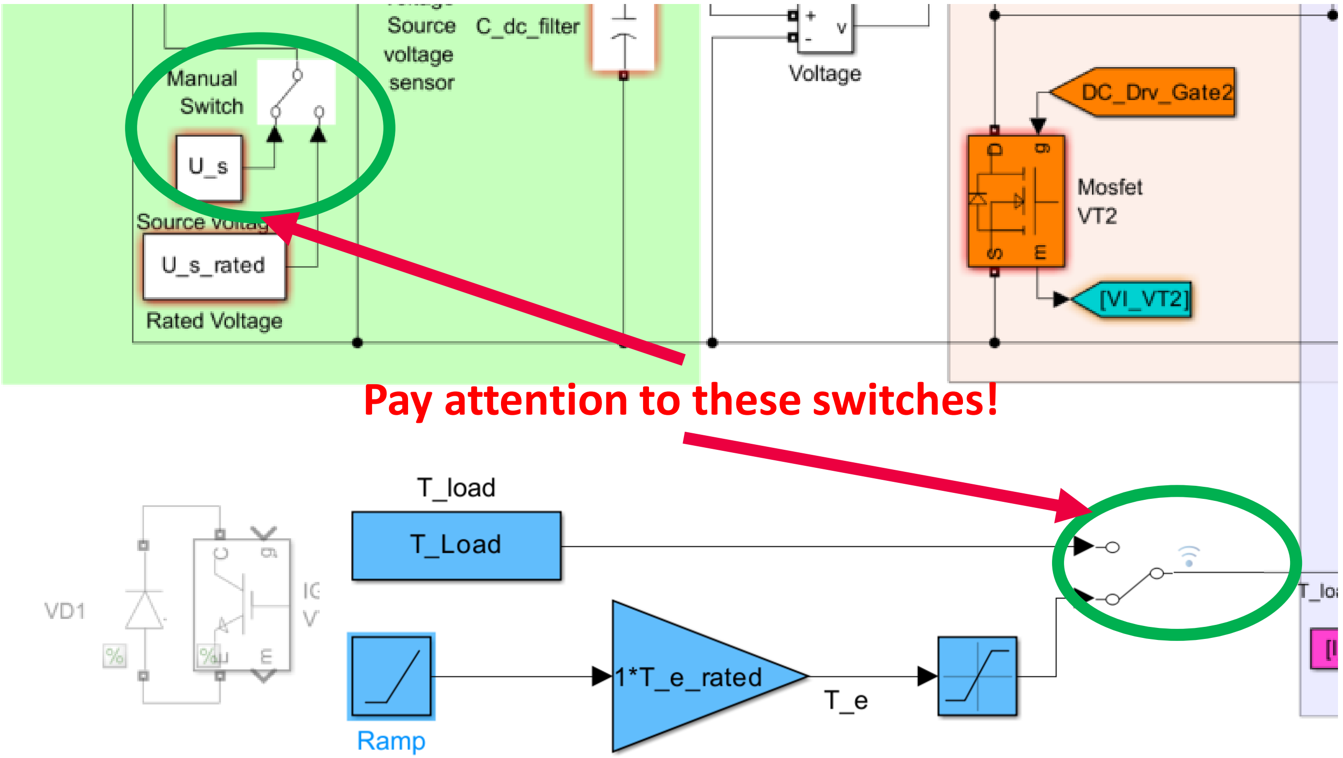
```
Cs_vt        =   330e-9;                  % - Snubber resistance Rs (Ω)
Rs_vt        =   1e6;                     % - Snubber capacitance Cs (F)
```

Reverse (antiparallel) diode parameters

```
Vf_rd        =   0.65;                    % - Internal (antiparallel) diode forward voltage Vf(V)
Vf_rd_Ia     =   0.75;                    % - Internal (antiparallel) diode forward voltage at rated current I_lim (V)
R_on_rd      =   (Vf_rd_Ia-Vf_rd)/I_lim;  % - Internal (antiparallel) diode resistance Rd(Ω)
```

Step 3

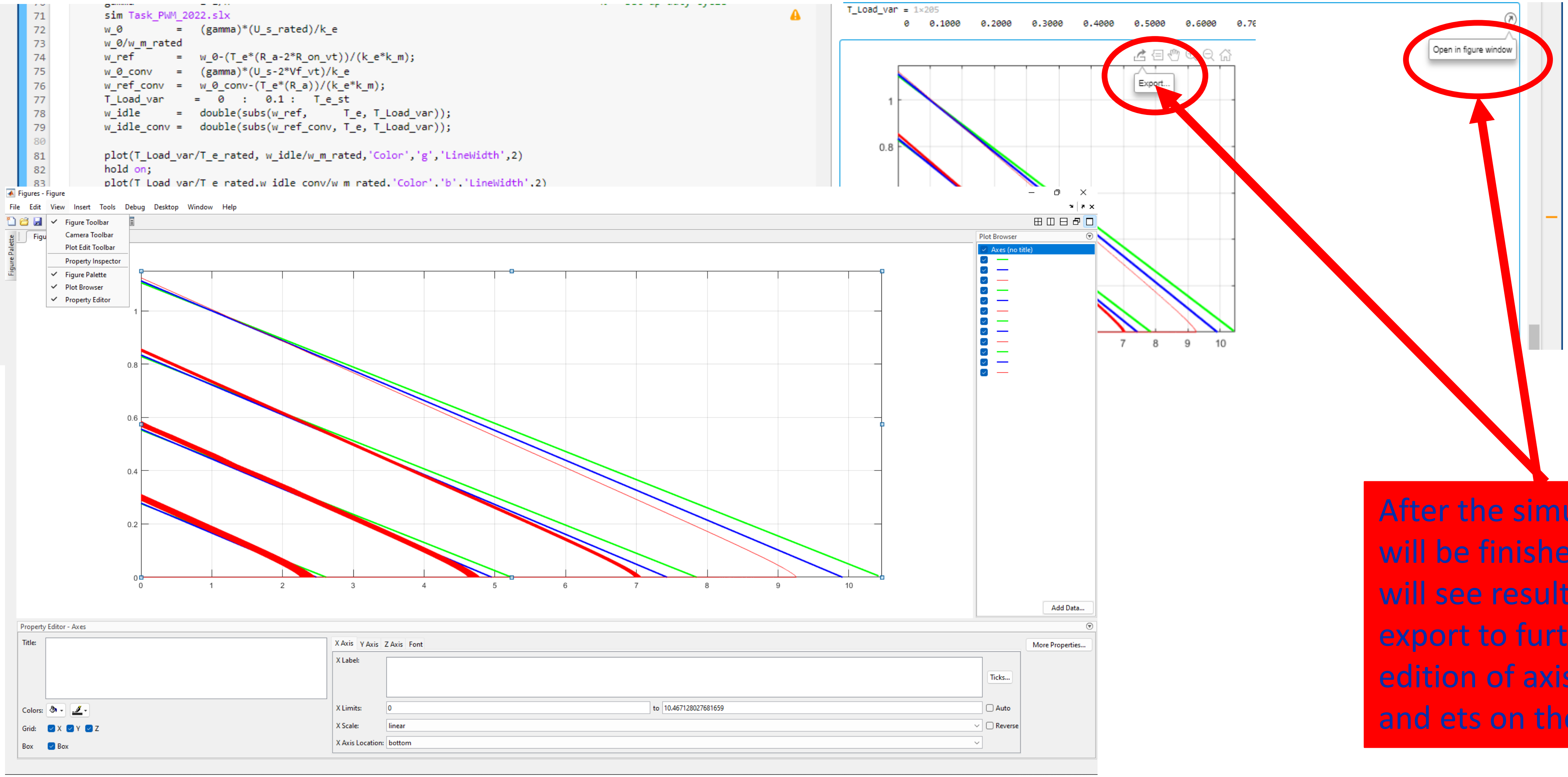
```
figure
syms T_e
for i          =   1   :   1   :  n
    gamma      =   i*1/n;                               % - set up duty cycle
    sim Actuators_Lab3_PWM_R2022b.slx                   % - this file should be in the same folder with Lab3.mlx
    w_0        =   (gamma)*(U_s_rated)/k_e;
    w_ref      =   w_0-(T_e*(R_a))/(k_e*k_m);
    w_0_conv   =   (gamma)*(U_s-2*Vf_vt)/k_e;
    w_ref_conv =   w_0_conv-(T_e*(R_a+2*R_on_vt))/(k_e*k_m);
    T_Load_var    =   0   :   0.1 :   T_e_st;
    w_idle     =   double(subs(w_ref,      T_e, T_Load_var));
    w_idle_conv =  double(subs(w_ref_conv, T_e, T_Load_var));
    plot(T_Load_var/T_e_rated, w_idle/w_m_rated,'Color','g','LineWidth',2)
    hold on;
    plot(T_Load_var/T_e_rated,w_idle_conv/w_m_rated,'Color','b','LineWidth',2)
    hold on;
    plot(Current_speed.signals(3).values*k_m/T_e_rated, Current_speed.signals(2).values/w_m_rated  ,'Color','r','LineWidth',0.5);
    hold on;
    end
grid on;
if f_sw==f_sw_opt_s_sw
    SW_type='Symmetric';
elseif f_sw==f_sw_opt_n_sw
    SW_type='Asymmetric';
else
    SW_type='Not set'
end
xlim([0 T_e_st/T_e_rated])
ylim([0 1.15])
xlabel('T_e / T_e_ _r_a_t_e_d')
ylabel('\omega / \omega_m_ _r_a_t_e_d')
legend('DC Drive theoretical characteristic','DC Drive with power converter','DC Drive with PWM simulation', 'Location','northoutside')
v=axis;
text(T_e_st/T_e_rated-4, 0.7, {  strcat('U_s_ _r_a_t_e_d=',          num2str(U_s_rated,      '%3.2f'), ' [V] ' );...
                                 strcat('U_s=',                     num2str(U_s,            '%3.2f'), ' [V] ' );...
                                 strcat('f_s_w=',                   num2str(f_sw,           '%3.2f'), ' [Hz]' );...
                                 strcat('Switching type: ',         SW_type                                   );...
                                 strcat('f_s_w_ _o_p_t_ _s_ _s_w=', num2str(f_sw_opt_s_sw,  '%3.2f'), ' [Hz]' );...
                                 strcat('f_s_w_ _o_p_t_ _n_ _s_w=', num2str(f_sw_opt_n_sw,  '%3.2f'), ' [Hz]' );...
                                 strcat('I_a_ _r_a_t_e_d=',         num2str(I_a_rated,      '%3.1f'), ' [A] ' );...
                                 strcat('T_e_ _r_a_t_e_d=',         num2str(T_e_rated,      '%3.1f'), ' [N*m]');...
                                 strcat('k_l_i_m=',                 num2str(k_lim,          '%3.1f'), '     ' )},...
      'BackgroundColor', [1 1 1])
% hold off;
```



Pay attention to this settings. To obtain a group of characteristics it is recommended to select appropriate switching method. In this case you will get results as 4 characteristics, one of them will be for duty cycle gamma= 0.5

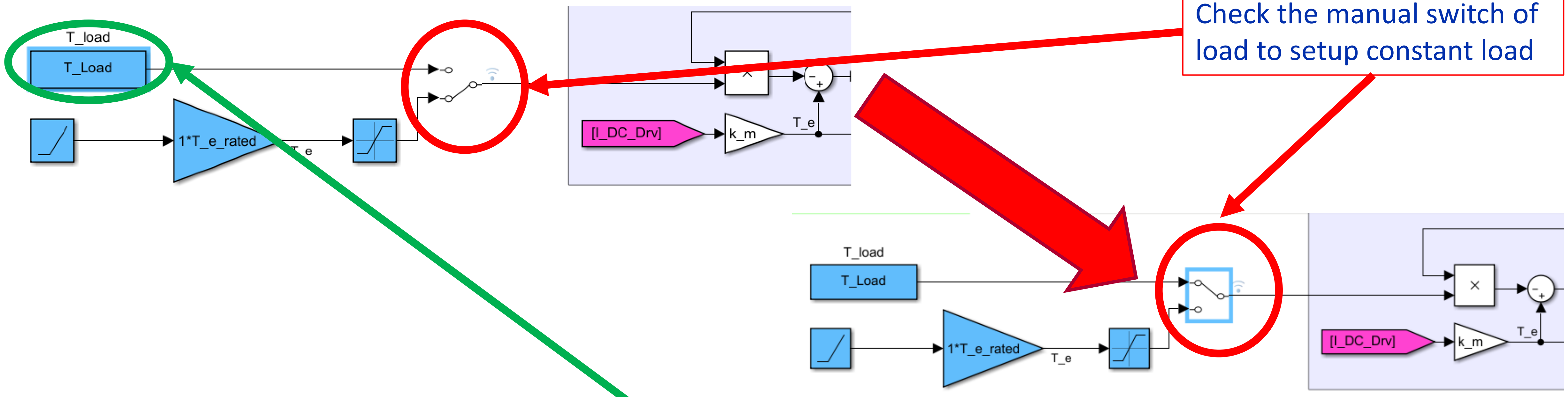
But after this experiment it recommended to setup gamma = gamma_all(n) to perform correct efficiency analysis

Step 3



After the simulation will be finished, you will see results. Press export to further edition of axis, titles and ets on the picture

Step 4

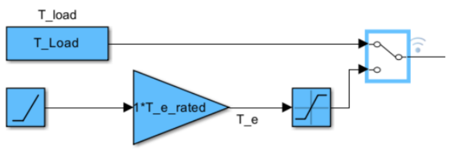


Check the manual switch of load to setup constant load

Check the load section of the Actuators_Lab_5_R20XX.mlx to setup correct value of load torque T_load

Step 4

Set up gamma = 0.5 and $T_{load} = T_{e_{rated}}$ and comment "Ctrl+R" lines 94 - 140 for energy efficiency experiment



You may uncomment frequency required and evaluate this selection only with F9

```
gamma          =   0.5;
Stop_time      =  30*tau_m
%f_sw           =   f_sw_opt_s_sw;                % f_sw for symmetric switching
f_sw          =   f_sw_opt_n_sw;                % f_sw for asymmetric sequential  and diagonal switching
T_sw           =   1/f_sw;                       % Reassigned switching period, s
T_Load         =   k_i_lim * T_e_rated;          % - Load torque set up as constant load;
sim (ModelName)                                  % - uncomment this line to do the efficicency experiment
```

or

```
gamma          =   0.5;
Stop_time      =  30*tau_m
f_sw           =   f_sw_opt_s_sw;                % f_sw for symmetric switching
% f_sw         =   f_sw_opt_n_sw;                % f_sw for asymmetric sequential  and diagonal switching
T_sw           =   1/f_sw;                       % Reassigned switching period, s
T_Load         =   k_i_lim * T_e_rated;          % - Load torque set up as constant load;
sim (ModelName)                                  % - uncomment this line to do the efficicency experiment
```

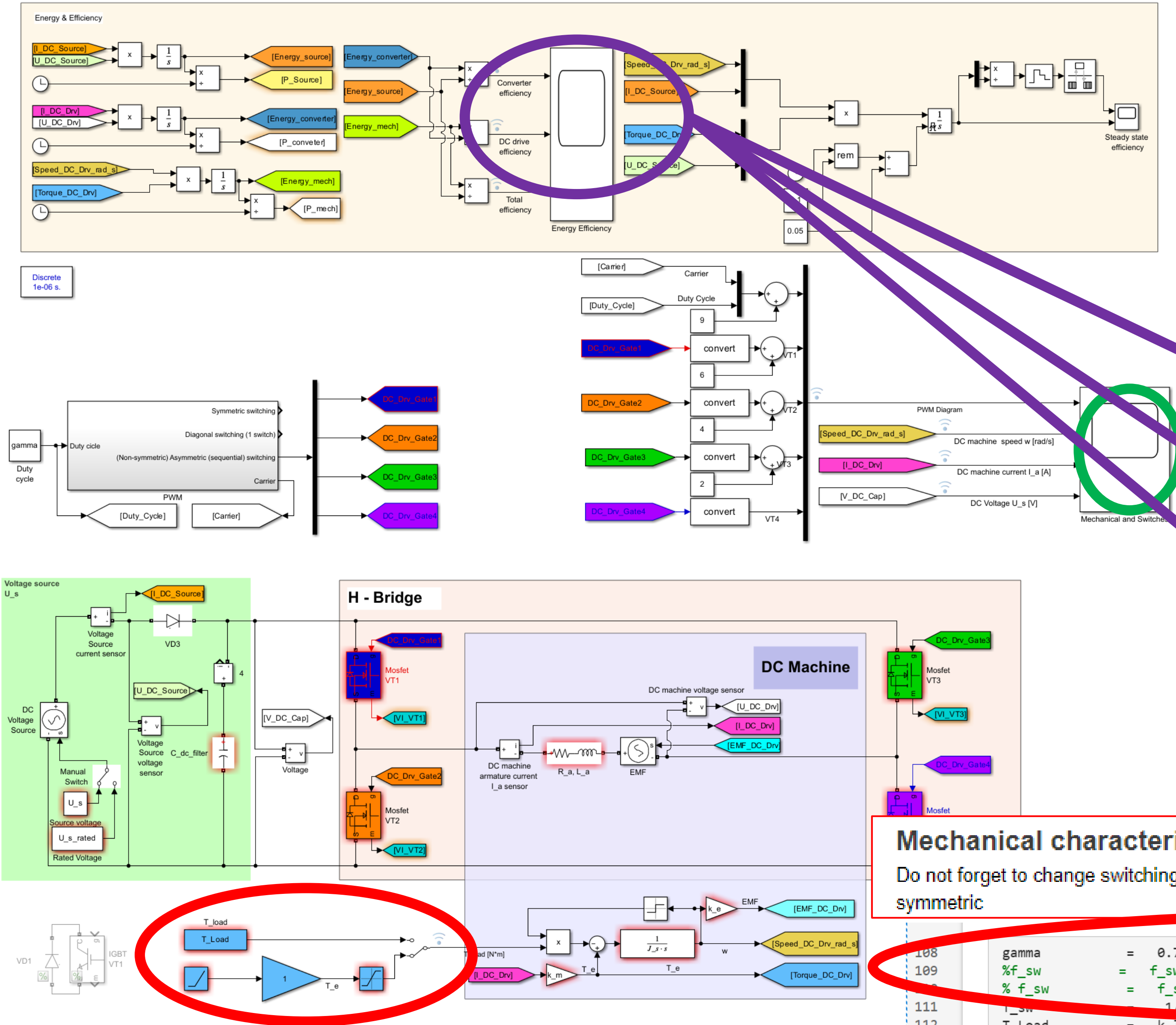
```
141 gamma          =   0.5;
142 Stop_time      =   30*tau_m
143 %f_sw          =   f_sw_opt_s_sw;              % f_sw for symmetric switching
144 % f_sw         =   f_sw_opt_n_sw;              % f_sw for asymmetric sequential  and diagonal switching
145 T_sw           =   1/f_sw;                     % Reassigned switching period, s
146 T_Load         =   k_i_lim * T_e_rated;        % - Load torque set up as constant load;
147 sim (ModelName)                                % - uncomment this line to do the efficiency experiment
```

- Evaluate Selection in Command Window F9
- Open Selection Ctrl+D
- Help on Selection F1
- Copy Output
- Copy All Output
- Cut Ctrl+X
- Copy Ctrl+C
- Paste Ctrl+V
- Wrap Comments Ctrl+J
- Comment Ctrl+R
- Uncomment Ctrl+Shift+R
- Duplicate Line(s) Ctrl+Shift+C
- Convert Between Code and Text Ctrl+E
- Change Case Ctrl+Shift+A
- Smart Indent Ctrl+I
- Convert to Function
- Convert to Local Function

```
% figure
% syms T_e
% for i               =   1   :   1   :  n
%     gamma           =   gamma_all(i)                              % - set up duty cycle
%
%     sim (ModelName)                                               % - this file should be in the same folder with Lab3.mlx
%     w_0             =   (gamma)*(U_s_rated)/k_e;
%     w_ref           =   w_0-(T_e*(R_a))/(k_e*k_m);
%     w_0_conv        =   (gamma)*(U_s-2*Vf_vt)/k_e;
%     w_ref_conv      =   w_0_conv-(T_e*(R_a+2*R_on_vt))/(k_e*k_m);
%     T_Load_var      =   0   :   0.1 :   T_e_st;
%     w_idle          =   double(subs(w_ref,      T_e, T_Load_var));
%     w_idle_conv     =   double(subs(w_ref_conv, T_e, T_Load_var));
%     plot(T_Load_var/T_e_rated, w_idle/w_m_rated,'Color','g','LineWidth',2)
%     hold on;
%     plot(T_Load_var/T_e_rated,w_idle_conv/w_m_rated,'Color','b','LineWidth',2)
%     hold on;
%     plot(Current_speed.signals(3).values*k_m/T_e_rated, Current_speed.signals(2).values/w_m_rated  ,'Color','r','LineWidth',0.5);
%     hold on;
% end
% R_a             =   R_a-2*R_on_vt                          % - Full active resistance of armature cirquit (Ohm)
% grid on;
% if f_sw==f_sw_opt_s_sw
%     SW_type='Symmetric';
% elseif f_sw==f_sw_opt_n_sw
%     SW_type='Asymmetric';
% else
%     SW_type='Not set'
% end
% xlim([0 T_e_st/T_e_rated])
% ylim([0 1.15])
% xlabel('T_e / T_e_ _r_a_t_e_d')
% ylabel('\omega / \omega_m_ _r_a_t_e_d')
% legend('DC Drive theoretical characteristic','DC Drive with power converter','DC Drive with PWM simulation', 'Location','northoutside')
% v=axis;
% text(T_e_st/T_e_rated-4, 0.7, {  strcat('U_s_ _r_a_t_e_d=',         num2str(U_s_rated,      '%3.2f'), ' [V] ' );...
%                                  strcat('U_s=',                     num2str(U_s,            '%3.2f'), ' [V] ' );...
%                                  strcat('f_s_w=',                   num2str(f_sw,           '%3.2f'), ' [Hz]' );...
%                                  strcat('Switching type: ',         SW_type                           );...
%                                  strcat('f_s_w_ _o_p_t_ _s_ _s_w=', num2str(f_sw_opt_s_sw,  '%3.2f'), ' [Hz]' );...
%                                  strcat('f_s_w_ _o_p_t_ _n_ _s_w=', num2str(f_sw_opt_n_sw,  '%3.2f'), ' [Hz]' );...
%                                  strcat('I_a_ _r_a_t_e_d=',         num2str(I_a_rated,      '%3.1f'), ' [A] ' );...
%                                  strcat('T_e_ _r_a_t_e_d=',         num2str(T_e_rated,      '%3.1f'), ' [N*m]');...
%                                  strcat('k_l_i_m=',                 num2str(k_i_lim,         '%3.1f'), '     ' )},...
%      'BackgroundColor', [1 1 1])
%
%
% hold off;
```

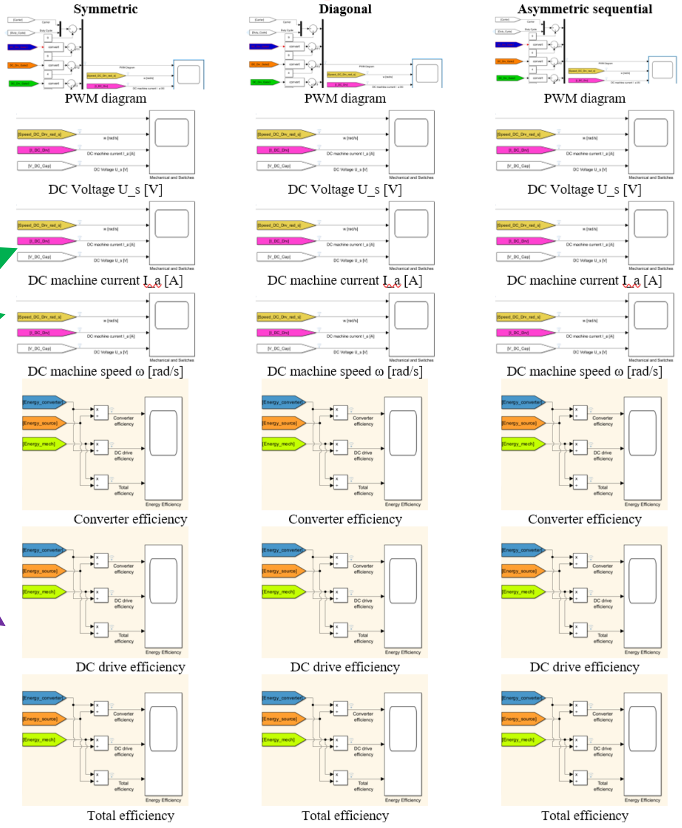
Pay attention to this settings. You may comment lines 64-107 and run selection 108-113

Do not forget to switch T_load to constant block



Part 4. Simulation results

- Analyze drive parameters with different pulse width with duty cyc gamma= 0.75 and T_load=$k_{lim} * T_{e\_rated}$



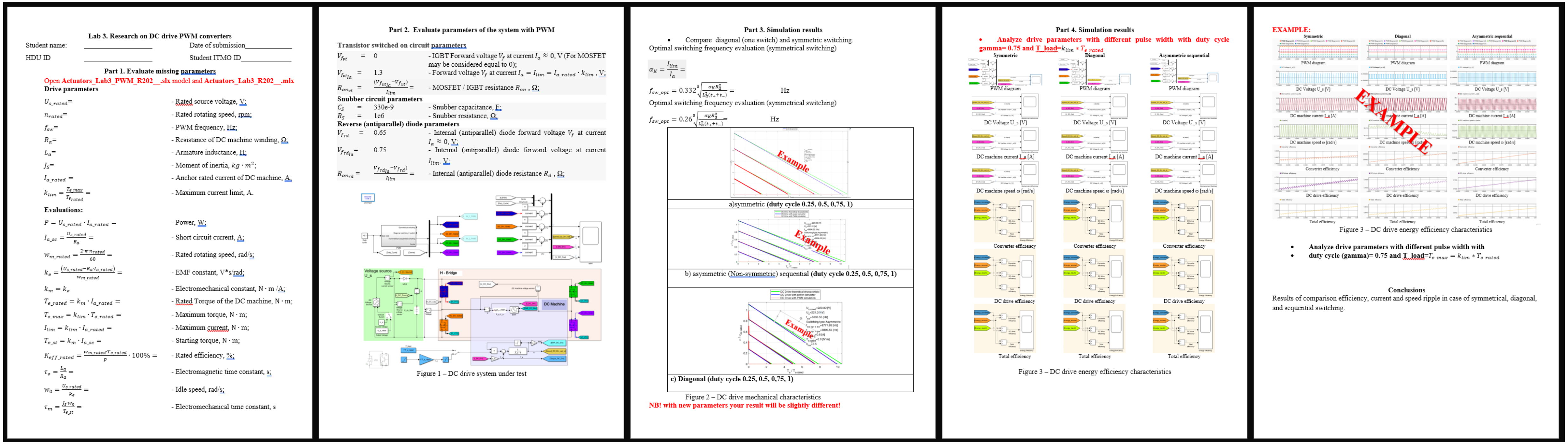
Mechanical characteristic

Do not forget to change switching frequency f_sw when changing switching method from Symetric to any other or vice versa any asymmetric to symmetric

```
gamma        =   0.75;
%f_sw          =   f_sw_opt_s_sw;                      % f_sw for symmetric switching
% f_sw         =   f_sw_opt_n_sw;                      % f_sw for asymmetric sequential  and diagonal switching
T_sw          =     1/f_sw;                            % Reassigned switching period, s
T_Load        =   k_lim* T_e_rated;                    % - Load torque set up as constant load;
%sim Actuators_Lab3_PWM_R2020b.slx                     % - uncomment this line to do the efficiency experiment
```

Fulfill the template and upload it: https://clck.ru/34SRNH

1st Deadline is the 9th of April (Beijing 23:59 GMT+8) 09/ 04 /2025


Lab 3. Research on DC drive PWM converters

Student name: Date of submission

HDU ID Student ITMO ID

Part 1. Evaluate missing parameters

Open Actuators_Lab3_PWM_R202__.slx model and Actuators_Lab3_R202__.mlx

Drive parameters

Part 2. Evaluate parameters of the system with PWM

Transistor switched on circuit parameters

Snubber circuit parameters

Reverse (antiparallel) diode parameters

Figure 1 – DC drive system under test

Part 3. Simulation results

Compare diagonal (one switch) and symmetric switching.

Optimal switching frequency evaluation (symmetrical switching)

a)symmetric (duty cycle 0.25, 0.5, 0,75, 1)

b) asymmetric (Non-symmetric) sequential (duty cycle 0.25, 0.5, 0,75, 1)

c) Diagonal (duty cycle 0.25, 0.5, 0,75, 1)

Figure 2 – DC drive mechanical characteristics

NB! with new parameters your result will be slightly different!

Part 4. Simulation results

Analyze drive parameters with different pulse width with duty cycle gamma= 0.75 and T_load=$k_{lim} * T_{e\ rated}$

Figure 3 – DC drive energy efficiency characteristics

EXAMPLE:

Figure 3 – DC drive energy efficiency characteristics

Analyze drive parameters with different pulse width with duty cycle (gamma)= 0.75 and T_load=$T_{e\ max} = k_{lim} * T_{e\ rated}$

Conclusions

Results of comparison efficiency, current and speed ripple in case of symmetrical, diagonal, and sequential switching.