Lab 5. Research on DC drive PWM converters

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Part 1. Evaluate missing parameters

- Open Actuators_Lab_5_R2022b.slx model and Actuators_Lab5_R20XX.mlx
- Source data

U_{s_rated}=75 - Rated source voltage, V;

n_{rated}=600 - Rated rotating speed, rpm;

f_{sw}= 1.21e+03 - PWM frequency, Hz;

R_a=0.075 - Resistance of DC machine winding, Ω;

L_a=5.54e-04 - Armature inductance, H;

J_S=0.238 - Moment of inertia, $kg \cdot m^2$;

$I_{a\_rated} =$ 50 - Anchor rated current of DC machine, A;

k_{i_lim} =1.8 - Maximum current limit, A.

Evaluations:

$P = U_{s\_rated} \cdot I_{a\_rated} = 3750$ - Power, W;

$I_{a\_sc} = \frac{U_{s\_rated}}{R_a} = 1000$ - Short circuit current, A;

$w_{m\_rated} = \frac{2 \cdot \pi \cdot n_{rated}}{60} = 62.8319$ - Rated rotating speed, rad/s;

$k_e = \frac{(U_{s\_rated} - R_a \cdot I_{a\_rated})}{w_{m\_rated}} = 1.134$ - EMF constant, V*s/rad;

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

$T_{e\_rated} = k_m \cdot I_{a\_rated}$ =56.69 - Rated Torque of the DC machine, N · m;

$T_{e\_max} = k_{lim} \cdot T_{e\_rated}$ =102.0581 - Maximum torque, N · m;

$T_{e\_st} = k_m \cdot I_{a\_sc}$ =1.13e+03 - Starting torque, N · m;

$K_{eff\_rated} = \frac{w_{m\_rated} \cdot T_{e\_rated}}{P} \cdot 100\% = 95$ - Rated efficiency, %;

$\tau_e = \frac{L_a}{R_a} = 0.0074$ - Electromagnetic time constant, s;

$w_0 = \frac{U_{s\_rated}}{k_e}$ =66.1388 - Idle speed, rad/s;

$\tau_m = \frac{J_S \cdot w_0}{T_{e\_st}} = 0.0139$ - Electromechanical time constant, s

Part 2. Evaluate parameters of the system with PWM

Transistor switched on circuit parameters

$V_{f_{vt}}$ = 0 - IGBT Forward voltage V_f at current $I_a \approx 0$, [V] (For MOSFET may be considered equal to 0);

$V_{f_{vt_{Ia}}}$ = 1.2 - Forward voltage V_f at current $I_a = I_{lim} = I_{a\_rated} \cdot k_{lim}$, [V];

$R_{on_{vt}} = \frac{(V_{f_{vt_{Ia}}} - V_{f_{vt}})}{I_{lim}} = 0.0133$ - 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

$V_{f_{rd}}$ = 0.85 - Internal (antiparallel) diode forward voltage V_f at current $I_a \approx 0$, [V];

$V_{f_{rd_{Ia}}}$ = 0.95 - Internal (antiparallel) diode forward voltage at current I_{lim}, [V];

$R_{on_{rd}} = \frac{(V_{f_{rd_{Ia}}} - V_{f_{rd}})}{I_{lim}} = 0.0011$ - Internal (antiparallel) diode resistance R_d, [Ω];

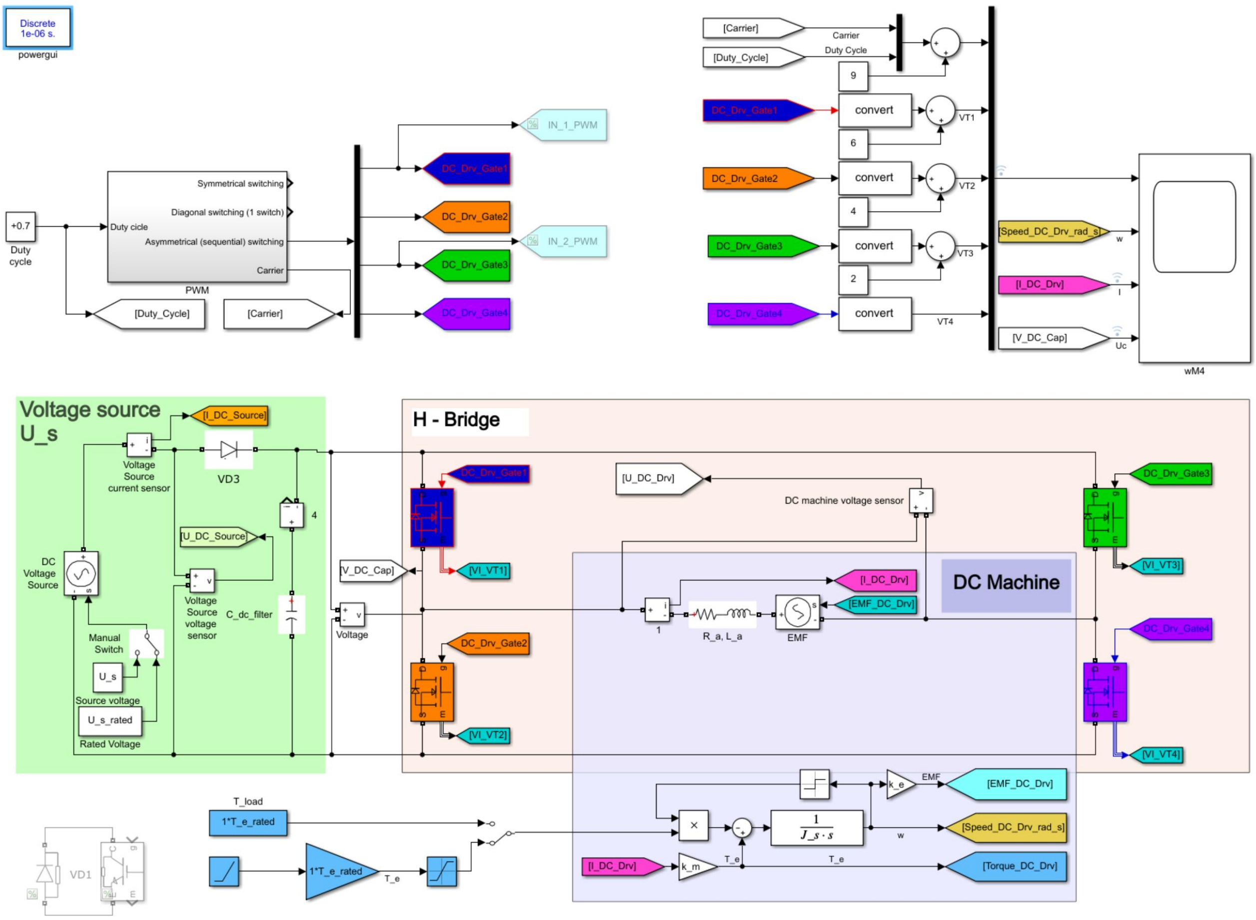


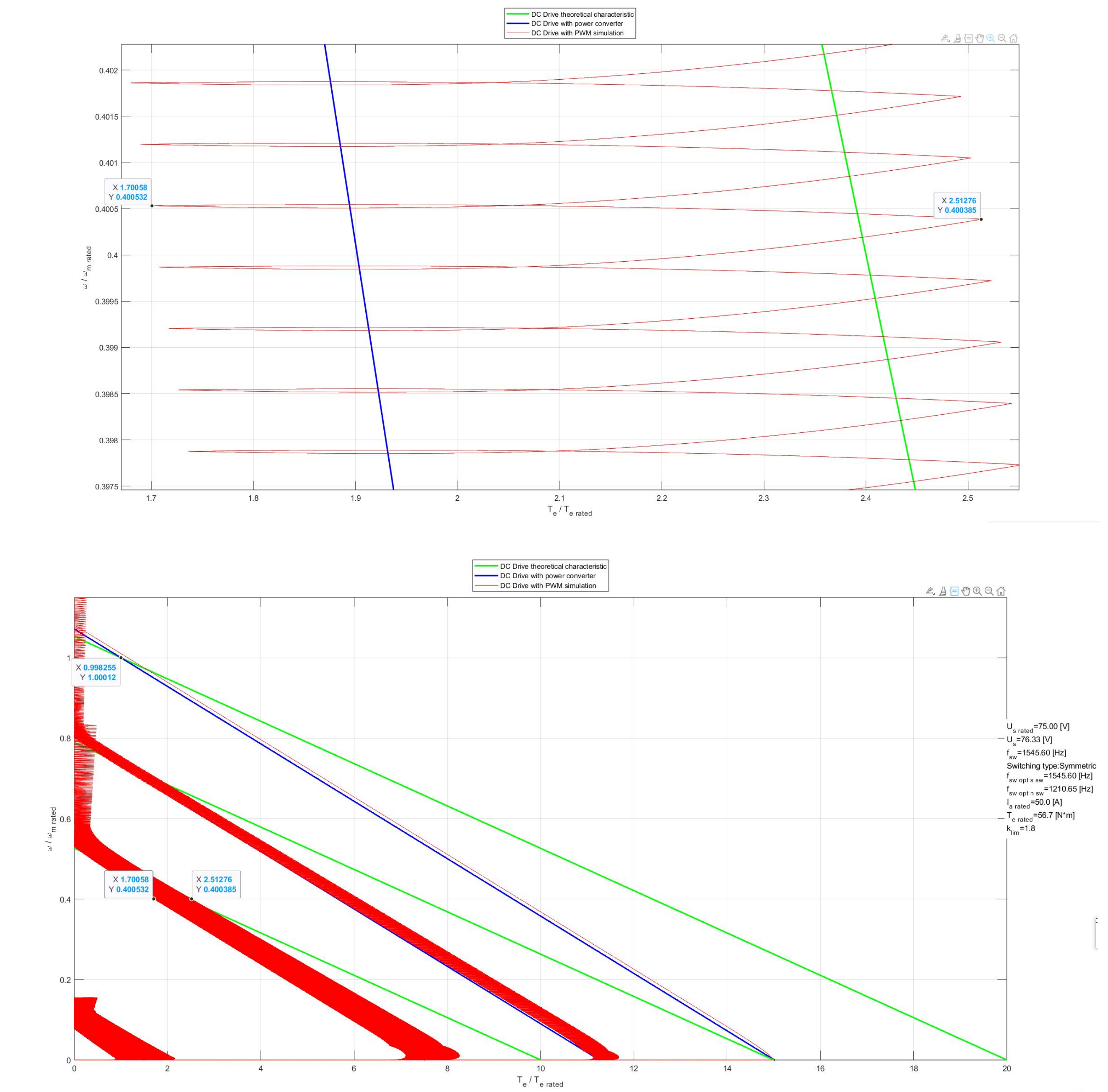
Figure 1 – DC drive system under test

Part 3. Simulation results

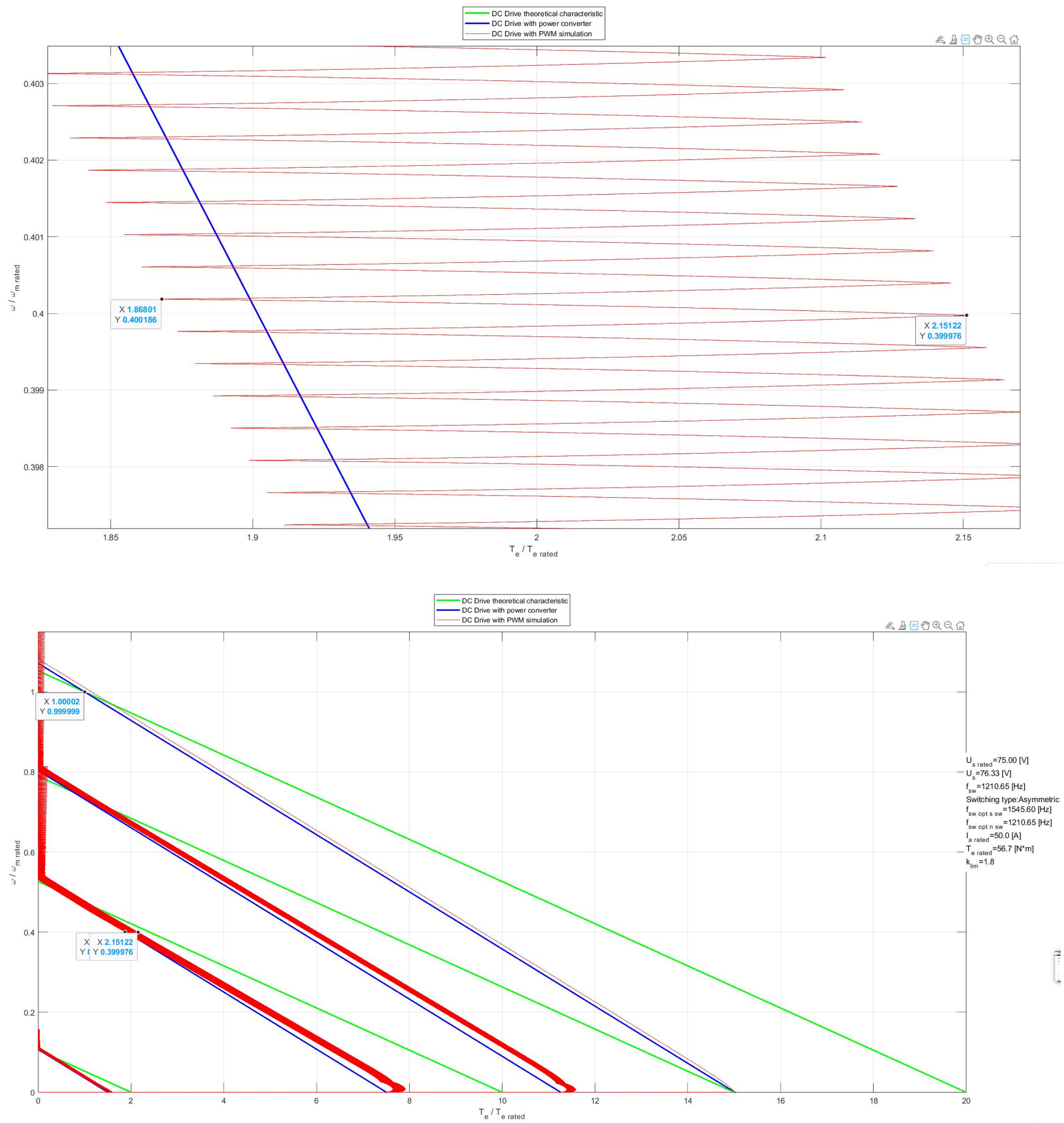
NB! Duty cycles values are in your variant data: as *gamma_all* values.

[1; 0.75; 0.5; 0.1]

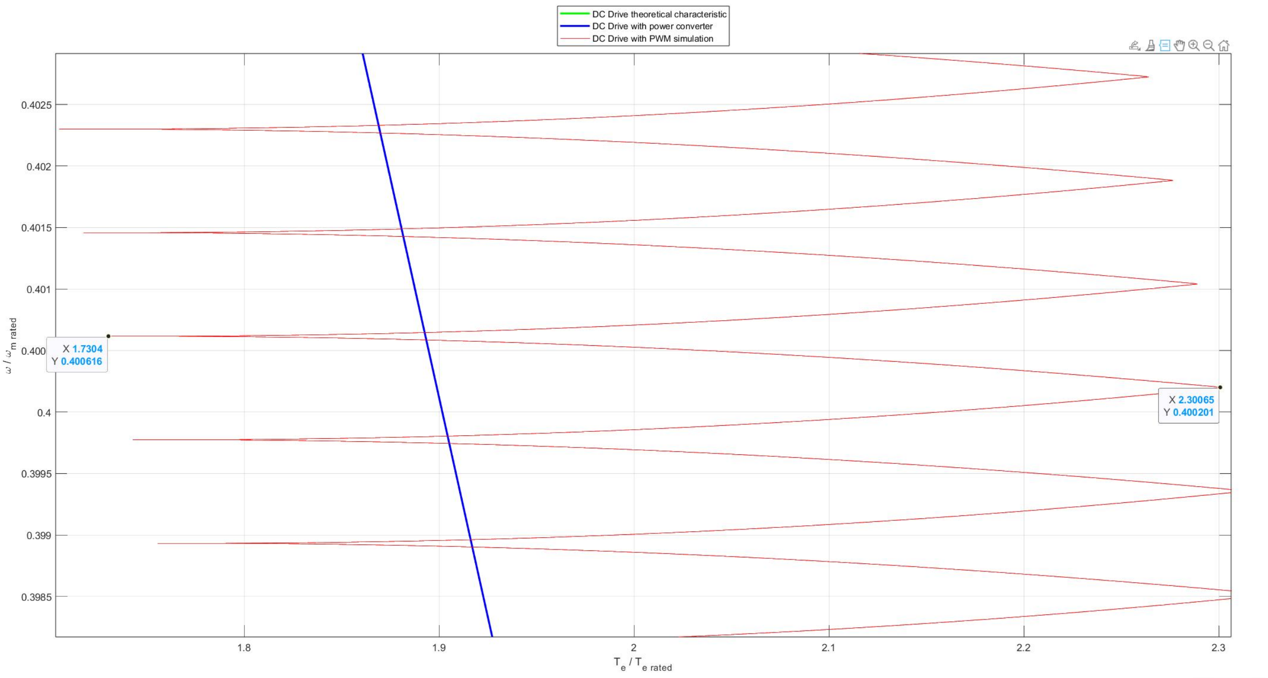
- Compare diagonal (one switch) and symmetric switching

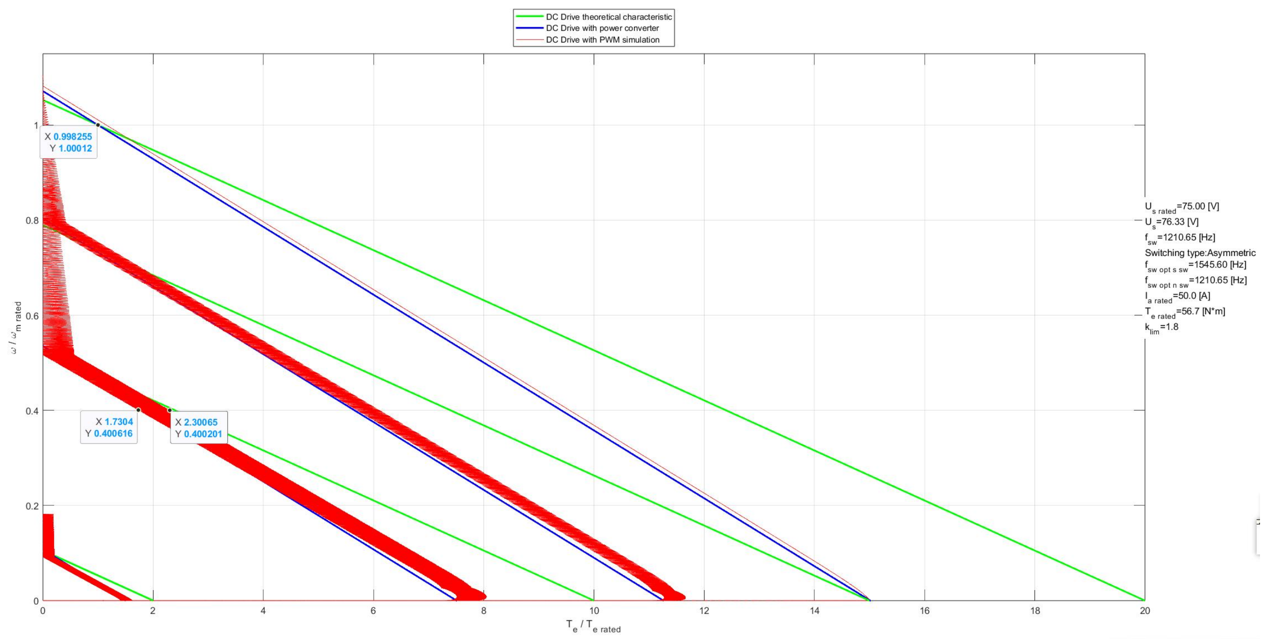


a)symmetric



b) asymmetric sequential





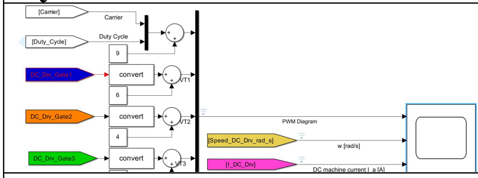
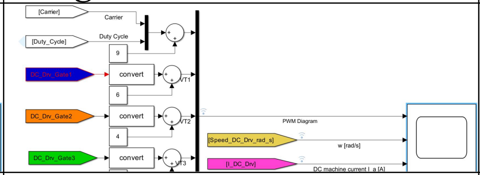
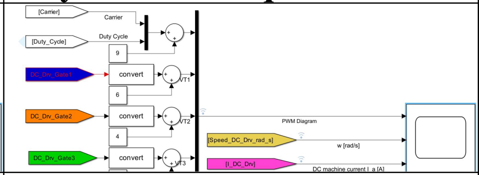
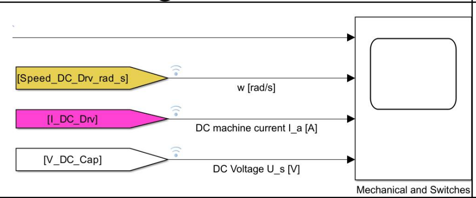
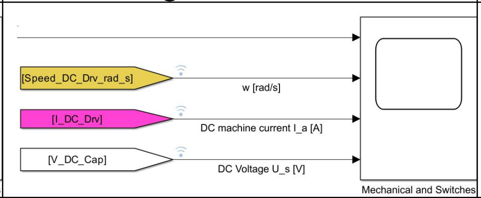
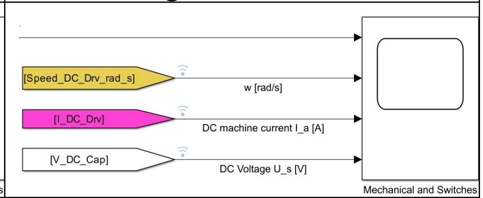
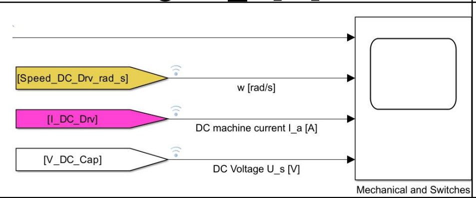
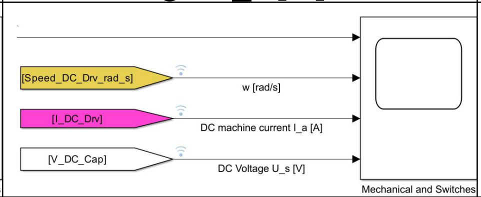
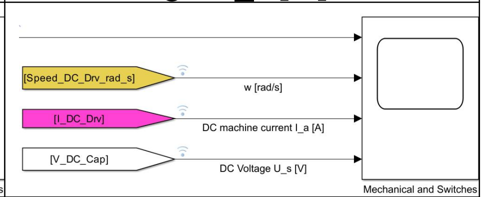
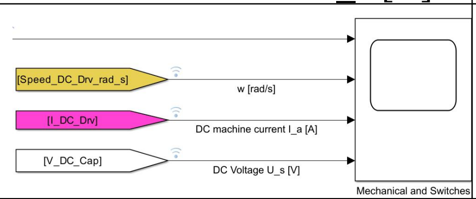
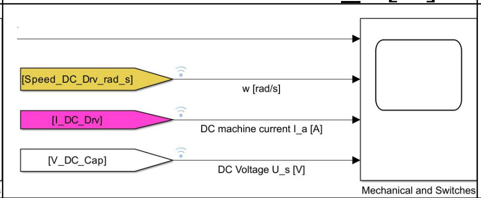
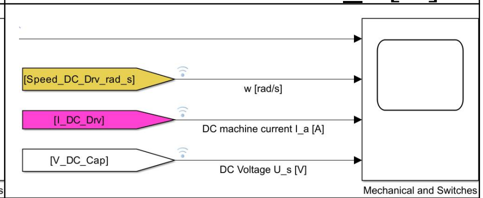
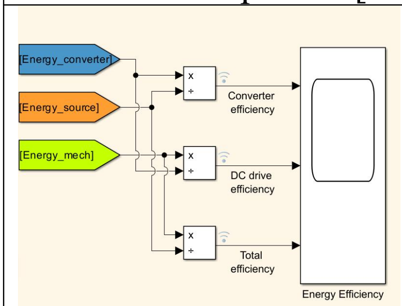
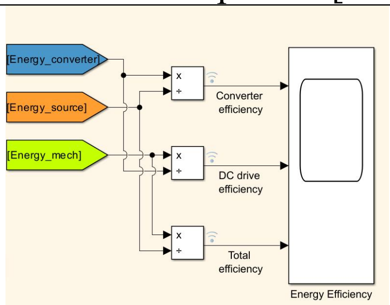
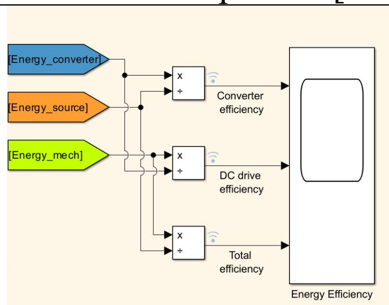
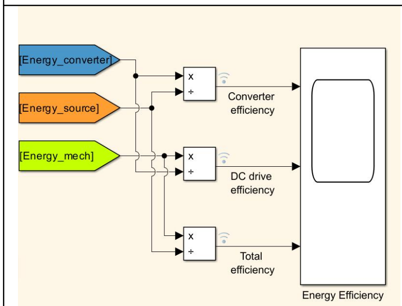
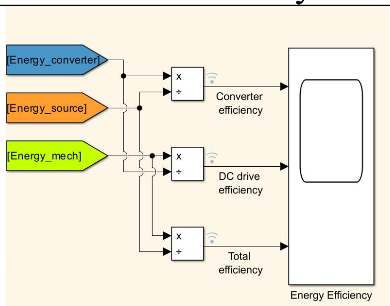
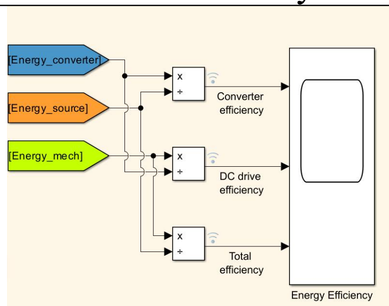
c) Diagonal this is example! Replace it if your own simulation result!

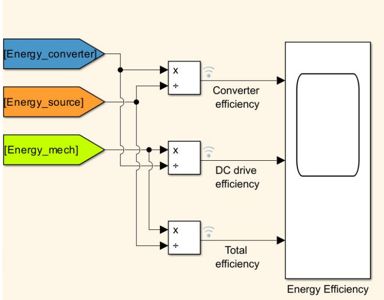
Figure 2 – DC drive mechanical characteristics

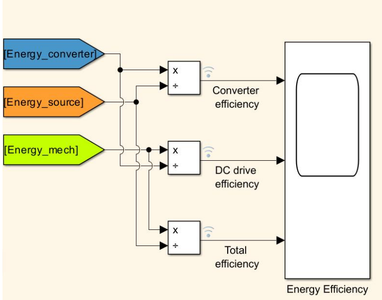
NB! with new parameters your result will be slightly different!

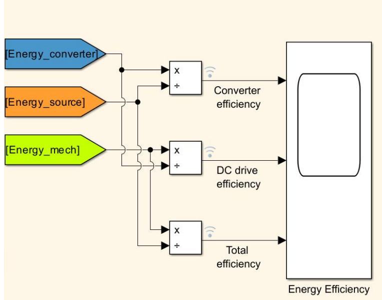
Part 4. Simulation results

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

Symmetric	**Diagonal**	**Asymmetric sequential**
		
PWM diagram	PWM diagram	PWM diagram
		
DC Voltage U_s [V]	DC Voltage U_s [V]	DC Voltage U_s [V]
		
DC machine current I_a [A]	DC machine current I_a [A]	DC machine current I_a [A]
		
DC machine speed ω [rad/s]	DC machine speed ω [rad/s]	DC machine speed ω [rad/s]
		
Converter efficiency	Converter efficiency	Converter efficiency
		
DC drive efficiency	DC drive efficiency	DC drive efficiency



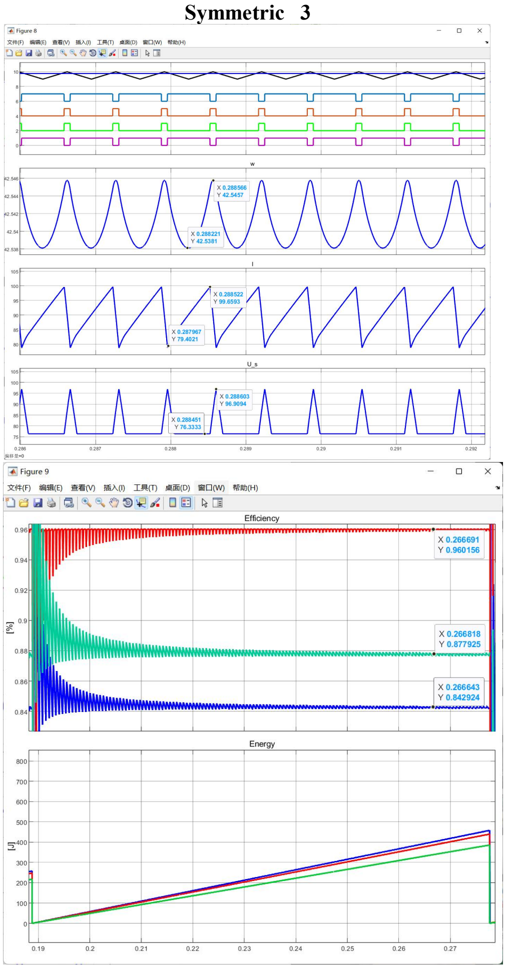




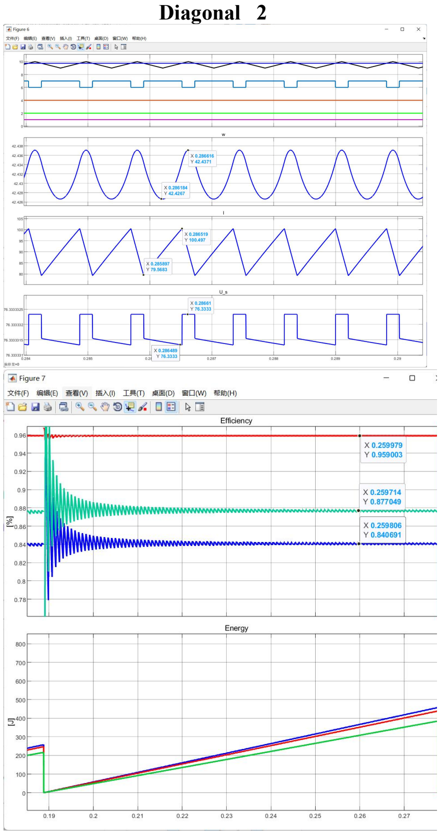
Total efficiency	Total efficiency	Total efficiency

EXAMPLE:

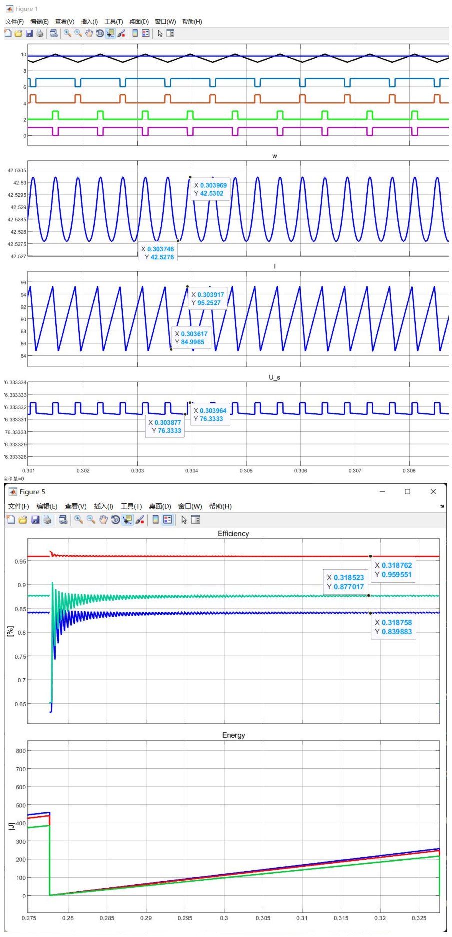
Symmetric 3



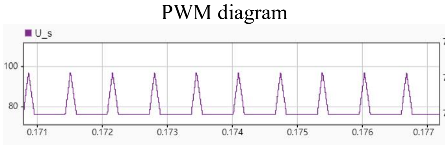
Diagonal 2



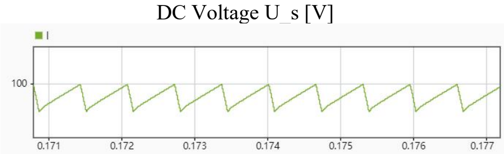
Asymmetric sequential 1



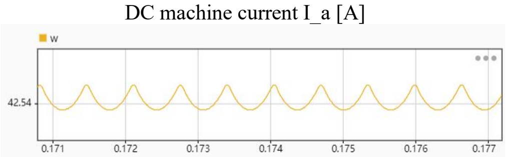
PWM diagram



DC Voltage U_s [V]

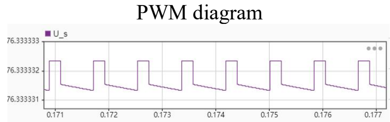


DC machine current I_a [A]

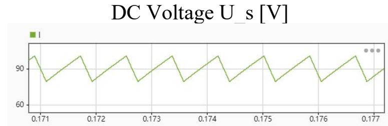


DC machine speed ω [rad/s]

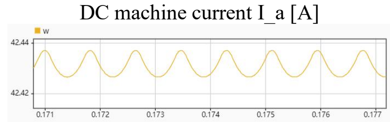
PWM diagram



DC Voltage U_s [V]

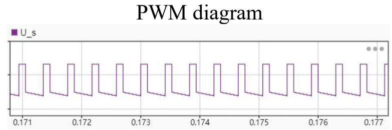


DC machine current I_a [A]

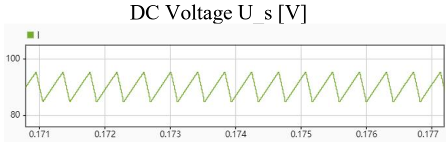


DC machine speed ω [rad/s]

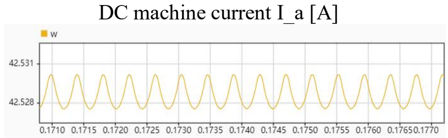
PWM diagram



DC Voltage U_s [V]

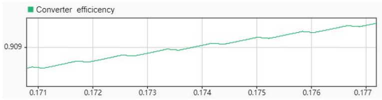


DC machine current I_a [A]

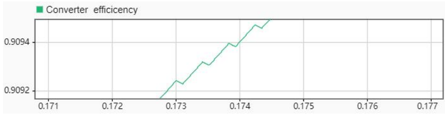


DC machine speed ω [rad/s]

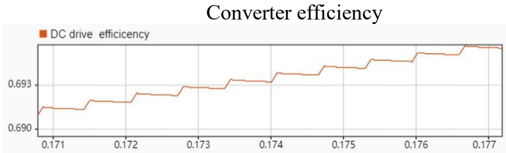
Converter efficiency



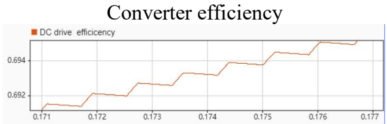
Converter efficiency



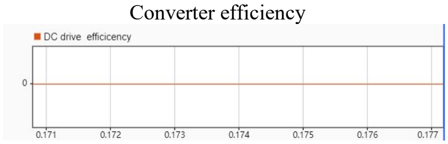
Converter efficiency



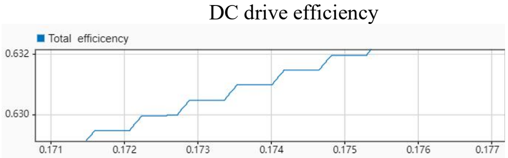
DC drive efficiency



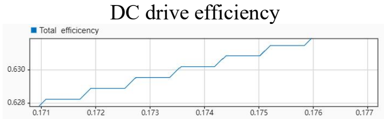
DC drive efficiency



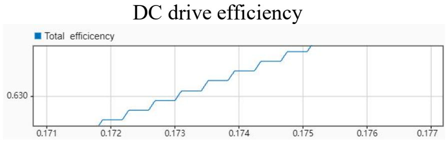
DC drive efficiency



Total efficiency



Total efficiency



Total efficiency

Figure 3 – DC Drive with PWM converter efficiency

Optimal switching frequency evaluation (symmetrical switching)

$$f_{sw\_opt} = 0.332\sqrt[3]{\frac{\alpha_K r_a^2}{L_a^2(t_+ + t_-)}} = \quad 1540 \quad \text{Hz}$$

Optimal switching frequency evaluation (non-symmetrical sequentional and diagonal switching)

$$f_{sw\_opt} = 0.26\sqrt[3]{\frac{\alpha_K r_a^2}{L_a^2(t_+ + t_-)}} = \quad 1210 \quad \text{Hz}$$

- **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.

Symmetric switching:
Achieved the highest overall efficiency, with the lowest ripple observed in both armature current (Ia) and rotational speed (ω).
Voltage remained stable with minimal fluctuation.
It offers smooth and precise motor control, making it the most stable method among the three.
Peak performance occurs at an optimal switching frequency of approximately 1540 Hz.

Diagonal switching:
Exhibited significant current ripple, caused by asymmetric current paths.
This also led to moderate ripple in speed, making motor response less stable.
Efficiency dropped by 5–8% compared to symmetric switching due to increased switching and conduction losses.
Suitable for cost-sensitive designs where control performance is not critical.

Asymmetric sequential switching:
Showed intermediate performance in terms of current and speed ripple—better than diagonal, but still less optimal than symmetric.
Efficiency was slightly higher than diagonal at low switching frequencies (~1210 Hz), making it a practical compromise for systems with varying load dynamics.