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

$U_{s\_rated}=$	65	- Rated source voltage, V;
$n_{rated}=$	600	- Rated rotating speed, rpm;
$f_{sw}=$	3500	- PWM frequency, Hz;
$R_a=$	0.005	- Resistance of DC machine winding, Ω;
$L_a=$	0.554e-3	- 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;
$k_{i\_lim} =$	2.2	- Maximum current limit, A.

Evaluations:

$P = U_{s\_rated} \cdot I_{a\_rated} =$ 3250 - Power, W;

$I_{a\_sc} = \frac{U_{s\_rated}}{R_a} =$ 764.7059 - Short circuit current, A;

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

$k_e = \frac{(U_{s\_rated} - R_a \cdot I_{a\_rated})}{w_{m\_rated}} =$ 0.9669 - EMF constant, V*s/rad;

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

$T_{e\_rated} = k_m \cdot I_{a\_rated} =$ 48.3443 - Rated Torque of the DC machine, N · m;

$T_{e\_max} = k_{lim} \cdot T_{e\_rated} =$ 106.3553 - Maximum torque, N · m;

$T_{e\_st} = k_m \cdot I_{a\_sc} =$ 739.3683 - Starting torque, N · m;

$K_{eff\_rated} = \frac{w_{m\_rated} \cdot T_{e\_rated}}{P} \cdot 100\% = 93.4615$ - Rated efficiency, %;

$\tau_e = \frac{L_a}{R_a} =$ 0.0065 - Electromagnetic time constant, s;

$w_0 = \frac{U_{s\_rated}}{k_e} =$ 67.2275 - Idle speed, rad/s;

$\tau_m = \frac{J_S \cdot w_0}{T_{e\_st}} =$ 0.0216 - Electromechanical time constant, s

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);
$V_{fvt_{Ia}}$	=	2.2	- Forward voltage V_f at current $I_a = I_{lim} = I_{a\_rated} \cdot k_{lim}$, [V];
$R_{on_{vt}}$	=	$\frac{(V_{fvt_{Ia}} - V_{fvt})}{I_{lim}} =$ 0.02	- 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}	=	0.85	- Internal (antiparallel) diode forward voltage V_f at current $I_a \approx 0$, [V];
$V_{frd_{Ia}}$	=	0.95	- Internal (antiparallel) diode forward voltage at current I_{lim}, [V];
$R_{on_{rd}}$	=	$\frac{(V_{frd_{Ia}} - V_{frd})}{I_{lim}} =$ 9.09e4	- Internal (antiparallel) diode resistance R_d, [Ω];

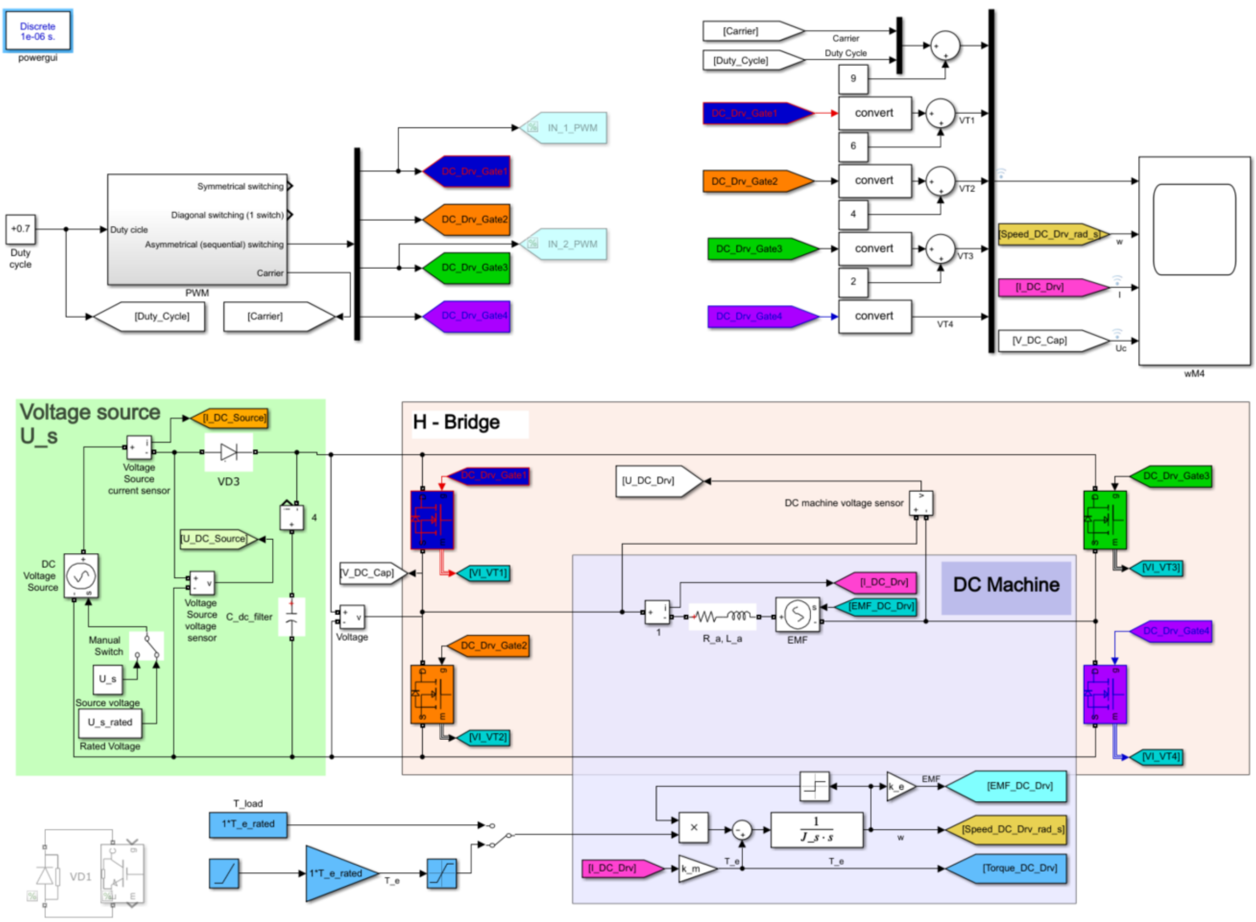


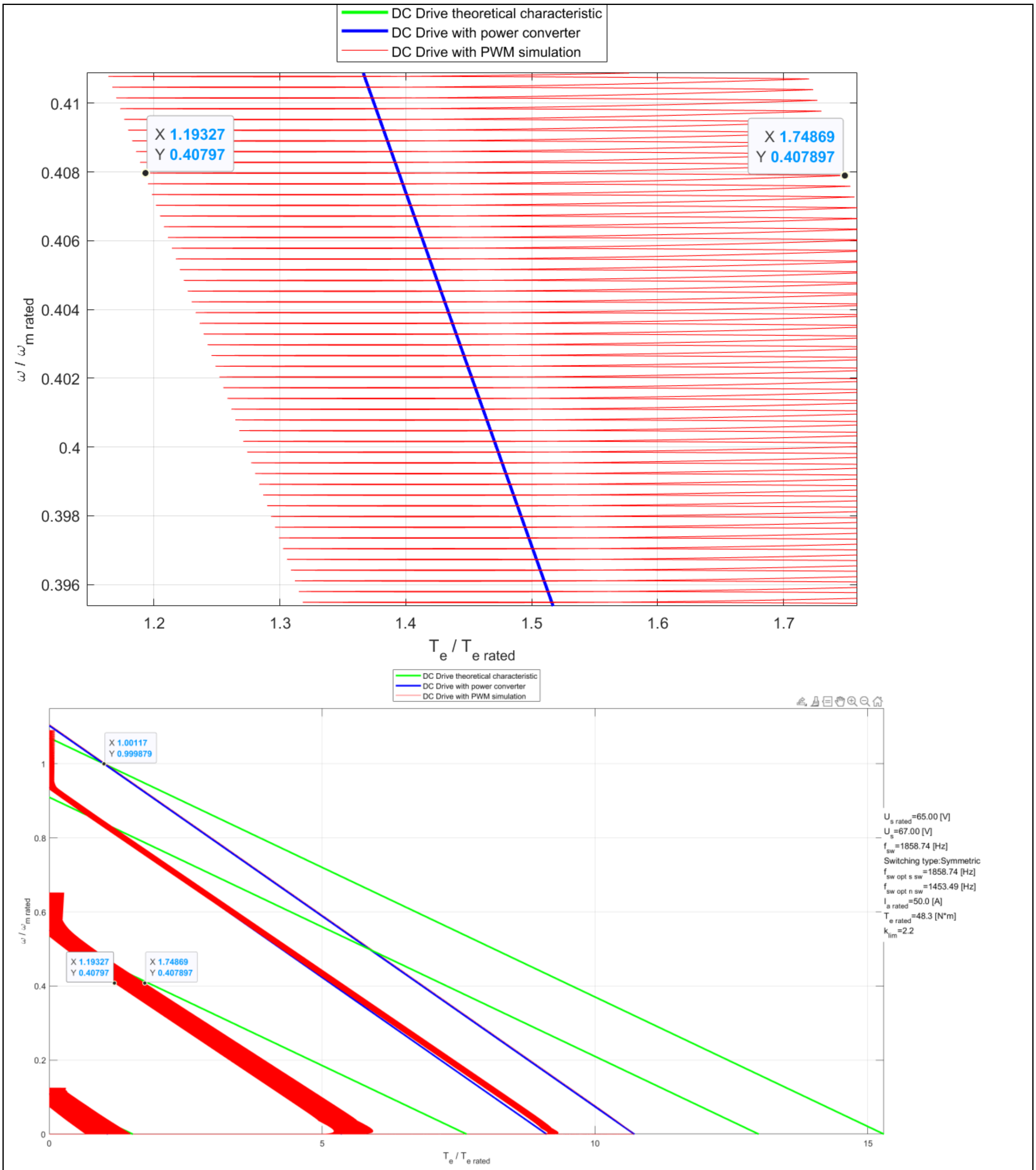
Figure 1 – DC drive system under test

Part 3. Simulation results

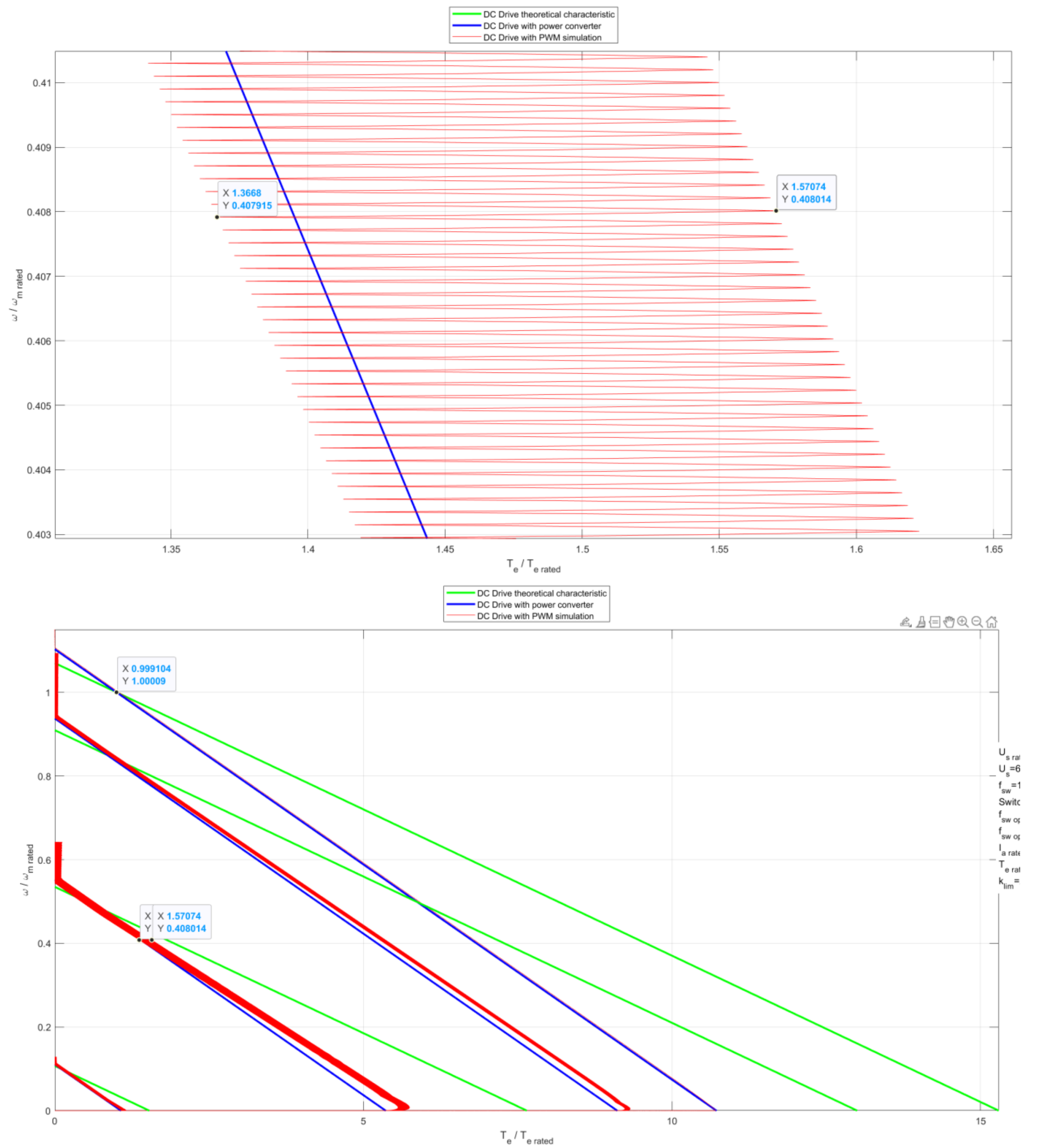
NB! Duty cycles values are in your variant data: as *gamma_all* values.

$gamma_{all}$
[1; 0.95; 0.5; 0.2]

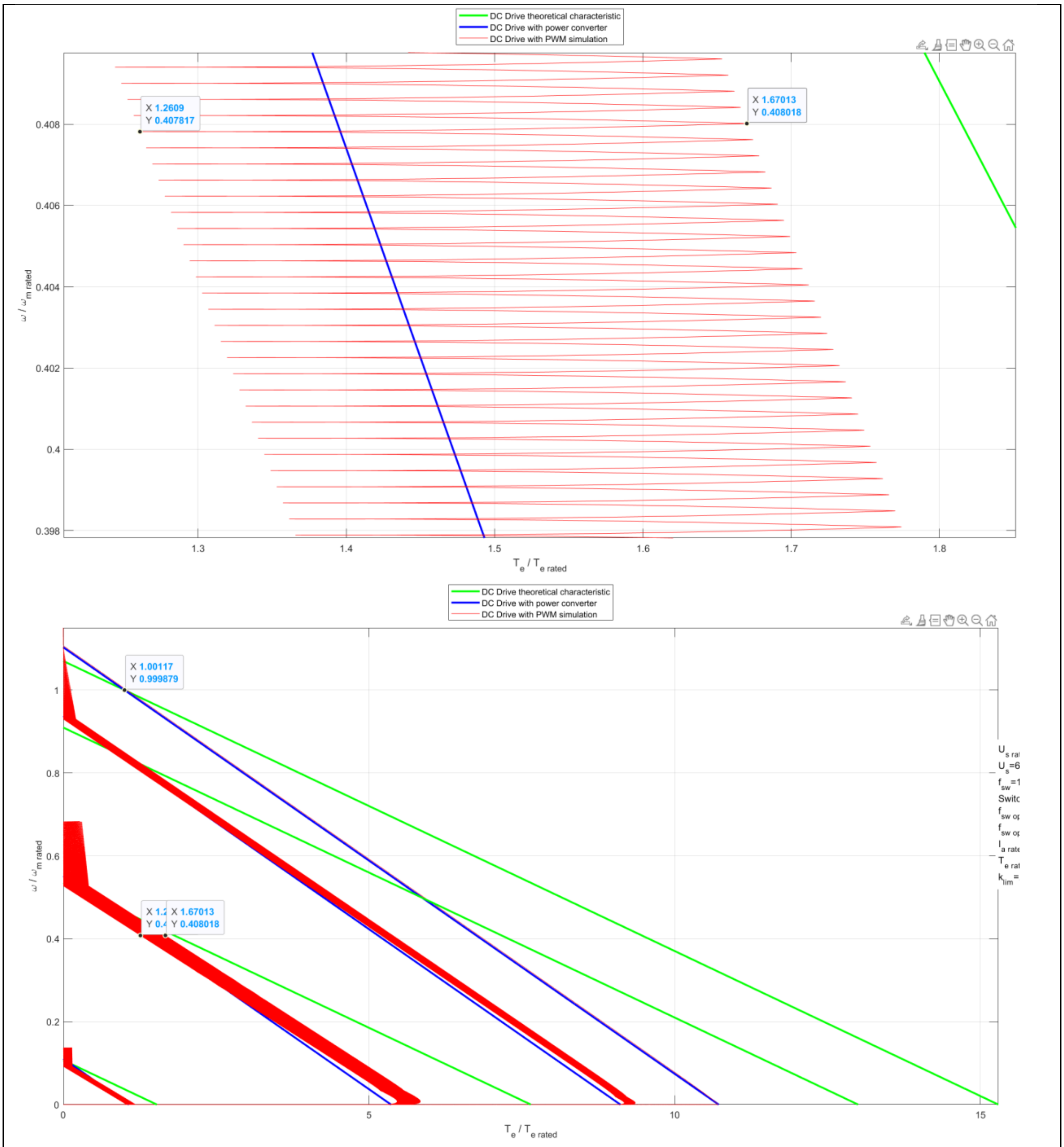
- Compare diagonal (one switch) and symmetric switching



a)symmetric



b) asymmetric sequential



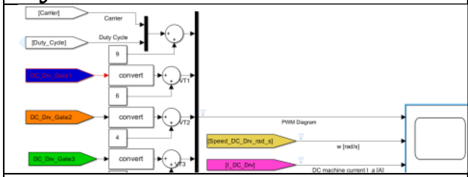
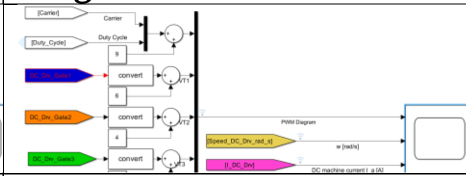
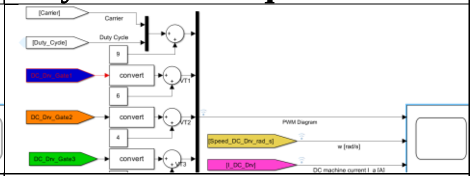
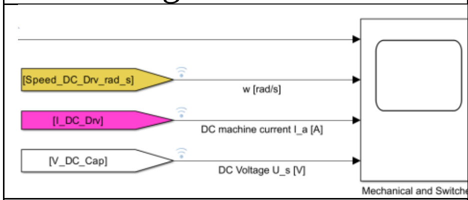
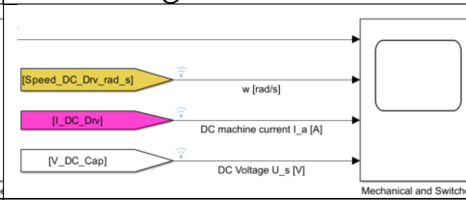
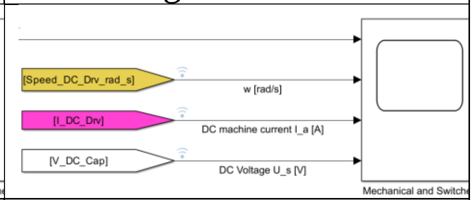
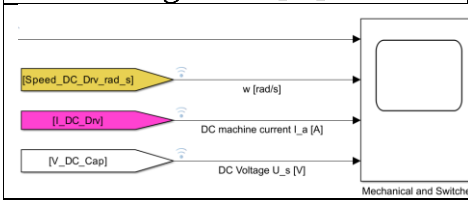
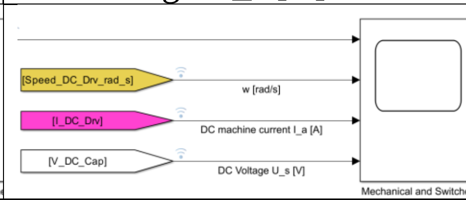
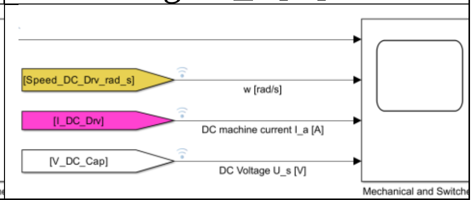
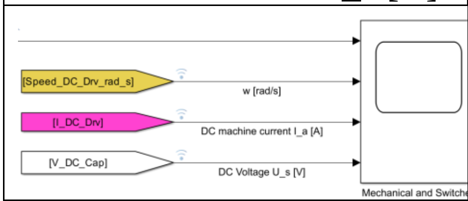
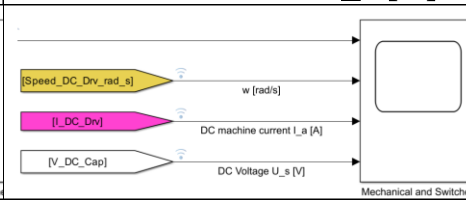
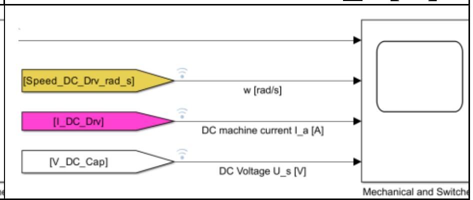
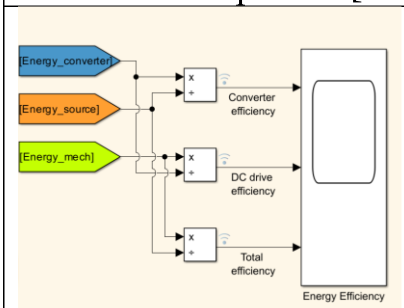
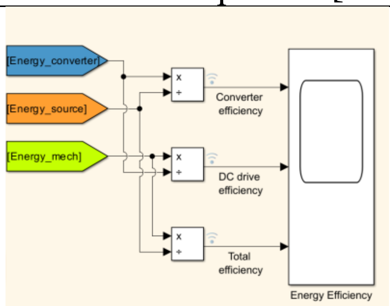
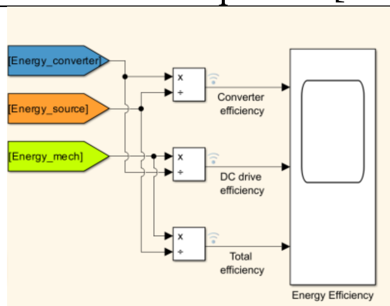
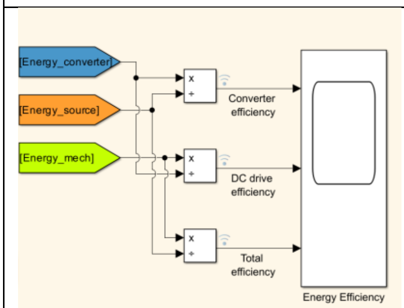
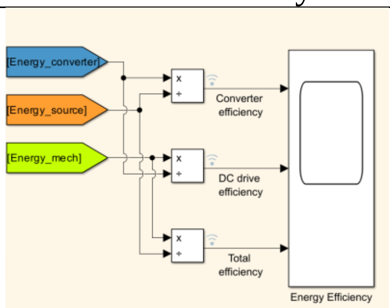
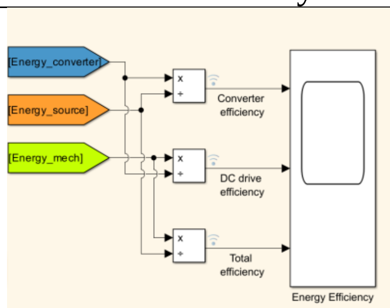
c) Diagonal this is example! Replace it if your own simulation result!

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

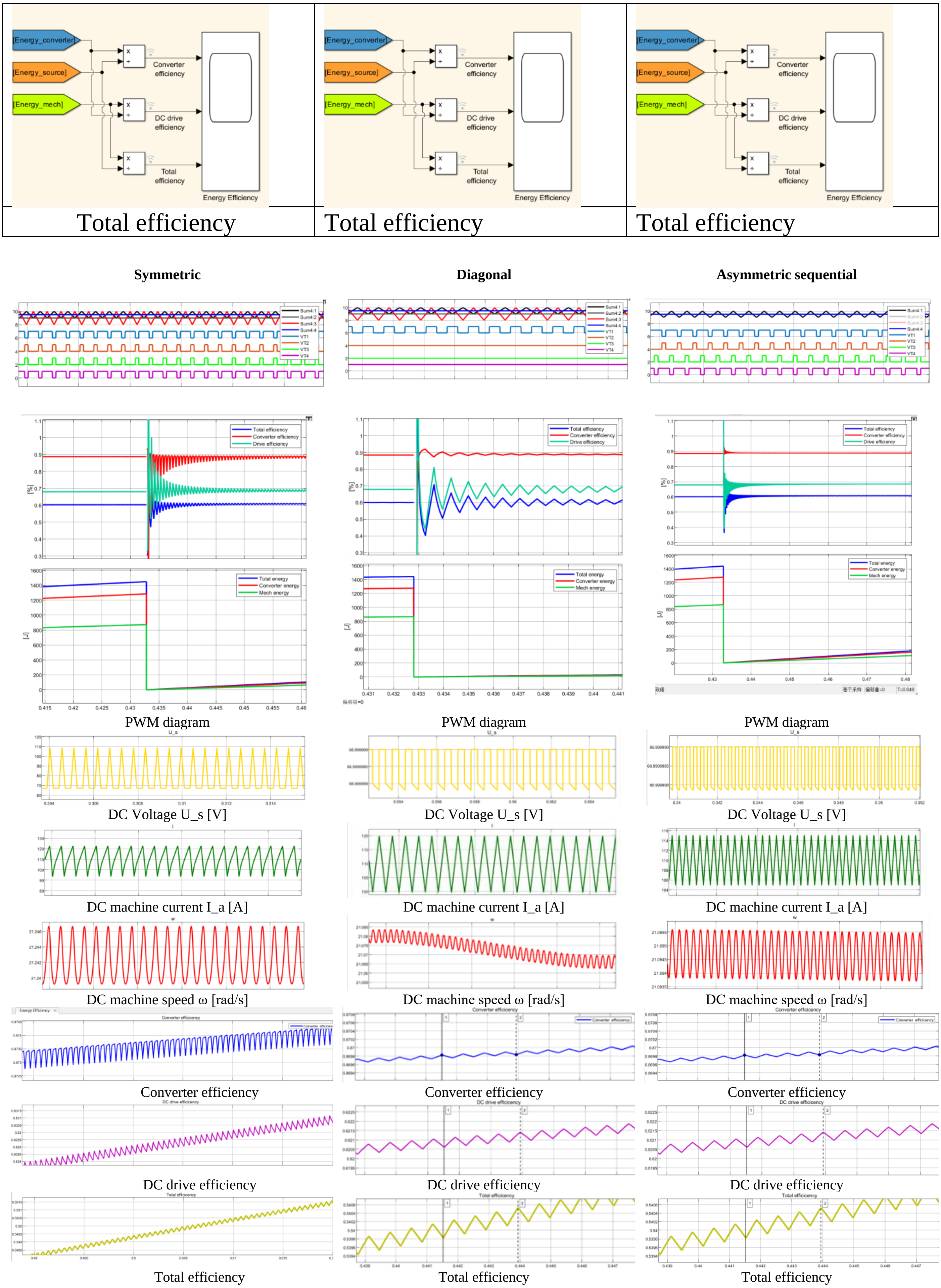


Figure 3 – DC Drive with PWM converter efficiency

Optimal switching frequency evaluation (symmetrical switching)

$$f_{sw\_opt} = 0.332\sqrt[3]{\frac{\alpha_K r_a^2}{L_a^2(t_+ + t_-)}} = \quad 1858.736 \quad \text{Hz}$$

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

$$f_{sw\_opt} = 0.26\sqrt[3]{\frac{\alpha_K r_a^2}{L_a^2(t_+ + t_-)}} = \quad 1453.488 \quad \text{Hz}$$

- **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.

Performance at $\gamma = 0.75$, Tload=Te_max*Tload*=*Te_max*

- Symmetric switching:
  - Lowest voltage (Us*Us*) and current (Ia*Ia*) ripple.
  - Peak efficiency near optimal switching frequency (1858.7 Hz).
- Diagonal switching:
  - Significant current ripple due to asymmetric current paths.
  - Efficiency drops by 5–8% (higher switching and conduction losses).
- Asymmetric sequential switching:
  - Intermediate performance, suitable for specific load conditions.

Optimal Switching Frequency Analysis

- Symmetric switching allows a higher optimal frequency (1858.7 Hz) due to uniform loss distribution.
- Asymmetric strategies require lower frequencies (1453.5 Hz) to minimize losses caused by unbalanced current paths.

Symmetric switching:

- Advantages: High efficiency, low ripple, stable speed.
- Best for: Precision control (e.g., servo systems).

Diagonal switching:

- Advantages: Simpler circuitry.
- Drawbacks: Low efficiency, high ripple (suitable only for cost-sensitive applications).

Asymmetric sequential switching:

- Trade-off: Balances efficiency and complexity (ideal for dynamic loads).