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Lab 3. Research on DC drive PWM converters

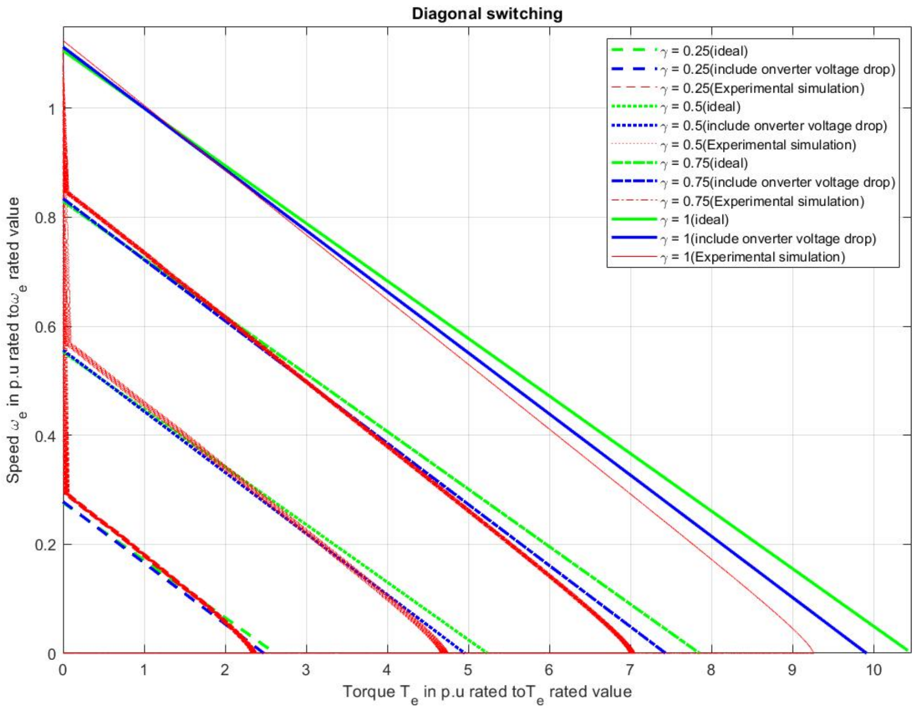
- Part 1. Evaluate missing parameters
- Source data

U_{s_rated}=220; - Source voltage, V;
n_{rated}=750; - Nominal rotating speed, rpm;
P=170; - Power, W;
f_{sw}=5000; - PWM frequency, Hz;
R_a=27.2; - Resistance of DC machine winding, Ohm;
L_a=0.128; - Armature inductance, H, %τ_e=La/Ra;
J_S=0.004; - Moment of inertia, kg*m^2;
K_{eff}= 0.9045; - Efficiency,%

Evaluations:

$I_{a\_rated} = \frac{P}{U_{s\_rated}} = 0.7727$ - Anchor nominal current of DC machine, A;
$I_{a\_sc} = \frac{U_{s\_rated}}{R_a} = 8.0882$ - Short circuit current, A;
$w_{m\_rated} = \frac{2*\pi*n_{rated}}{60} = 78.5398$ - Nominal rotating speed, rad/s;
$T_{e\_rated} = \frac{K_{eff}*P}{w_{m\_rated}} = 1.9577$ - Nominal Torque of the DC machine, N*m;
$T_{e\_max} = 3.5 * T_{e_{rated}} = 6.8520$ - Maximum Torque, N*m;
$I_{lim} = \frac{T_{e\_max}}{T_{e_{rated}}} = 3.5 I_{a\_rated} = 2.7045$ - Maximum current limit, A;
$\tau_e = \frac{L_a}{R_a} = 0.0047$ - Electromagnetic time constant, s;
$k_e = \frac{(U_{s\_rated} - R_a * I_{a\_rated})}{w_{m\_rated}} = 2.5335$ - EMF constant, V*s/rad;
$k_m = k_e = 2.5335$ - Electromechanical constant, N*m/A;
$T_{e\_st} = k_m * I_{a_{sc}} = 20.4917$ - Starting torque, N*m;
$w_0 = \frac{U_{s\_rated}}{k_e} = 86.8359$ - Idle speed, rad/s;
$\tau_m = \frac{J_s * w_0}{T_{e\_st}} = 0.0170$ - Electromechanical time constant, s;

- Compare to diagonal (one switch) switching



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

Conclusion:

From the results of the first part we can get the characteristic curve of the motor **speed ω**, **duty cycle γ** and **torqueT_e** of the DC machine, We can draw the following conclusions:

- The Pulse Width Modulator (PWM) provides the motor with an adjustable pulse width with a certain frequency. From the graphs 1) above, we can see the)relationship between the **duty cycle γ** and the motor **speed ω**:
  1) the larger the pulse width (that is, the **larger** the **duty cycle γ**), the **higher** the motor **speed ω** (because the larger the average voltage supplied to the motor).
  2) Conversely, the smaller the pulse width (that is, the **smaller** the **duty cycle γ**), the **lower** the motor **speed ω** (because the average voltage supplied to the motor is smaller).
- Relationship between **torqueT_e** of the DC machine and motor **speed ω**:
  1) When the **duty cycle γ is constant**, the **torqueT_e** and motor **speed ω** have a **linear inverse relationship**

Part 2. Evaluate parameters of the system with PWM

Transistor switched on circuit parameters

% - Forward voltage Vf (V) (For MOSFET may be considered equal to 0)

V_{f_vt} = 1.2

% - Forward voltage Vf at rated current I_lim (V)

V_{f_Ia} = 1.3 (replace with

% - FET resistance R_on (Ohm)

$R_{on\_vt} = (V_{f\_Ia} - V_{f_{vt}} -)/I_{lim}$

Snubber circuit parameters

% - Snubber resistance Rs (Ohm)

Cs = 330e-9

% - Snubber capacitance Cs (F)

Rs = 1e6

Reverse (antiparallel) diode parameters

% - Internal (antiparallel) diode forward voltage Vf(V)

V_{f_rd} = 0.65

% - Internal (antiparallel) diode forward voltage at rated current I_lim (V)

$V_{f\_Ia\_rd}$ = 0.75

% - Internal (antiparallel) diode resistance Rd(Ohm)

R_{on_rd} = (Vf_Ia-Vf_rd)/I_lim

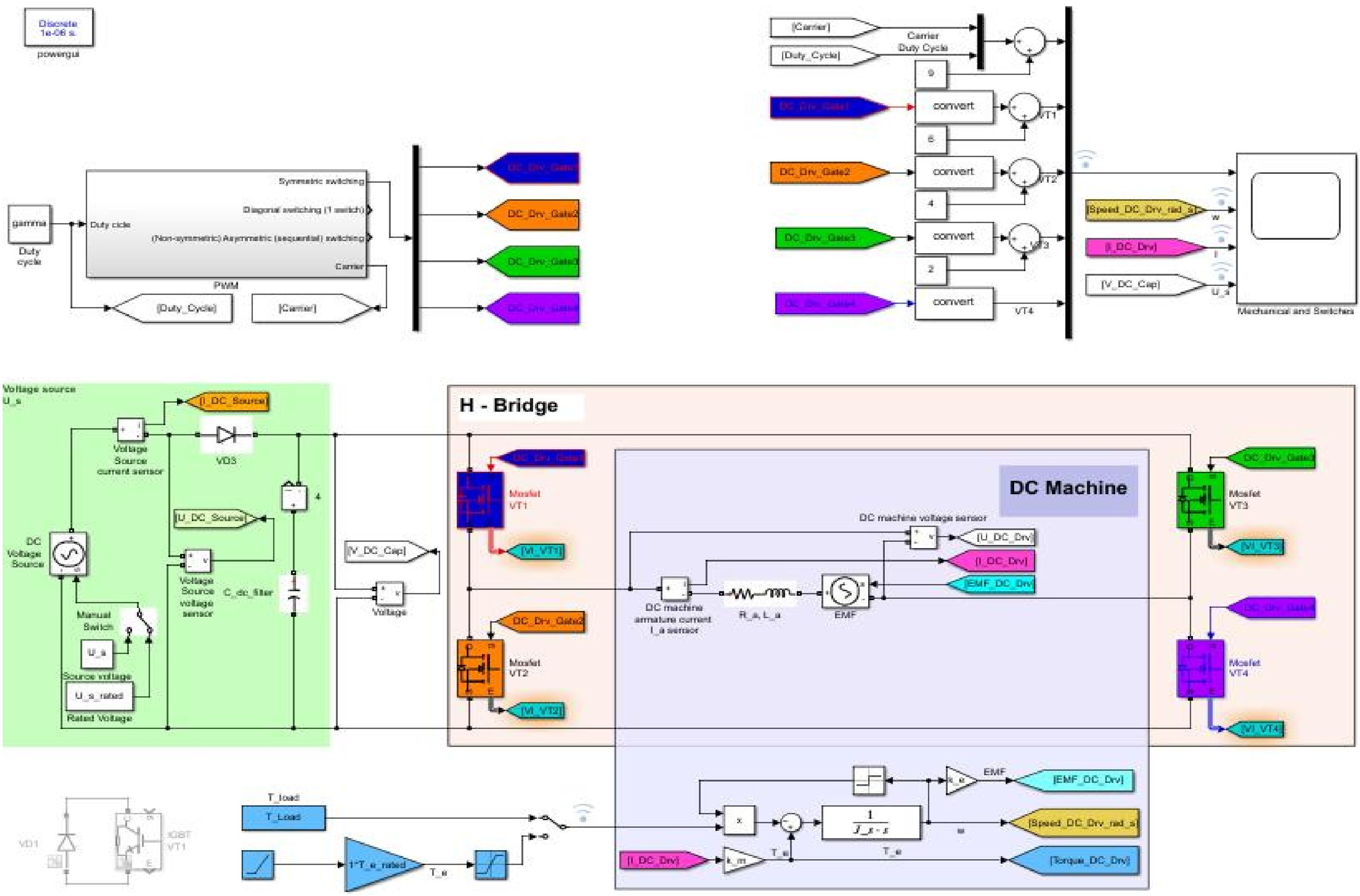


Figure 1 – DC drive system under test

parameter modification

As shown in Figure 1, the transistor used in the model is a Mosfet transistor, and the Forward voltage of this transistor is considered to be equal to 0, so the given parameter is modified as:

Transistor switched on circuit parameters

% - Forward voltage Vf (V) (For MOSFET may be considered equal to 0)

$\boldsymbol{V_{f\_vt}}$ = **0**

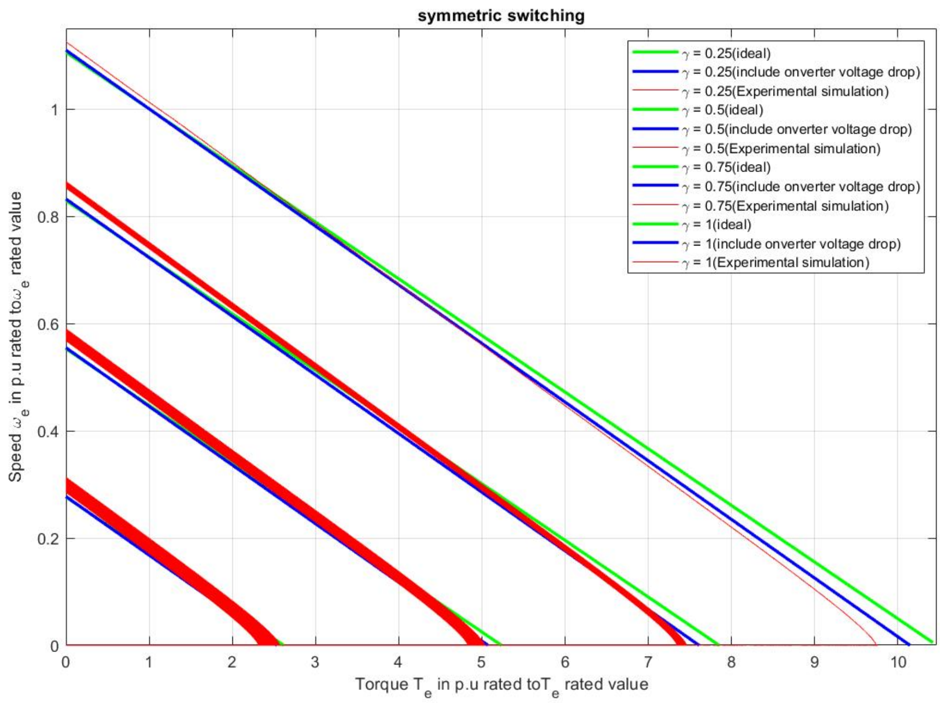
% - Forward voltage Vf at rated current I_lim (V)

V_{f_Ia} = 1.3 (replace with

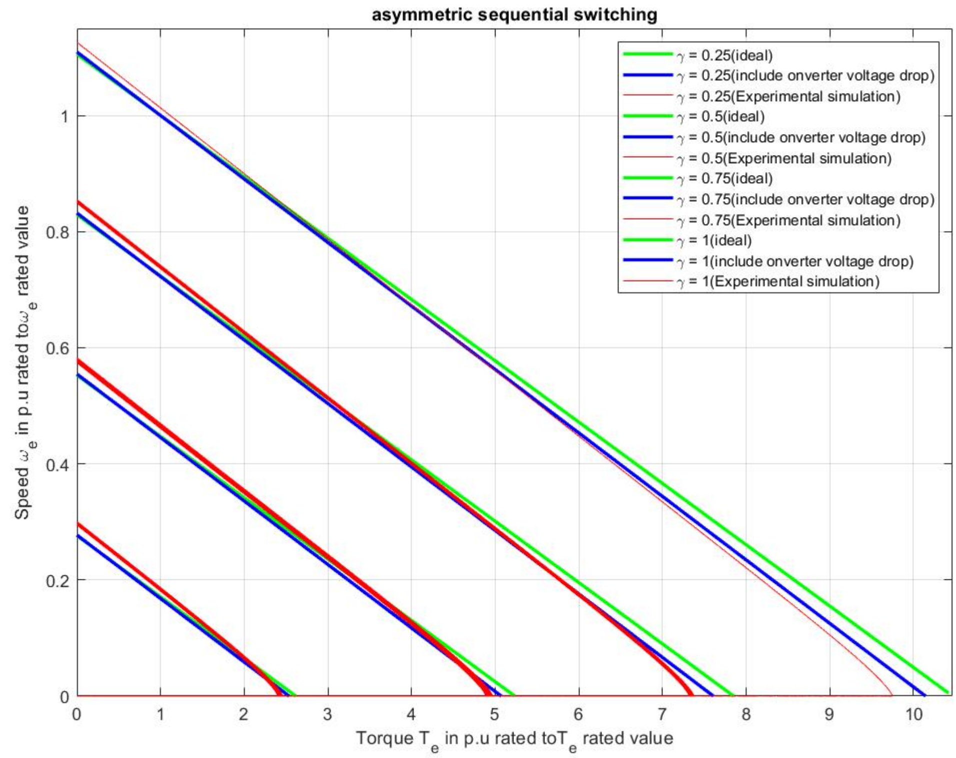
% - FET resistance R_on (Ohm)

R_{on_vt} = $(V_{f\_Ia} - V_{f_{vt}} -)/I_{lim}$

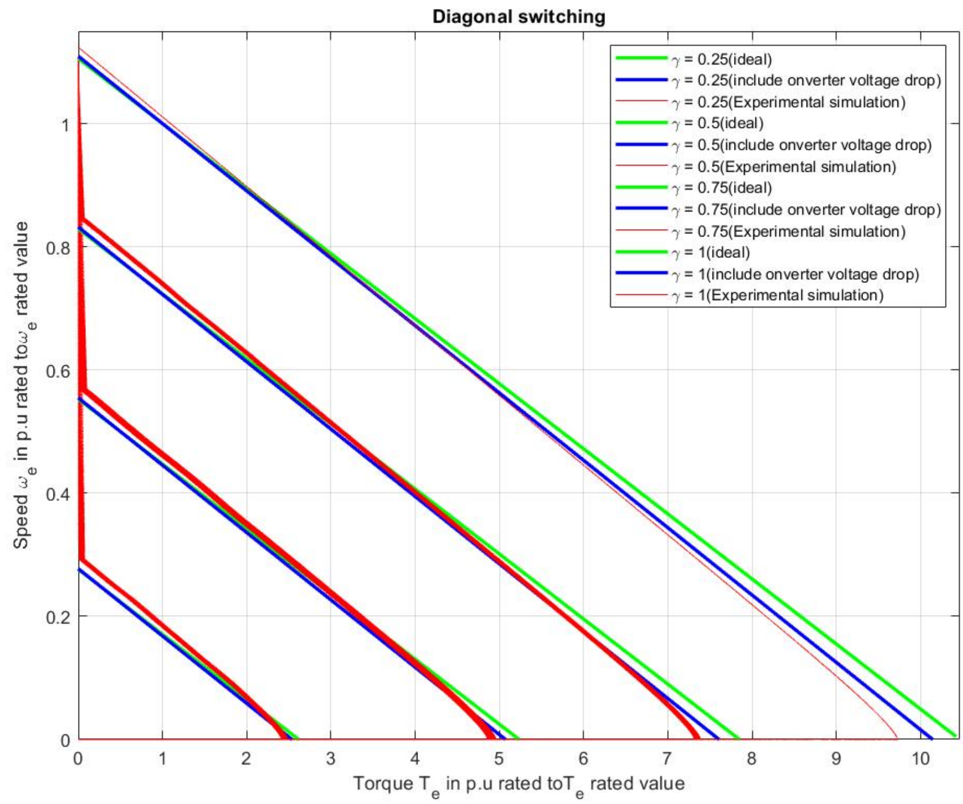
Part 3. Simulation results



a)symmetric



b) asymmetric sequential



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

Figure 2 – DC drive mechanical characteristics

Conclusion:

- PWM switching methods include:
  1) Symmetric
  2) Asymmetric
  3) Non-symmetric sequential switching
- According to the simulation results in Figures a), b), and c), there are errors between the DC drive simulation results of the PWM converter and the ideal switching and considering the parameters of the converter.
- the energy performance of DC drive with PWM converter is always determined by additional losses in the copper of the machine and switching losses in power transistors

- **Analyze drive parameters with different pulse width with duty cycle gamma= 0.75 and T_load=**$3.5 * T_{e\_rated}$

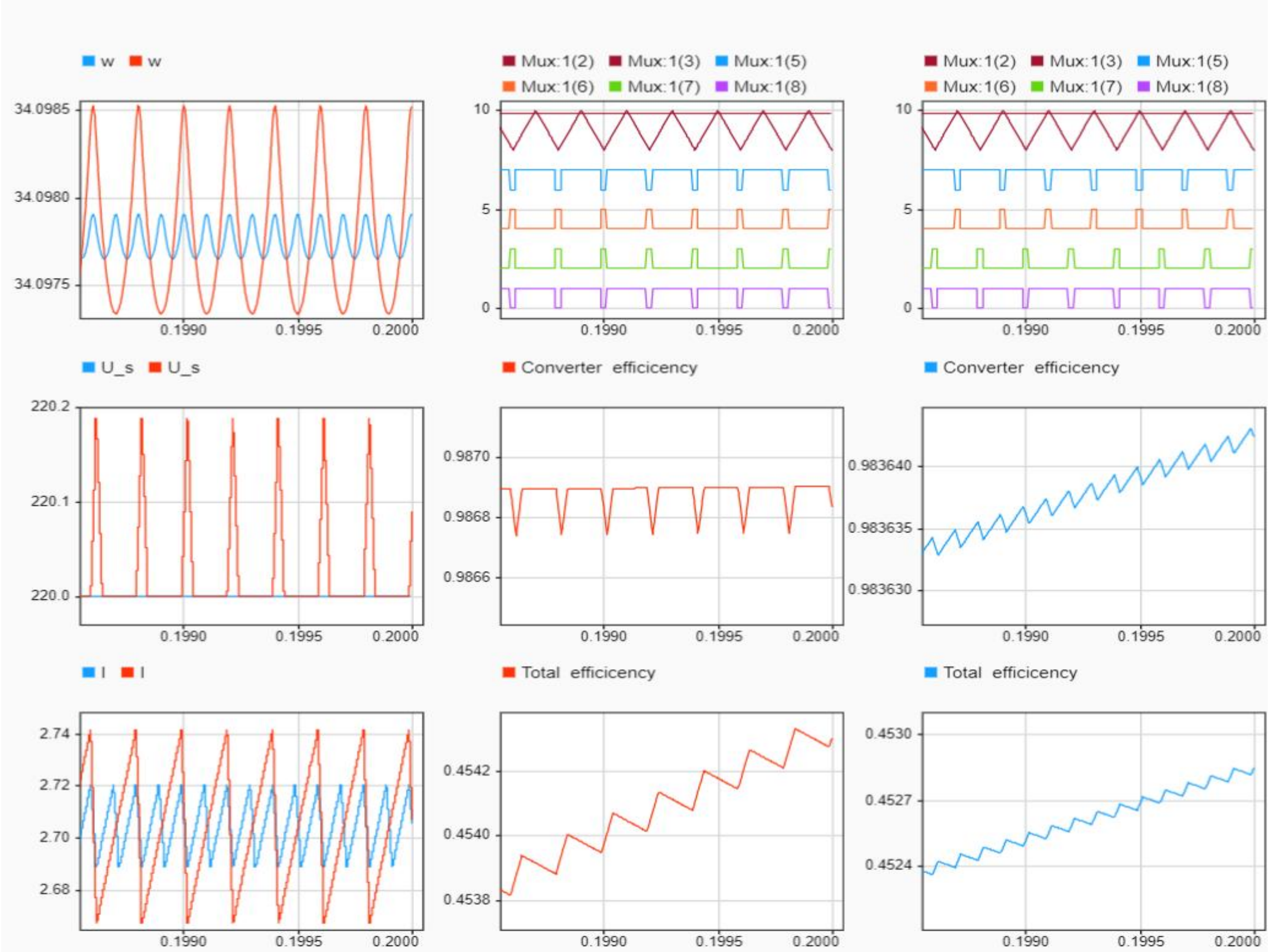


Figure 3 – DC Drive with PWM converter efficiency

The **red line** in the above figure represents **symmetric switching**, and the **blue line** represents **asymmetric switching**

Optimal switching frequency evaluation (**symmetrical switching**)

$$f_{sw\_opt} = 0.332\sqrt[3]{\frac{\alpha_K r_a^2}{L_a^2(t_+ + t_-)}} = 3.9526 \times 10^3 \qquad \text{Hz}$$

Optimal switching frequency evaluation (**asymmetric switching**)

$$f_{sw\_opt} = 0.26\sqrt[3]{\frac{\alpha_K r_a^2}{L_a^2(t_+ + t_-)}} = 3.096 \times 10^3 \qquad \text{Hz}$$

Conclusion:

- When $\alpha_k$and L_a, R_a, t_+, t_- are the same, the **frequency** of **symmetric switching** is higher than the frequency of **asymmetric switching**

- Both average **converter efficiency and average total efficiency** are higher for **symmetrical switching** than for **asymmetrical switching**
- **Asymmetric switching** is more **stable** than symmetrical switching (because the **angular velocity $\boldsymbol{\omega}$, voltage $\boldsymbol{U_s}$, and current $\boldsymbol{I}$** of **symmetrical switching** fluctuate more than **asymmetric switching**)