EN 659: Energy Efficient Industrial Drives

January – April 2025

Assignment – 2: **Active Rectifiers**

Q1. Refer to the circuit shown in the Fig.1, which connects a 3-phase AC source to a DC source via a two-level voltage source converter (VSC).

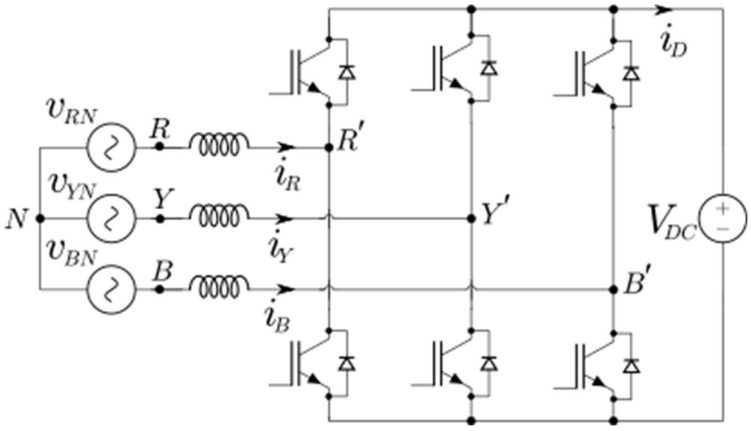

Fig. 1: Power flow between AC and DC voltage sources

a. $V_m\angle 0^o$ and $V_n\angle\delta$ are the per-phase RMS voltages of v_{RN} (AC source voltage) and fundamental component of $v_{R'N}$ (converter voltage), respectively. P and Q are the active power and reactive power delivered by the AC source, respectively. L is the per-phase inductance. Derive expressions for V_n and δ in terms of (V_m, V_{DC}, P, Q, L). Also derive an expression for the modulation index of the VSC.

b. Given $V_m = 325\text{V}$, $P_{max} = 5000\text{W}$, $Q_{max} = 3000\text{VAR}$, $P_{min} = -5000\text{W}$, $Q_{min} = -3000\text{VAR}$ and L is 2% (this means that 2% of the rated voltage is dropped across the inductor when rated power flows). Determine the minimum value of DC voltage needed to facilitate any given active and reactive power flow within the limits, assuming that the converter is switched using conventional space vector PWM (CSVPWM). Present details of all the calculations. What is the average current flowing through the DC source when maximum reactive and active power flows?

c. Simulate the circuit using MATLAB / PLECS and validate the above analytical results. The IGBT switches and diodes are ideal. Present per-phase AC-side current and voltage waveforms under four different combinations of P and Q (one in each quadrant of P-Q plane). Indicate the power factor on each waveform which validates the analytical estimates. Also present the waveforms of DC-side current i_D and validate their average values against the analytical estimates. Tabulate the converter modulation index against each combination of (P, Q).

Note: Expressions derived in Q1 can be utilized in Q2 and Q3.

Q2. Refer to the circuit shown in the Fig.2, which connects a 3-phase AC voltage source to a DC current source via a two-level voltage source converter (VSC).

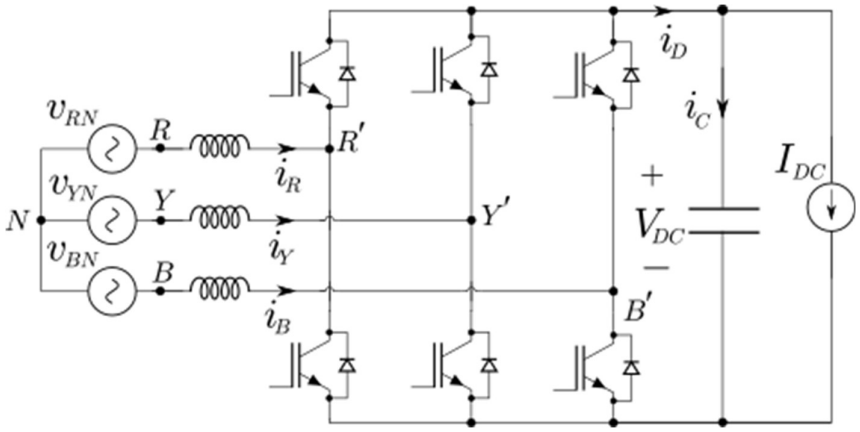

Fig. 2: Power flow between AC voltage and DC current sources

a. Given $V_m = 325\text{V}$, $\text{P}_{\text{max}} = 5000\text{W}$, $\text{Q}_{\text{max}} = 3000\text{VAR}$, $\text{P}_{\text{mi}} = \text{-}5000\text{W}$, $\text{Q}_{\text{min}} = \text{-}3000\text{VAR}$ and L is 2% (this means that 2% of the rated voltage is dropped across the inductor when rated power flows). Determine the minimum value of DC voltage needed to facilitate any given active and reactive power flow within the limits, assuming that the converter is switched using conventional space vector PWM (CSVPWM). Present details of all the calculations. Also determine the maximum and minimum current flowing through the DC current source among the operating conditions in the whole range of active and reactive powers.

b. Simulate the circuit using MATLAB / PLECS and validate the above analytical results. Choose a suitable value of the capacitance which limits the peak-to-peak ripple in the DC voltage to 5V. The IGBT switches and diodes are ideal. Present per-phase AC-side current and voltage waveforms under four different combinations of P and Q (one in each quadrant of P-Q plane). Indicate the power factor on each waveform which validates the analytical estimates. Also present the waveforms of DC-side current i_D and validate their average values against the analytical estimates. Tabulate the converter modulation index against each combination of (P, Q).

Q3. Refer to the circuit shown in the Fig.3, which connects a 3-phase AC source to a 3-phase load via two back-to-back two-level voltage source converters (VSCs).

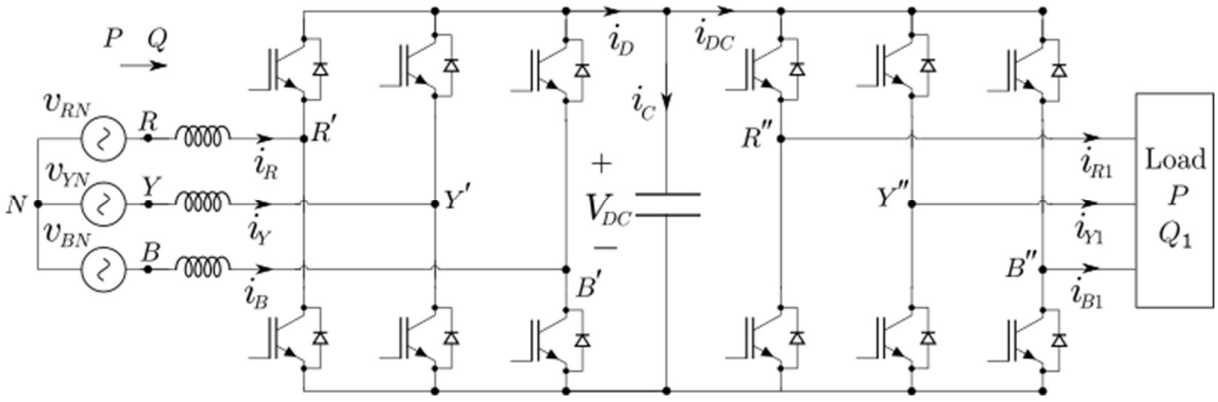

Fig. 3: Power flow between AC source and load

a. Given $V_m = 325\text{V}$, $\text{P}_{\text{max}} = 5000\text{W}$, $\text{Q}_{\text{max}} = 3000\text{VAR}$, $\text{P}_{\text{min}} = -5000\text{W}$, $\text{Q}_{\text{min}} = -3000\text{VAR}$, $\text{Q1}_{\text{min}} = 500\text{VAR}$, $\text{Q}_{\text{max}} = 4000\text{VAR}$ and L is 2% (this means that 2% of the rated voltage is dropped across the inductor when rated power flows). Determine the minimum value of DC voltage needed to facilitate any given active and reactive power flow within the limits, assuming that both the converters are switched using conventional space vector PWM (CSVPWM). Present details of all the calculations. What is the maximum average value of the current i_{D} and i_{DC}?

b. Simulate the circuit using MATLAB / PLECS and validate the above analytical results. Suitable circuit elements can be chosen in the load. Choose a suitable value of the capacitance which limits the peak-to-peak ripple in the DC voltage to 5V. The IGBT switches and diodes are ideal. Present per-phase AC-side (source-side and load-side) current and voltage waveforms under four different combinations of P, Q and Q1. Indicate the power factor on the waveforms which validates the analytical estimates. Also present the waveforms of DC-side currents i_D, i_{DC} and validate their average values against the analytical estimates.