IMPERIAL COLLEGE LONDON

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
EXAMINATIONS 2014

EEE PART IV: MEng and ACGI

Corrected Copy

# FACTS AND POWER ELECTRONICS

Monday, 28 April 10:00 am

Time allowed: 3:00 hours

**There are SIX questions on this paper.**

**Answer FOUR questions.**

*All questions carry equal marks.*

*Please use a separate answer book for Sections A and B.*

**Any special instructions for invigilators and information for candidates are on page 1.**

| | | |
|---|---|---|
| Examiners responsible | First Marker(s) : | T.C. Green, B.C. Pal |
| | Second Marker(s) : | B.C. Pal, T.C. Green |

## Section A

1.

a) For the two sets of three-phase voltages shown below, $v_k$ and $v_l$ , describe how the voltages would appear once transformed into $DQ\gamma$ form. [4]

$$v_k = \begin{bmatrix} 300\cos(\omega t + 15°) \\ 300\cos(\omega t + 135°) \\ 300\cos(\omega t - 105°) \end{bmatrix} \qquad v_l = \begin{bmatrix} 25 + 25\cos(\omega t - 90°) \\ 25 + 25\cos(\omega t + 150°) \\ 25 + 25\cos(\omega t + 30°) \end{bmatrix}$$

b) Figure 1.1 shows a three-phase low-pass filter. Figure 1.2 shows the same filter transformed to the equivalent $DQ\gamma$ form. Justify the format of the transformed filter. [8]

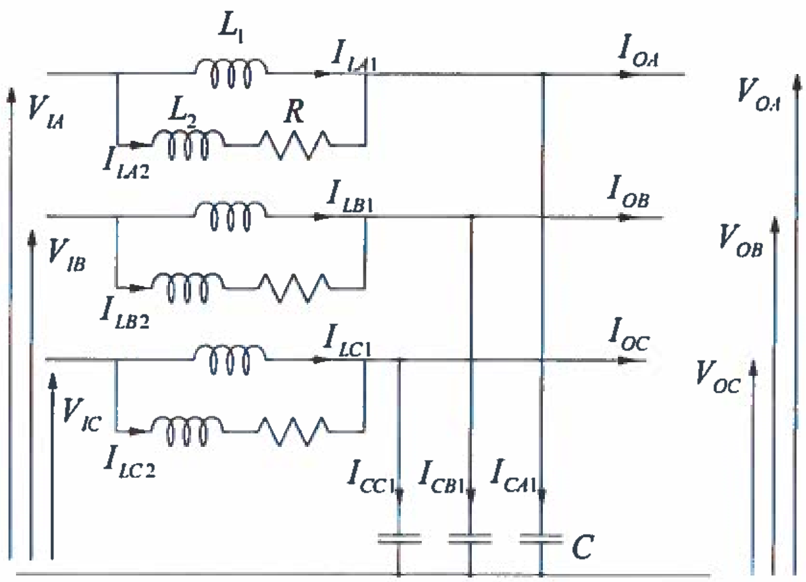


Figure 1.1 A three-phase low-pass filter.

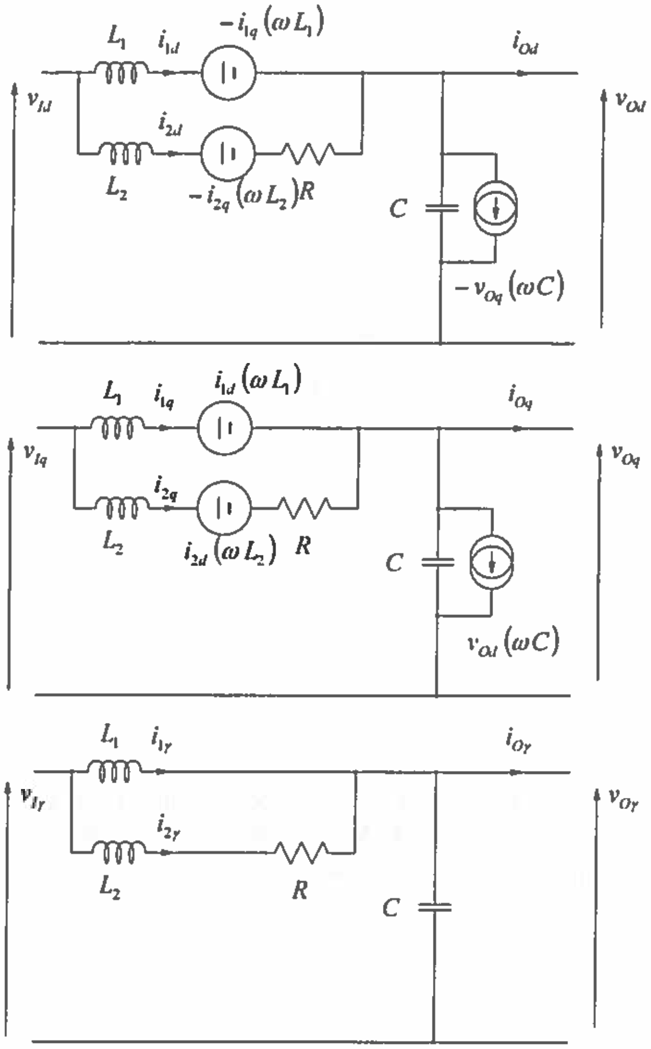


Figure 1.2 $DQ\gamma$ representation of filter in Figure 1.1

c) Consider the system shown in Figure 1.3. It is composed of a power source (in this case a PV panel followed by a DC/DC converter), a DC-link capacitor, a DC/AC converter, interface inductors, a 3-phase grid, a current controller and a high-level controller.

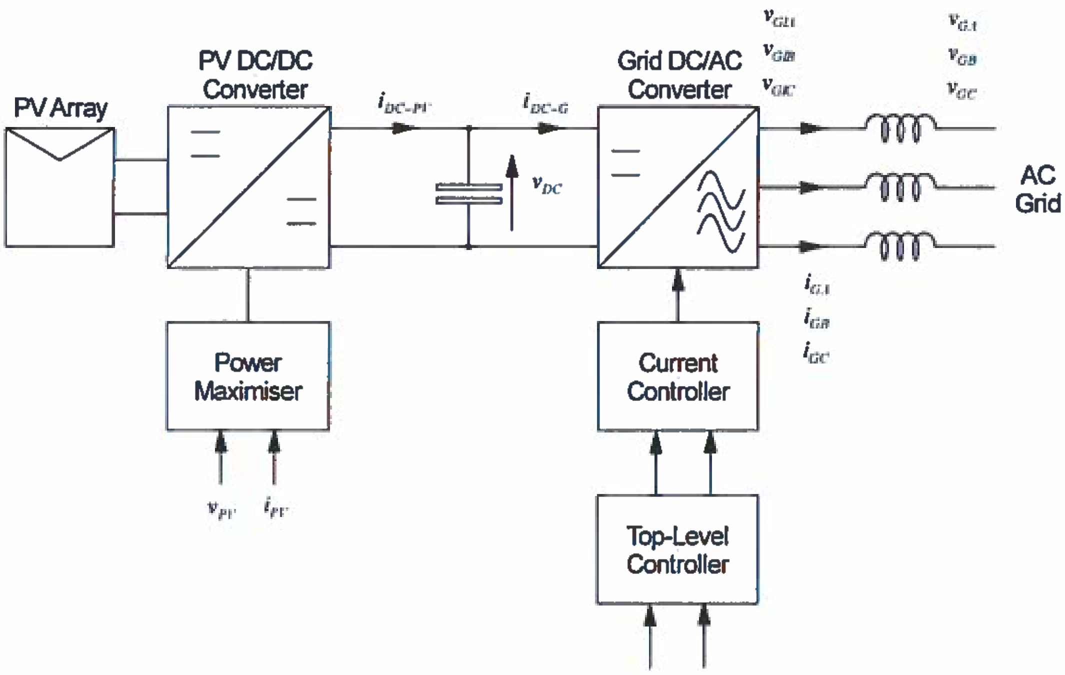


Figure 1.3 Schematic diagram of the current controller for a three-phase inverter.

i) Figure 1.4 shows the control system to be used for current controller of figure 1.3 which acts on the PWM signals of the DC/AC converter. Explain the purpose of each block in figure 1.4. [5]

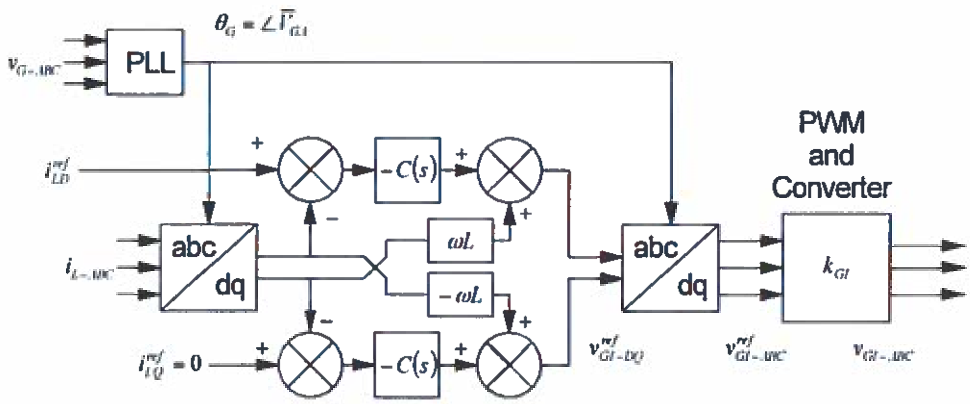


Figure 1.4 Schematic diagram of the current controller for a three-phase inverter.

ii) Sketch and describe the format of the top-level controller that sets current references for the controller of figure 1.3 in order to export the power from the source. [3]

2.

a) Figure 2 illustrates an Voltage Source Converter (VSC) connected to a 350 kV (line-to-line) AC grid at 50 Hz and a DC network at ±330 kV.

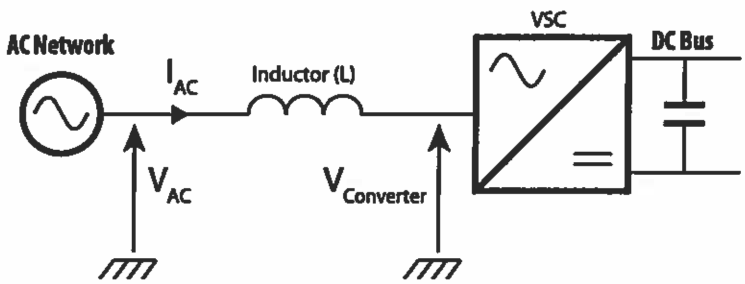


Figure 1 - VSC schematic

Consider the converter inverting 600 MW (power going from DC to AC) and generating 200 MVAr of capacitive reactive power (at the AC connection point).

i) Compute the magnitude and angle of the AC current. [1]

ii) Assuming that the phase reactors are 190 mH, calculate the magnitude and angle of the converter voltage. [1[

iii) What is the modulation index at which the VSC running? [1]

b) The cells of a Modular Multi-Level Converter (MMC) can be implemented in several ways.

i) Explain briefly the differences between full H-bridge cells (FB) and half-bridge cells (HB) for use in an MMC. [3]

ii) Draw the four switching states of a full H-bridge cell and indicate through which devices the current is flowing depending on its direction. [3]

c) Discuss the main advantages and disadvantages of the half-bridge MMC, especially compared to other converter topologies such as the 3-level neutral point clamped (NPC) converter. [4]

d) An half-bridge MMC has the following parameters:

- Power rating: 800 MW
- DC bus voltage: ±330 kV
- Nominal cell voltage: 1,650 V

i) Determine the maximum AC line voltage that this MMC converter can generate. [2]

ii) Calculate the number of IGBT/diode modules and DC capacitors. [2]

iii) Assuming that the stack of cells can sustain a maximum energy deviation of 850 kJ, calculate the minimum value of the cell capacitors in order to limit their voltage excursion to 5%. [3]

3.

a)

i) An ideal power semiconductor switch has zero on-state resistance (to an arbitrary current rating), zero off-state conductance (to an arbitrary voltage rating), and transitions between the on and off-state in zero time. Discuss the fundamental trade offs in achieving these characteristics for both majority and minority carrier devices.

[5]

ii) Wide band gap semiconductors (such as SiC) are of great interest to the power electronics community. Explain why this is.

[3]

b) IGBTs are commonly available in ratings to a few kV. When circuits require ratings greater than this, devices are often put in series. Explain why sharing networks are required and sketch a sharing network that would ensure sharing in both the transient and DC states.

[5]

c) It is suggested that, rather than using a sharing network, the drain voltage waveform could be fed back to aid the switching of a chain of devices. Fig 3.1 shows the proposed setup.

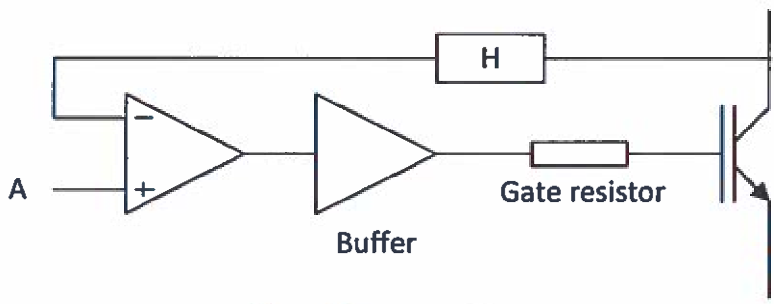


Figure 3.1 Drain voltage feedback system for one device to be used in a series string

i) What are the purposes of the buffer and gate resistor?

[2]

ii) The component "H" has a flat frequency response and a gain of 1/1000. What is its purpose?

[1]

iii) Explain how the system is expected to work. In your answer, make reference to what the signal fed in as "A" represents.

[4]

## Part B

4.

a)

i) How is the loadability of a transmission circuit defined?

[3]

ii) How does circuit length influence the loadability of a transmission circuit?

[3]

b) Unlike a telecommunication line, a power line should not be terminated by its characteristic impedance – justify this statement through technical arguments.

[4]

c) A 500 kV transmission circuit is 500 Km long. Despite the fact that the line has two current carrying capacities (summer and winter) both of them are hardly utilised. Justify with reason.

[3]

d) Many HV/EHV circuits, particularly in developed countries are re-insulated to upgrade to a higher voltage. What are the other implications on the terminal equipment that must be assessed and addressed before upgrading them to higher voltage?

[3]

e) Describe two important benefits of FACTS technologies.

[4]

5

a)

i) Describe the principle of series compensation in a power transmission system.

[4]

ii) With the help of power angle characteristics of a transmission line, show how a series capacitor boosts the steady state power transfer margin.

[5]

iii) A simple 500 kV transmission circuit shown in Fig 5.1 transfers 400 MW of power. Additional generation from a wind farm at the sending end is planned. The wind farm has 100 turbines each of 3.6 MW capacity. Obtain the range of the degree of compensation required to extract the power from the wind farm producing at full capacity keeping the power transfer stability margin at the same level of uncompensated case. Assume 1.0 p.u. voltage at the sending and receiving ends. The line impedance is 0.16 p.u. and is purely reactive. Assume base MVA to be 100.

[6]

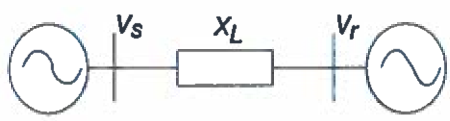


Fig 5.1: A simple interconnected power system model

b) Many power transmission grids around the world have installed quadrature boosters for power flow control. With the help of schematic and vector diagram show how they control the power flow.

[5]

6

a)

i) Describe through a suitable circuit schematic how a Unified Power Flow Controller (UPFC) works.

[5]

ii) With the help of a vector diagram, show the phase angle and voltage regulation capability of the UPFC.

[8]

b)

i) Describe the loss characteristics of static var compensator (SVC) employing a Fixed Capacitor and Thyristor Controlled Reactor (FC+TCR) and a Thyristor Switched Capacitor and Thyristor Controlled Reactor (TSC+TCR).

[5]

ii) Justify with reason which of these technologies is more suitable for dynamic voltage support at the substation feeding a large steel production plant.

[2]