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**PHYSICS**

**9792/02**

Paper 2 Part A Written Paper

**May/June 2011**

PRE-RELEASED MATERIAL

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The question in Section B of Paper 2 will relate to the subject matter in these extracts. You should read through this booklet before the examination.

The extracts on the following pages are taken from a variety of sources.

University of Cambridge International Examinations does not necessarily endorse the reasoning expressed by the original authors, some of whom may use unconventional Physics terminology and non-SI units.

You are also encouraged to read around the topic, and to consider the issues raised, so that you can draw on all your knowledge of Physics when answering the questions.

You will be provided with a copy of this booklet in the examination.

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This document consists of **6** printed pages and **2** blank pages.



### Extract 1: The heating effect of an alternating current

1. An alternating current (a.c.) can be represented by the equation:

$$I = I_0 \sin(2\pi ft)$$

where  $f$  is the frequency of the supply.

The heating effect depends on  $I^2R$ , and so an average of  $I^2$  is needed, not an average of  $I$ . To find the average value, you need the average value of  $\sin^2$  as time runs on.

The graph of  $\sin(2\pi ft)$  and the graph of  $\cos(2\pi ft)$  look the same, except for a shift of origin. Because they are the same pattern,  $\sin^2(2\pi ft)$  and  $\cos^2(2\pi ft)$  have the same average as time goes on. But

$$\sin^2(2\pi ft) + \cos^2(2\pi ft) = 1$$

Therefore the average values of each of them must be  $\frac{1}{2}$ .

Therefore the average value of the power in an a.c. transmission system must be half of the peak power.

2. The power wasted as heat in a transmission line of resistance  $R$  is

$$I_0^2 R \sin^2(2\pi ft)$$

Fig. E1.1 is a sketch graph of  $\sin^2 x$  against  $x$ .

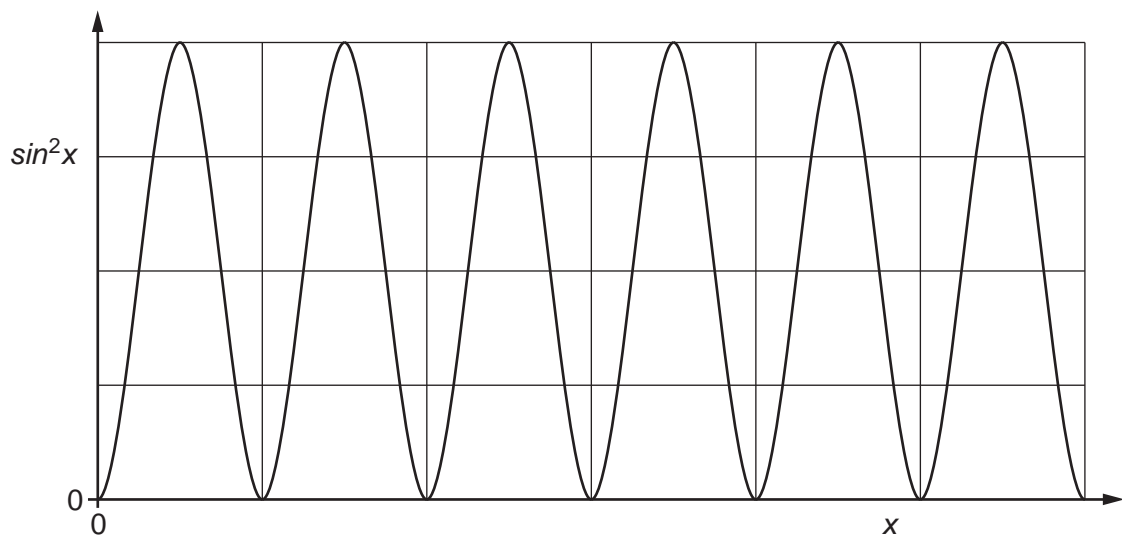


Fig. E1.1

Adapted from: [http://www.practicalphysics.org/go/Guidance\\_107.html](http://www.practicalphysics.org/go/Guidance_107.html)

## Extract 2: Classic HVDC Transmission

Using high voltage direct current – HVDC – to interconnect two points in a power grid, is in many cases, the best economic solution. High voltages are used in transmission systems because a higher voltage implies a lower current for a given power of transmission. With a lower current, there is less heat generated in the transmission lines and less energy is wasted.

Furthermore, it has excellent environmental benefits.

HVDC technology is used to transmit electricity over long distances by overhead transmission lines and over short distances when undersea cables are involved. It is also used to interconnect separate power systems, where traditional alternating current (a.c.) connections cannot be used. The Swedish company ABB pioneered HVDC technology and is the undisputed world leader in the HVDC field.

Fig. E2.1 shows the Herrenwyk station of the Baltic Cable HVDC Link.



**Fig. E2.1**

In a HVDC system, electric power is taken from one point in a three-phase a.c. network, converted to d.c. in a converter station, transmitted to the receiving point by an overhead line or cable and then converted back to a.c. in another converter station. It is then injected into the receiving a.c. network. Wherever possible, any voltage transformation is carried out when the current is an a.c. as transformers, which are highly efficient and cheap both to construct and operate, will not function with a d.c.

Typically, an HVDC transmission system has a rated power of more than 100 MW and many are in the 1,000–3,000 MW range.

HVDC transmissions are used for the transmission of power over long or very long distances because it then becomes economically attractive when compared with more conventional a.c. lines.

With an HVDC system, the power flow can be controlled rapidly and accurately as to both the power level and the direction. This possibility is often used in order to improve the performance and efficiency of the connected a.c. networks.

**Adapted from:** <http://www.abb.com/industries/us/9AAC30300393.aspx>

### Extract 3: Advantages of HVDC transmission

The advantage of HVDC is the ability to transmit large amounts of power over long distances with lower capital costs and with lower losses than a.c. Depending on voltage level and construction details, losses are quoted as about 3% per 1,000 km. High voltage direct current transmission allows efficient use of energy sources remote from load centres.

In a number of applications HVDC is more effective than a.c. transmission.

Examples include:

- undersea cables, where there are additional a.c. losses. (e.g., 250 km Baltic Cable between Sweden and Germany and the 600 km NorNed cable between Norway and the Netherlands),
- endpoint-to-endpoint long-haul bulk power transmission without intermediate 'taps', for example, in remote areas,
- increasing the capacity of an existing power grid in situations where additional wires are difficult or expensive to install,
- power transmission and stabilisation between unsynchronised a.c. distribution systems,
- connecting a remote generating plant to the distribution grid, for example Nelson River Bipole,
- stabilising a predominantly a.c. power-grid, without increasing prospective short circuit current,
- reducing line cost of long distance transmission; HVDC needs fewer conductors as there is no need to support multiple phases,
- thinner conductors can be used since HVDC does not suffer from the skin effect,
- facilitate power transmission between different countries that use a.c. at differing voltages and/or frequencies,
- synchronise a.c. produced by renewable energy sources.

HVDC can carry more power per conductor because, for a given power rating, the constant voltage in a d.c. line is lower than the peak voltage in an a.c. line. The peak voltage of a.c. determines the actual insulation thickness and conductor spacing. Because d.c. operates at a constant maximum voltage, this allows existing transmission line corridors with equally sized conductors and insulation to carry 100% more power into an area of high power consumption than a.c. which can lower costs.

Because HVDC allows power transmission between unsynchronised a.c. distribution systems, it can help increase system stability, by preventing cascading failures from propagating from one part of a wider power transmission grid to another. Changes in load that would cause portions of an a.c. network to become unsynchronised and separate would not similarly affect a d.c. link, and the power flow through the d.c. link would tend to stabilise the a.c. network. The magnitude and direction of power flow through a d.c. link can be directly commanded, and changed as needed to support the a.c. networks at either end of the d.c. link. This has caused many power system operators to contemplate wider use of HVDC technology for its stability benefits alone.

**From:** [http://en.wikipedia.org/wiki/High-voltage\\_direct\\_current](http://en.wikipedia.org/wiki/High-voltage_direct_current)

**Extract 4: The Skin Effect**

The Skin Effect was first described in a paper by Horace Lamb in 1883 for the case of spherical conductors, and was generalized to conductors of any shape by Oliver Heaviside in 1885.

When an electromagnetic wave interacts with a conductive material, mobile charges within the material are made to oscillate back and forth with the same frequency as the impinging fields. The movement of these charges, usually electrons, constitutes an alternating electric current, the magnitude of which is greatest at the conductor's surface. The decline in current density versus depth is known as the Skin Effect and the skin effect depth is the depth at which the current density reaches 1/e of its original value.

It is often best to assume, however, that when there is an alternating current in the cylindrical copper wire, the current flows only in the region between the surface of the wire and a depth equal to the skin effect depth and that there is no current at the centre of the cylindrical wire.

The Skin Effect has practical consequences in the design of radio-frequency and microwave circuits and in long distance a.c. electrical power transmission and distribution systems. It is also important in designing discharge tube circuits.

The skin effect depth (in metres) for copper can be calculated using the formula:

$$\text{skin effect depth} = 0.0760 / \sqrt{\text{frequency}}$$

**Adapted from:** <http://www.calculatoredge.com/electronics/skin%20effect.htm>

### Extract 5: Disadvantages of HVDC Transmission

The disadvantages of HVDC are in conversion, switching, control, availability and maintenance.

The required static inverters are expensive and have limited overload capacity. At smaller transmission distances the losses in the static inverters may be bigger than in an a.c. transmission line. The cost of the inverters may not be offset by reductions in line construction cost and lower line loss. With two exceptions, all former mercury rectifiers worldwide have been dismantled or replaced by thyristor units. Pole 1 of the HVDC scheme between the North and South Islands of New Zealand still uses mercury arc rectifiers, as does Pole 1 of the Vancouver Island link in Canada.

In contrast to a.c. systems, realising multi-terminal systems is complex, as is expanding existing schemes to multi-terminal systems. Controlling power flow in a multi-terminal d.c. system requires good communication between all the terminals; power flow must be actively regulated by the inverter control system instead of the inherent properties of the transmission line. Multi-terminal lines are rare. One is in operation at the Hydro Québec - New England transmission from Radisson to Sandy Pond. Another example is the Sardinia-mainland Italy link which was modified in 1989 to also provide power to the island of Corsica.

HVDC is less reliable and has lower availability than a.c. systems, mainly due to the extra conversion equipment. Single pole systems have availability of about 98.5%, with about a third of the downtime unscheduled due to faults. Fault redundant bipole systems provide high availability for 50% of the link capacity, but availability of the full capacity is about 97% to 98%.

HVDC circuit breakers are difficult to build because some mechanism must be included in the circuit breaker to force current to zero, otherwise arcing and contact wear would be too great to allow reliable switching.

Operating a HVDC scheme requires many spare parts to be kept, often exclusively for one system as HVDC systems are less standardized than a.c. systems.

**Adapted from:** [http://en.wikipedia.org/wiki/High-voltage\\_direct\\_current](http://en.wikipedia.org/wiki/High-voltage_direct_current)



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