ELECTRODYNAMICS

Section A: Summary Notes

Electrical Machines

1. The Motor effect

In order to realise the motor effect, the following components are necessary:

A current needs to be flowing in a magnetic field. The current produces a magnetic field which interacts with the magnetic field from the magnet and this combination of force fields causes movement.

Electrical energy is converted into mechanical energy.

The direction of the magnetic field is from North to South (N to S).

The current direction is the direction of flow of the conventional current (+ve to –ve).

Examples are: drills, cd players, washing machines, etc.

Fleming’s Left Hand Rule can be used to predict the direction of the force acting on the conductor in a magnetic field.

Using the LEFT HAND:

- The first (pointer) finger points in the direction of the field, from North to South.
- The second (middle) finger points in the direction of conventional current, from positive to negative.
- The thumb will then point in the direction of the resultant force.

In an electric motor, an electric current passes through the coil in a magnetic field the combination of the two force fields produces a torque (turning force) which turns the motor.

A DC motor

Electric current supplied through the commutator.

The commutator reverses the current each half turn to keep the torque turning the coil in the same direction.

The brushes on the commutator allow for the free rotation of the coil.

The left hand rule can be applied to each arm of the rotating coil in order to determine the direction of rotation.
An AC motor

An AC motor is driven by alternating current. The motor will run in the same direction since current in the coil is alternating. To achieve this, an AC motor uses two slip rings which rotate with the coil.

Factors affecting the electric motor

In order to maximise the force created by the motor effect we can:

- Make the current stronger
- Increase the strength of the magnetic field
- Increase the number of windings in the coil
- Wrap the coil around an iron core
- Make sure that the angle between the magnetic field direction and the direction of the current is as close to 90º as possible, since the maximum effect is when the current flows at 90º to the magnetic field lines.

Faraday’s Law of Induction

The induced emf in a conductor is directly proportional to the rate of change of the magnetic flux through the conductor.

The AC and DC Generators

If a metallic coil is moved in a magnetic field an electric current is induced (created).

An emf is induced across the ends of a coil by a changing magnetic flux, which in turn causes a current to flow.

Mechanical energy is converted into electrical energy

![A DC Generator with a split ring and brushes](Image taken from Plato Multimedia Science School Simulations 11-16 – Physics – Electric Generator)

![An AC Generator with slip rings](Image taken from Plato Multimedia Science School Simulations 11-16 – Physics – Electric Generator)

Fleming’s Right Hand Rule can be used to predict the direction of the induced current.

Using the RIGHT HAND:

- The first (pointer) finger points in the direction of the field, from North to South.
- The thumb points in the direction of the movement.
• Then the second (middle) finger points in the direction of the induced conventional current, from positive to negative.

**Uses of DC generators**

• Bicycle dynamos to power bicycle’s light
• Torches, producing light by shaking/winding the torch
• Battery chargers

**Uses of AC generators** (alternators)

• Battery cars, to recharge the battery while car is being driven
• Power plants and diesel generators (kinetic energy is converted into electrical energy)
• Microphones

**Alternating Current**

An AC generator produces alternating current. Our power stations produce alternating current and the current that we get from the plug points in our homes is AC.

How does the current vary?

The current changes direction every half revolution, and is changing strength continually.

This has the advantage of changing the magnetic field in transformers on the national power grid.

Notice the similarity with sin curve.

The frequency of alternating current in South Africa is 50Hz.

The current has a constant potential difference of 220V.

The actual potential difference varies between 0V and 311V. This has the same effect as a constant value of 220V, which is known as the \( V_{\text{rms}} \) value

This value can be calculated using the following equation:

\[
V_{\text{rms}} = \frac{V_{\text{max}}}{\sqrt{2}}
\]

\( V_{\text{rms}} = \) rms potential difference (V)
\( V_{\text{max}} = \) maximum potential difference (V)

The current fluctuates with time, in step with the fluctuating potential difference.

\[
I_{\text{rms}} = \frac{I_{\text{max}}}{\sqrt{2}}
\]

\( I_{\text{rms}} = \) rms current (A)
\( I_{\text{max}} = \) maximum current (A)
The average power in an AC circuit is calculated by using:

\[ P_{ave} = \frac{V_{rms}I_{rms}}{R} \]

| \( P_{ave} \) | average power (W) |
| \( V_{rms} \) | rms potential difference (V) |
| \( I_{rms} \) | rms current (A) |
| \( R \) | resistance (\( \Omega \)) |

Section B: Practice Questions

Question 1  \((Taken from November Exam 2012)\)

The diagram below illustrates how electricity generated at a power station is transmitted to a substation.

1.1. Does the power station use AC or a DC generator?  

1.2. Sketch a graph of the potential difference generated at the power station versus time.  

1.3. The average power produced at the power station is \(4.45 \times 10^9\) W. Calculate the rms current in the transmission lines if the power is transmitted at a maximum voltage of 30 000 V.  

1.4. Give a reason why electricity should be transmitted at high voltage and low current.  

Question 2  \((Taken from Gauteng Preparatory Exam 2012)\)

The diagram below shows an electric motor consisting of a coil \(ABCD\) placed between two magnets. \(Y\) represents the commutator. When charge flows through the coil, the coil rotates.

2.1. Will side \(AB\) of the coil rotate upwards out of the page, or downwards into the page? Write only UPWARDS or DOWNWARDS.
2.2. State **two** changes that can be made to increase the efficiency of the motor. (2)

2.3. The graph below shows the potential difference versus time relationship for a resistor of 35 Ω connected to a power source.

![Graph showing potential difference versus time](image)

2.3.1. Is this resistor connected to a direct current or an alternating current power source? (1)

2.3.2. If the average power for this resistor is 450 W, calculate the $V_{rms}$ value for this resistor. (3)

2.3.3. Calculate the maximum potential difference for this resistor. (2)

**Question 3** *(Taken from Feb – March 2012)*

3.1. The essential components of a simplified DC motor are shown in the diagram below.

![Diagram of DC motor components](image)

When the motor is functioning, the coil rotates in a clockwise direction, as shown.

3.1.1. Write down the function of each of the following components:
   a) Split-ring commutator (1)
   b) Brushes (1)

3.1.2. What is the direction of the conventional current in the part of the coil labelled **AB**? Write down only FROM A TO B or FROM B TO A (1)

3.1.3. Will the coil experience a maximum or minimum turning effect (torque) if the coil is in the position as shown in the diagram above? (1)

3.1.4. State ONE way in which this turning effect (torque) can be increased. (1)

3.2. Alternating current (AC) is used for the long-distance transmission of electricity.

3.2.1. Give a reason why AC is preferred over DC for long-distance transmission of electricity. (1)
An electric appliance with a power rating of 2 000 W is connected to a 230 V\text{rms} household mains supply.

Calculate the:

a) Peak (maximum) voltage  \hspace{1cm} (3)

b) rms current passing through the appliance. \hspace{1cm} (3)

**Question 4**  \hspace{0.5cm} (Taken from November Exam 2011)

Diesel-electric trains make use of electric motors as well as generators.

4.1. The table below compares a motor and a generator in terms of the type of energy conversion and the underlying principle on which each operates. Complete the table by writing down on the question number (4.1.1. – 4.1.4.) and next to each number the answer.

<table>
<thead>
<tr>
<th></th>
<th>Type of energy conversion</th>
<th>Principle of operation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor</strong></td>
<td>4.1.1.</td>
<td>4.1.3.</td>
</tr>
<tr>
<td><strong>Generator</strong></td>
<td>4.1.2.</td>
<td>4.1.4.</td>
</tr>
</tbody>
</table>

The simplified diagram below represents an electric motor.

4.1. Give a reason why the section of the coil labelled BC in the above diagram does not experience a magnetic force whilst the coil is in the position as shown. \hspace{1cm} (2)

4.2. Graphs of the current and potential difference outputs of an AC generator are shown below:

Calculate the average power output of this generator. \hspace{1cm} (6)
Question 5  *(Taken from Feb – March 2011)*

AC generators at coal-fired power stations supply most of the electrical energy needed in our country.

5.1. State ONE structural difference between an AC and a DC generator.  

A certain AC generator (alternator) produces a peak current \( (I_{\text{max}}) \) of 6.43 A when connected to an electrical heater of resistance 48.4 \( \Omega \)

5.2. Calculate the rms current \( (I_{\text{rms}}) \) produced by the generator.  

5.3. Calculate the peak voltage \( (V_{\text{max}}) \) output of the generator.  

5.4. Draw a sketch graph of potential difference versus time for this AC generator. Clearly label the axes and indicate \( V_{\text{max}} \) on the potential difference axis.  

5.5. To meet energy demands in the country, the government plans building nuclear power stations. State ONE environmental advantage of the generation of electricity in nuclear power stations over coal-fired power stations.  

**Section C: Solutions**

**Question 1**

1.1. AC  

1.2. **Criteria for graph**

- Correct shape as shown, accept more than one cycle  
- If no / wrong labels – minus 1 mark

1.3. \[ V_{\text{rms}} = \frac{V_{\text{max}}}{\sqrt{2}} \]

\[ = \frac{30000}{\sqrt{2}} \]

\[ = 21213,20 \text{ V} \]

1.4. Less loss in energy as heat.

**Question 2**

2.1. Downwards  

2.2. Use a stronger magnet

Use more loops in the coil

Use a battery with greater emf  

**Any TWO**

2.3.1. Alternating current
2.3.2. \[ P_{\text{rms}} = \frac{V_{\text{rms}}^2}{R} \]  
\[
450 = \frac{V_{\text{rms}}^2}{35} \checkmark
\]
\[
V_{\text{rms}} = 125.5 \text{ V} \checkmark
\] (3)

2.3.3. \[ V_{\text{rms}} = \frac{V_{\text{max}}}{\sqrt{2}} \]  
\[
125.5 = \frac{V_{\text{max}}}{\sqrt{2}} \checkmark
\]
\[
V_{\text{max}} = 177.48 \text{ V} \checkmark
\] (2)

Question 3

3.1.1. a) Reverse the direction of the current in the coil each half cycle \(\checkmark\) (1)  
   b) Makes electrical contact with the commutator \(\checkmark\) (1)

3.1.2. B to A \(\checkmark\) (1)

3.1.3. Maximum \(\checkmark\) (1)

3.1.4. Any ONE of:  
   - Increase the current in the coil \(\checkmark\)  
   - Increase the magnitude of the magnetic field \(\checkmark\)  
   - Increase the number of turns in the coil \(\checkmark\)  
   - Use a soft iron core as the core of the coil \(\checkmark\) (1)

3.2.1. Any ONE of:  
   - Can be transmitted over long distances with major energy loss \(\checkmark\)  
   - The potential difference can be increased or decreased \(\checkmark\) (1)

3.2.2. a) \[ V_{\text{rms}} = \frac{V_{\text{max}}}{\sqrt{2}} \]  
\[
230 = \frac{V_{\text{max}}}{\sqrt{2}} \checkmark
\]
\[
\therefore V_{\text{max}} = 325.27 \text{ V} \checkmark
\] (3)
   
   b) \[ P_{\text{ave}} = V_{\text{rms}}I_{\text{rms}} \]  
\[
2000 = (230)I_{\text{rms}} \checkmark
\]
\[
\therefore I_{\text{rms}} = 8.70 \text{ A} \checkmark
\] (3)

Question 4

4.1.1. Electrical energy to mechanical / kinetic energy \(\checkmark\) (1)  
4.1.2. Mechanical / kinetic energy to electrical energy \(\checkmark\) (1)  
4.1.3. Motor effect \(\checkmark\) (1)  
4.1.4. Electromagnetic induction \(\checkmark\) (1)
4.2. BC is parallel to the magnetic field ✓✓
OR
The switch is open, therefore no current ✓✓ (2)

4.3. \[ P_{ave} = V_{rms} \cdot I_{rms} \]
\[ = \left( \frac{V_{max}}{\sqrt{2}} \right) \cdot \left( \frac{I_{max}}{\sqrt{2}} \right) \]
\[ = \left( \frac{311}{\sqrt{2}} \right) \cdot \left( \frac{21}{\sqrt{2}} \right) \]
\[ = 3265,5 \, W \] ✓✓ (6)

Question 5

5.1. AC generator – slip rings ✓
DC generator – split ring commutator ✓ (2)

5.2. \[ I_{rms} = \frac{I_{max}}{\sqrt{2}} \]
\[ = \frac{6.43}{\sqrt{2}} \]
\[ = 4.55 \, A \] ✓✓ (3)

5.3. \[ R = \frac{V_{max}}{I_{max}} \]
\[ 48.4 \, = \frac{V_{max}}{6.43} \]
\[ V_{max} = (48.4)(6.43) \]
\[ = 311,21 \, V \] ✓✓ (5)

5.4. **Criteria for graph**
- \( V_{max} \) correctly shown ✓✓
- Correct shape for at least one complete cycle ✓✓ (2)

5.5. Less air pollution ✓✓ (1)