8 Read the passage below and answer the questions that follow.

DPM Heng Swee Kiat announced in Budget 2020 that Singapore will be phasing out internal combustion engine vehicles (i.e. vehicles that use petrol or diesel as fuel) in favour of fully electric vehicles (EV) by 2040. The move is part of Singapore's commitment to tackle climate change and build an eco-friendlier city.

To increase the adoption rate of EVs, all HDB car parks in at least eight "EV-Ready Towns" across Singapore will be fitted with EV charging stations, according to Minister for Transport Ong Ye Kung during his Committee of Supply debate for the Singapore Green Plan on March 4, 2021.

The battery of an EV can be charged through either conductive or inductive methods. Conductive charging involves wired connection to the electricity supply grid. Inductive charging refers to wireless charging systems (WCS). WCS can function in both stationary and dynamic modes. This means that they can be utilized when the car is parked or stopped, such as in car parks, garages, or at traffic signals, or they can be utilized while the vehicle is in motion.

Battery chargers can be implemented inside (on-board) or outside (off-board) the vehicle. Fig 8.1 shows the typical architecture of an EV charging system, where both the on-board charger and the off-board charger are represented.

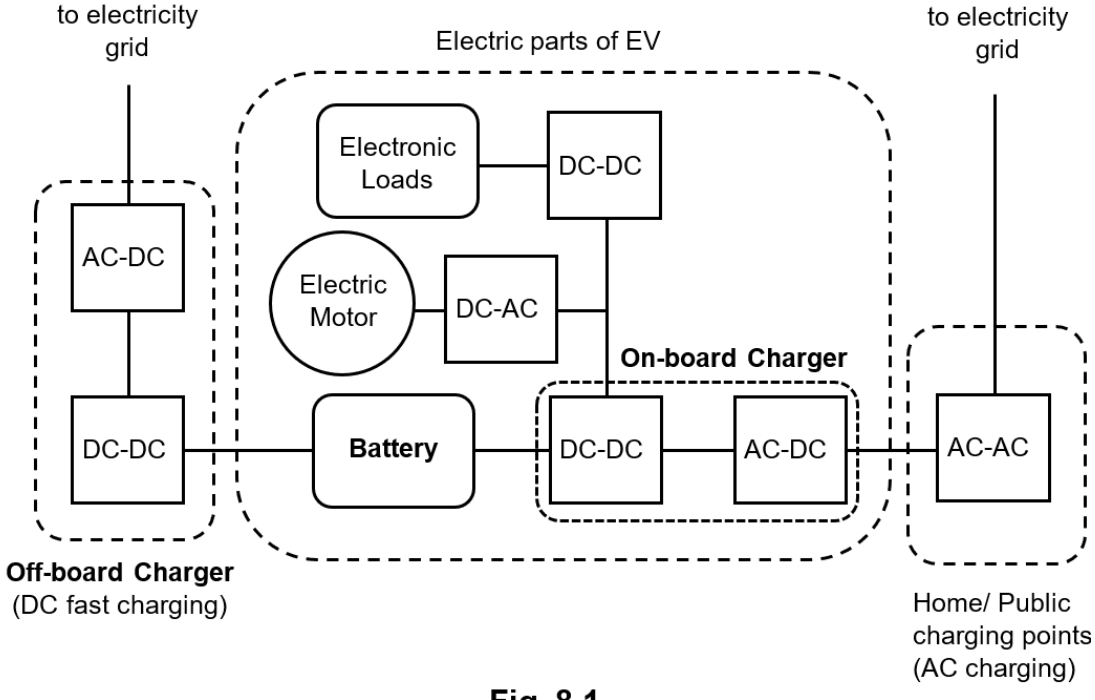

Fig. 8.1

On-board battery chargers are limited by size, weight and volume. On-board chargers are typically composed of two stages: a front-end AC-DC (a.c. to d.c.) stage and a back-end DC-DC (d.c. to d.c.) stage. The front-end conversion can be performed by a full-bridge diode rectifier circuit.

Off-board charging systems, with higher power ratings, are installed outside the vehicle. It is usually made up of two stages: a grid-facing AC-DC converter followed by a DC-DC converter providing an interface to the EV battery.

The batteries installed on EVs are not all the same. The battery capacity is the quantity that measures how much electricity can be stored. Charging power is the quantity that measures the amount of effective energy per unit time that is transferred from the charging station to the battery of the car. Ideally it could be equal to the power of the charging station but in reality, it is almost always limited by a series of factors including charging station power, maximum charging power of the machine, maximum current of the charging cable and grid energy availability.

(a) The alternating voltage from the power sub-station has to be stepped down from 21 kV to 250 V with a transformer before connecting to a domestic EV charger with a rated output of 8.0 kW.

(i) Calculate the current in the secondary coil of the transformer.

current in the secondary coil = ... A [2]

(ii) Assuming the transformer is ideal, calculate the current in the primary coil of the transformer.

current in the primary coil = ... A [2]

(iii) Determine the ratio of the number of turns in the primary coil to the number of turns in the secondary coil in the transformer.

ratio = ... [2]

(iv) If the output voltage from the charger is half-wave rectified to give a d.c. voltage, determine the peak value of this rectified voltage. Explain your working clearly.

peak rectified voltage = ... V [2]

(v) The charger is used to charge an EV installed with a 27 kWh battery. Calculate the duration, in hours, required for the battery to be 80% charged.

time = ... hr [2]

(b) The current from the battery must first be converted from a d.c. to an a.c before it can power the electric motor. This is achieved using a circuit known as an *Inverter*. Fig. 8.2 shows a schematic of a simple inverter.

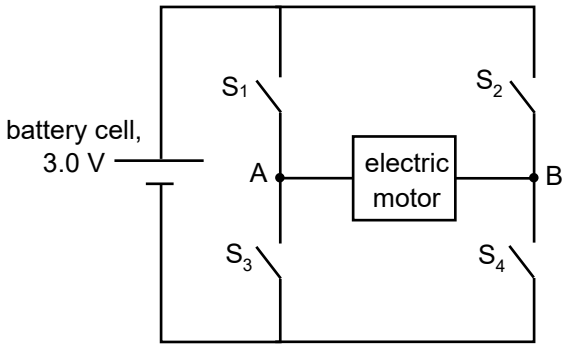

Fig. 8.2

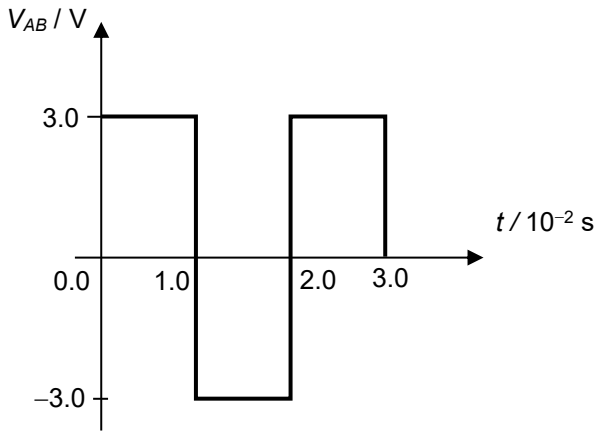

Fig. 8.3

Fig. 8.3 shows the output voltage V_{AB} across points A and B, connected to the motor in the circuit.

(i) The 4 switches S_1, S_2, S_3 and S_4 in Fig. 8.2 are electronically controlled to operate in pairs, so that at any one instant, 2 of switches will be closed while the other 2 will be open.

State and explain how the switches can be paired and operated to produce the output voltage V_{AB} in Fig. 8.3.

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.....[3]

(ii)

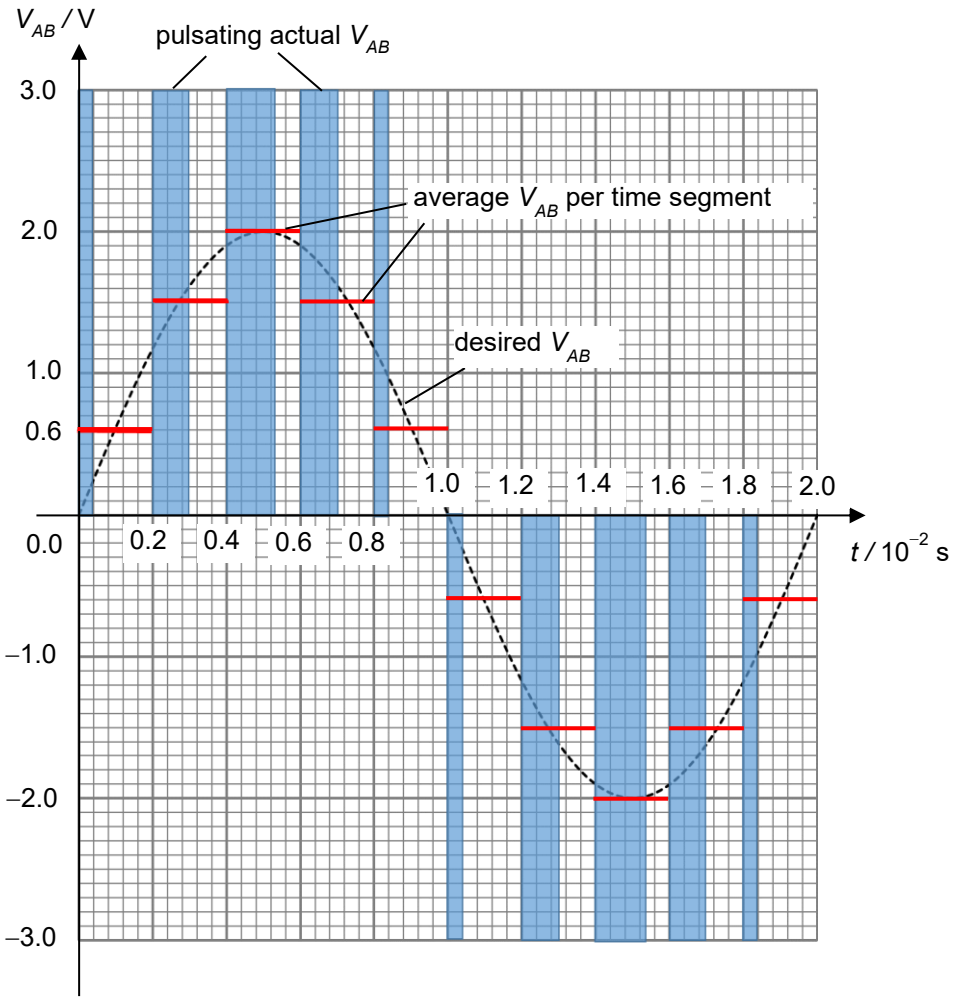

Fig. 8.4

To produce an output waveform that resembles a sinusoidal waveform, the opening and closing of the switches are specially programmed. While one pair of switches is open, the other pair of switches does not just stay closed for the duration of the half-cycle. Instead, they are made to rapidly open and close multiple times in a pulsating pattern. Each pulse varies in width, as shown in Fig. 8.4. This is known as *Pulse Width Modulation*.

The cycle is broken up into multiple smaller segments. By rapidly pulsating the switches the average voltage per segment can be controlled to increase or decrease from one time segment to the next.

The resultant output experienced by the motor can thus be made to approximate a sine wave. The more segments there are, the closer the output mimics a smooth wave.

1. Using information from Fig. 8.4, show that the average output voltage V_{AB} for the time segment $0.00 \leq t \leq 0.20 \times 10^{-2}$ s is 0.60 V.

[1]

2. Explain how the magnitude and the frequency of the average output voltage V_{AB} can be changed.

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.....[2]

(c) Inductive charging, or wireless charging, consists of a transfer of energy from the charging station to the vehicle without using a cable.

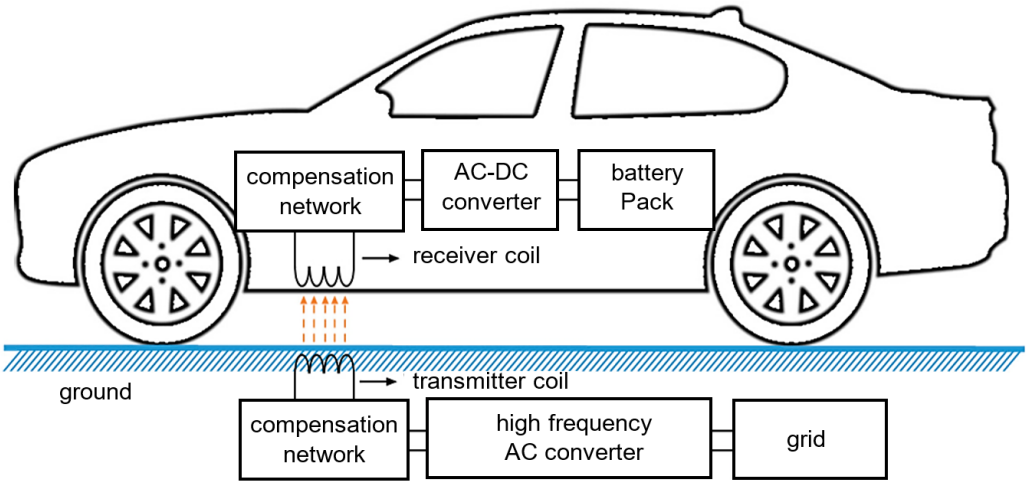

Fig. 8.5

Fig. 8.5 shows two conductive coils, one placed under the car body and the other installed at the ground level of the charging station.

(i) Use Faraday's law to explain how the battery in the EV is charged.

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.....[2]

(ii) Wireless charging is rarely used due to the high inefficiencies involved. Charging cables allow for a near 100% energy transfer from the source to the battery, but a wireless charger can have efficiencies as low as 60%.

Suggest two reasons why the energy transfer process might be inefficient.

1. ……..

……..

…… [1]

2. ……..

……..

…… [1]

[Total: 20]