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D Y PATIL UNIVERSITY

End Term Examinations (April 2019)

School : School of Engineering **Program:** M-Tech Automotive Product Engineering

Course: Hybrid Vehicle Technology **Course Code**: APE 605

Semester: IV **Max Marks:** 30 **Duration (mins):** 150 mins

Note : 1. All questions are compulsory. 2. All sub questions carry equal marks
3. The question paper is to be printed in colour.

Fuel consumption model

FE.1a Match the Following:

1. Gross torque produced by the combustion process
2. The effect of changes in kinetic energy in the engine
3. Another way of expressing the fuel consumption in g/s
4. Torque to the transmission
5. Speed of the crankshaft
6. A measure of how effectively chemical energy in the fuel is converted to work on the piston
7. The losses from indicated torque to the engine output torque

ω_{ICE}

T_{ICE}

P_{fuel}

η_{Ind}

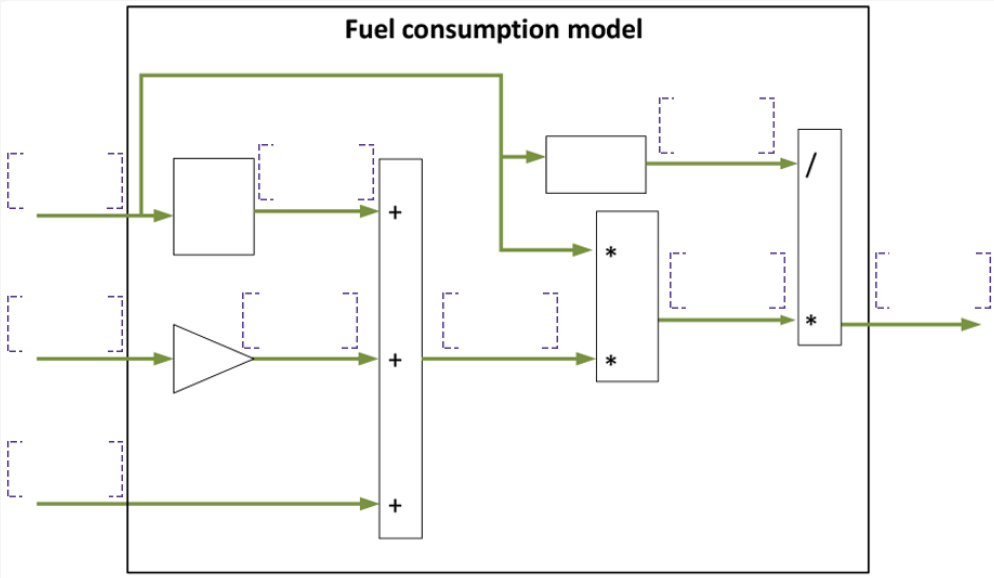
T_{Ind}

T_{Frict}

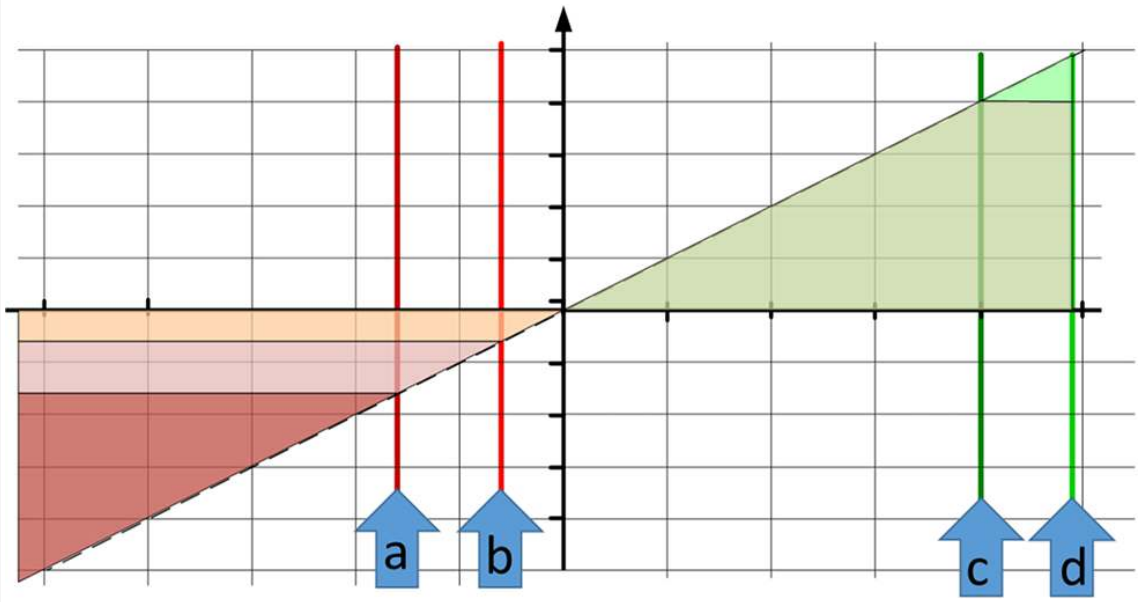
$T_{Inertia}$

FE.1b Drag and drop the quantity symbols to the right place in the fuel consumption model below. Note that there will be some unused placeholders in the model when you have placed all quantity symbols.

ω_{ICE} T_{Frict} $T_{Inertia}$ T_{ICE} T_{Ind} η_{Ind} P_{fuel}

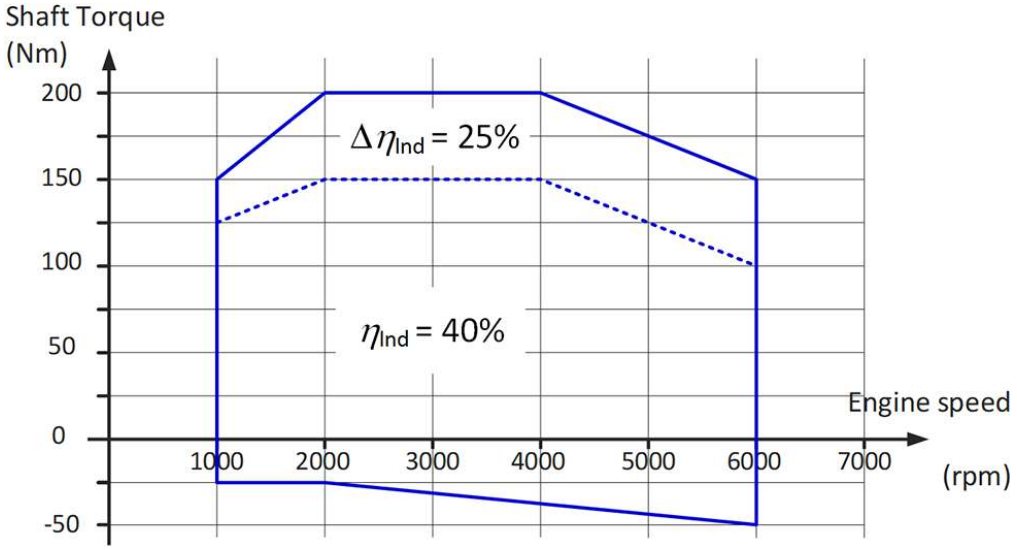


FE.2. Suppose a parallel mild hybrid with a P0 belt driven EM is controlled according to the strategy in the diagram below:

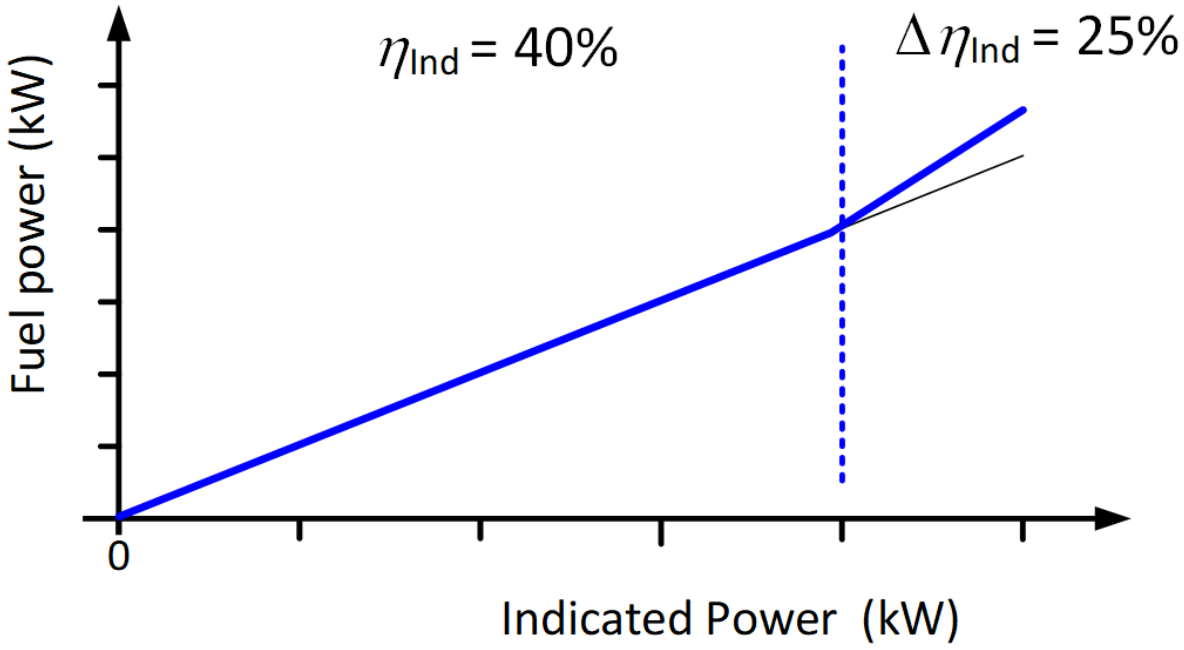


All the four limits a, b, c and d are depending on engine speed:
- a is when the maximum negative EM torque is reached
- b is the full engine braking torque
- c is the maximum engine torque
- d is when the maximum EM torque is reached

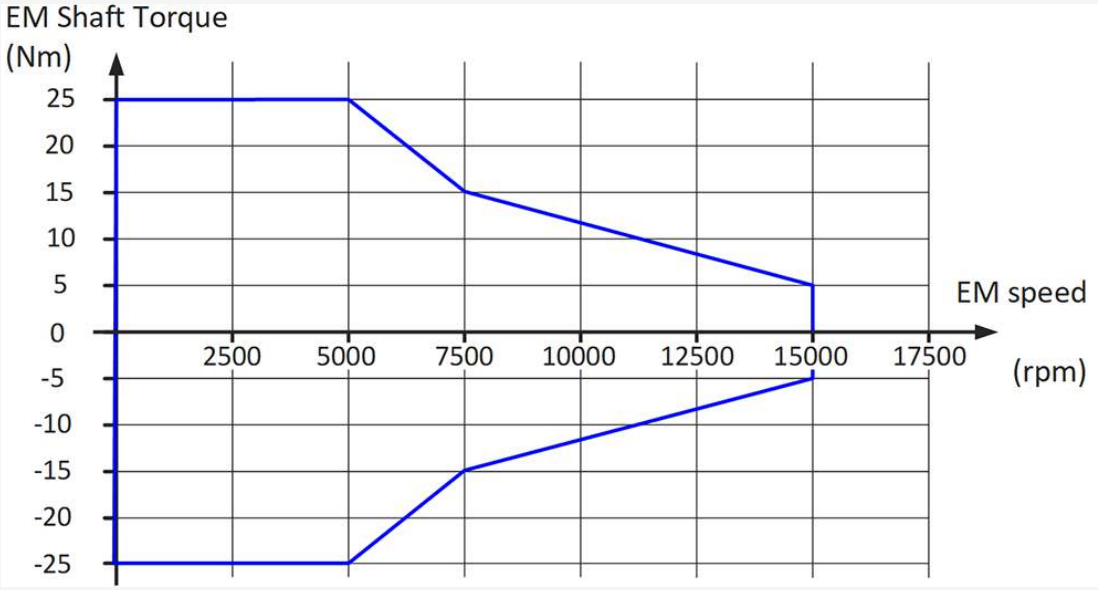
In the shaft torque vs engine speed diagram below the engine (ICE) operating range is shown. From the minimum torque up to the dashed line the indicated efficiency is constant 40%. Above the dashed blue line the marginal efficiency is 25%.



In the fuel power vs indicated power diagram below, the two efficiency values reappear for determining the fuel power. Note that there is no axis grading, because the power levels, at which the marginal efficiency changes over, will be different at different engine speeds. However, the power limit can be determined from the dashed line in the shaft torque vs engine speed diagram above.



The electric machine (EM) has an operating range according to the below diagram. The EM is connected to the crank shaft via a belt drive with a speed ratio of 1.0. The combined efficiency of the EM, inverter and belt drive is assumed to be 90% both when operating as a motor and when operating as a generator.



FE.2a. Assume the engine is operating at speed 2000 rpm when the driver presses the accelerator pedal fully. What is the ICE torque (Nm)?

Enter your answer in the input field below as an integer number.

Nm

FE.2b. What is the torque (Nm) the electric machine add to the crankshaft torque?

Enter your answer in the input field below as an integer number.

Nm

FE.2c. What is the battery power? (kW)

Enter your answer in the input field below **with one correct decimal**.

kW

FE.2d. Assume the engine is operating at speed 5000 rpm when the driver fully releases the accelerator pedal. What is the ICE torque? (Nm)

Enter your answer in the input field below as an integer number.

Nm

FE.2e. What is the torque (Nm) the electric machine add to the crankshaft?

Enter your answer in the input field below as an integer number.

Nm

FE.2f. What is the battery power (kW)?

Enter your answer in the input field below with one correct decimal.

kW

FE.2g. Aim for maximizing the mild hybrid regeneration capability at speeds up to 1500 rpm, while still allowing for the ICE to operate in its full speed range! Which gear speed ratio should be used between crankshaft and EM?

Enter your answer in the input field below with one correct decimal.

- correct

FE.2h. What is the battery power (kW) at 2000 rpm and maximum regeneration, with the new gear ratio (see FE.2g above)?

Enter your answer in the input field below with one correct decimal.

kW

FE.2i. With the new speed ratio (see FE.2g above), what is the combined torque (Nm) the ICE and EM can act on the crankshaft, at 1500 rpm, when the accelerator pedal is fully released?

Enter your answer in the input field below with one correct decimal.

-87.5 Nm

Fuel savings in a mild hybrid

.**FE.3.** We continue to analyse the same mild hybrid as in the previous exercise.

The mild hybrid controller shall determine in which of some different operating points the battery energy will save most fuel energy. To do that it needs to determine how much the fuel power can be reduced per kW of battery power in the following two situations.

FE.3a. Situation A: Engine torque of 175 Nm at 1500 rpm is reduced to 150 Nm, by supplying 25 Nm from the EM.
- How high is the fuel power reduction divided by the battery discharge power?

Enter your answer in the input field below, with two correct decimals.

times

FE.3b. Situation B: Engine torque of 50 Nm at 1500 rpm is reduced to 25 Nm, by supplying 25 Nm from the EM.

- How high is the fuel power reduction divided by the battery discharge power?

times

FE.3c. Situation C: When the propulsion requires 50 Nm at 3000 rpm the controller requests an engine torque of 75 Nm and uses the surplus to charge the battery.

- How high is the increase in fuel power per kW power charging the battery?

_____ times

FE.3d. Will it save fuel over the whole driving cycle if energy charged in situation C is used in situation A?

Select yes or no.

(•) Yes

( ) No

FE.3e. Will it save fuel over the whole driving cycle if energy charged in situation C is used in situation B?

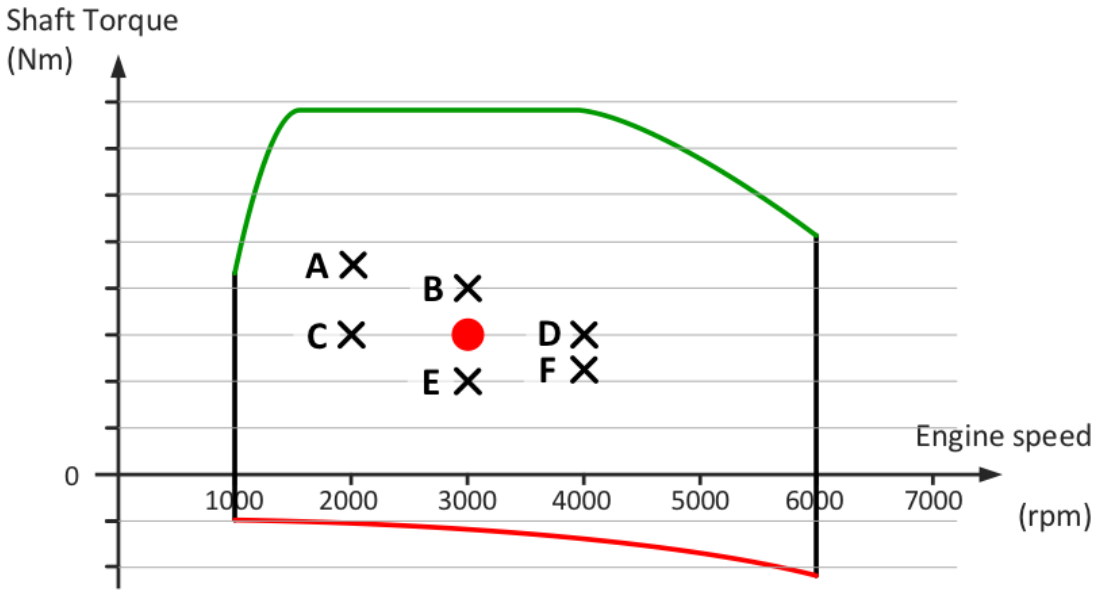
Select yes or no.

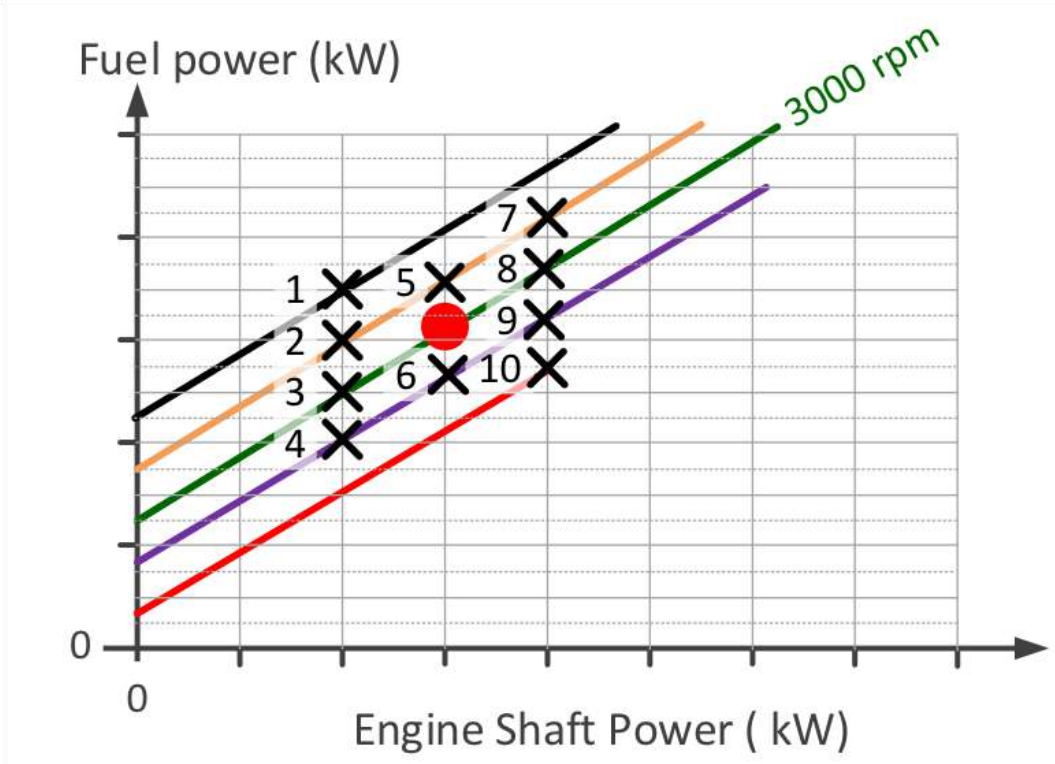
(•) Yes

( ) No

FE.4. In this exercise there are two different diagrams describing the operating points of an engine. Your task is to identify where the six operating points, A to F, in the first diagram can be found in the fuel power diagram below. To make it easier you only have 10 different operating points to select from.

Note: The red points in the two diagrams are both the same operating point, and should be used as a reference, since there are no scales on three of the diagram axes. The axes are all linear and drawn to scale.





FE.4a. Which one of the operating points 1-10 in the fuel power diagram corresponds to operating point **A**? Select the correct operating point from the drop-down-list.

Select an option [1 to 10]

FE.4b. Which one of the operating points 1-10 in the fuel power diagram corresponds to operating point **B**? Select the correct operating point from the drop-down-list.

Select an option [1 to 10]

FE.4c. Which one of the operating points 1-10 in the fuel power diagram corresponds to operating point **C**? Select the correct operating point from the drop-down-list.

Select an option [1 to 10]

FE.4d. Which one of the operating points 1-10 in the fuel power diagram corresponds to operating point **D**?

Select the correct operating point from the drop-down-list.

Select an option [1 to 10]

FE.4e. Which one of the operating points 1-10 in the fuel power diagram corresponds to operating point **E**?

Select the correct operating point from the drop-down-list.

Select an option [1 to 10]

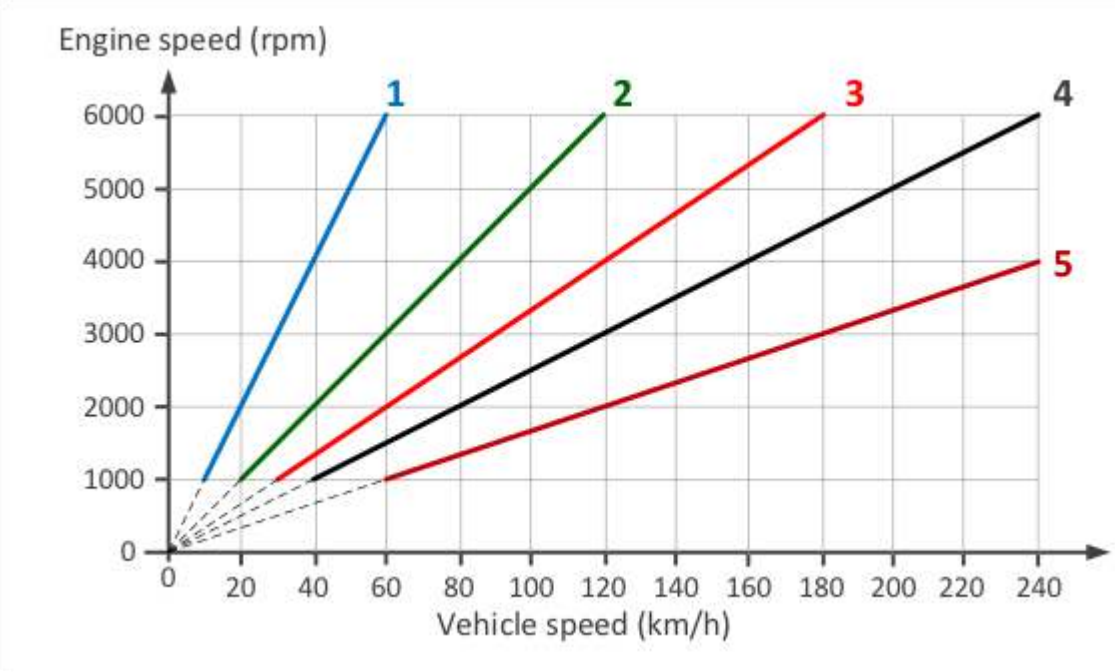
FE.4f. Which one of the operating points 1-10 in the fuel power diagram corresponds to operating point **F**?

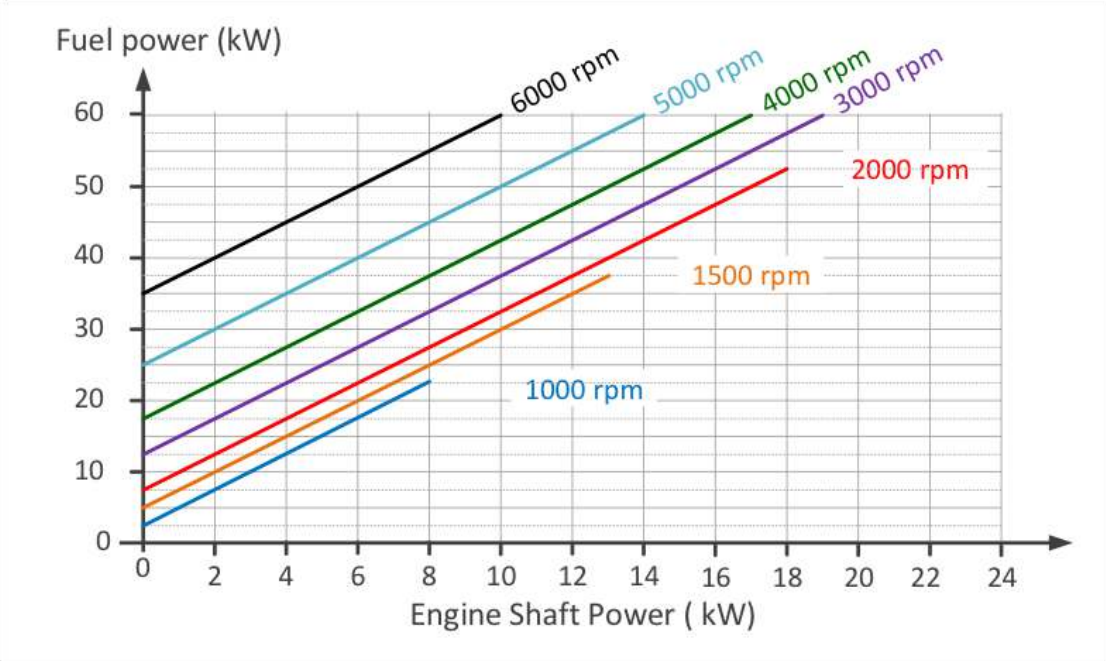
Select the correct operating point from the drop-down-list.

Select an option [1 to 10]

Parallel hybrid

FE.5. A car has a P3 parallel powertrain. With a five step gearbox, the engine speed as a function of vehicle speed varies like in the first diagram below. The engine's fuel power as a function of engine power is shown in the second diagram below.





The transmission efficiency is assumed to be 100%. The combined electric machine, inverter and battery efficiency is 90 %, both at charging and discharging, and their no-load losses are zero.

The vehicle drives at 60 km/h and the powertrain must provide a traction power of 600 N.

The electric machine has a constant maximum shaft power of +/- 25 kW above its nominal speed, and at 60 km/h the EM speed exceeds the nominal speed.

Your task is now to analyze several different ways of controlling the powertrain in this specific driving situation.

FE.5a. Answer the three following questions:

- What is the lowest fuel power possible at zero battery power?

Enter your answer in the input field below, as an integer number.

kW

- What is then the engine speed?

Enter your answer in the input field below, as an integer number.

rpm

- And what is the engine torque value?

Enter your answer in the input field below, with two correct decimals.

Nm

FE.5b. Answer the three following questions:

- What is the lowest possible fuel power at a battery power of -5 kW (charging)?

Enter your answer in the input field below, as an integer number.

kW

- What is then the engine speed?

Enter your answer in the input field below, as an integer number.

rpm

- And what is the engine torque value?

Enter your answer in the input field below, as an integer number.

Nm

FE.5c. Answer the three following questions:

- What is the lowest possible fuel power at a battery power of 5 kW (discharging)?

Enter your answer in the input field below, with two correct decimals.

kW

- What is then the engine speed?

Enter your answer in the input field below.

rpm

- And what is the engine torque value?

Enter your answer in the input field below, as an integer number.

Nm

FE.5d. Answer the four following questions:

- What is the lowest possible fuel power for all possible battery power?

Enter your answer in the input field below, as an integer number.

kW

- What is then the engine speed?

Enter your answer in the input field below, as an integer number.

rpm

- And what is the engine torque value?

Enter your answer in the input field below, as an integer number.

Nm

- And what is the battery power?

Enter your answer in the input field below, with one correct decimal.

kW

FE.5e. Search for the operating point of the engine which leads to the highest possible ratio between reduced fuel power and the battery power required, and then answer the three following questions:

- At that operating point, what is the engine speed?

Enter your answer in the input field below, as an integer number.

rpm

- And what is the engine torque value?

Enter your answer in the input field below, with one correct decimal.

Nm

- And what is the ratio between the change in fuel power and battery power?

Enter your answer in the input field below, with one correct decimal.

FE.5f. What gear is used in FE.5a?

Select the correct mode in the drop-down-list.

Select an option

FE.5g. What gear is used in FE.5b?

Select the correct mode in the drop-down-list.

Select an option 1st 2nd 3rd 4th 5th

FE.5h. What gear is used in FE.5c? Select the correct mode in the drop-down-list.

Select an option 1st 2nd 3rd 4th 5th

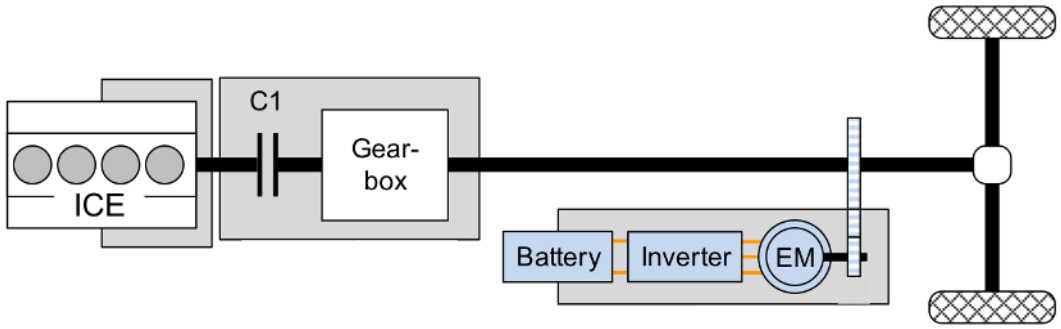
FE.5i. What gear is used in FE.5e?

Select the correct mode in the drop-down-list.

Select an option 1st 2nd 3rd 4th 5th

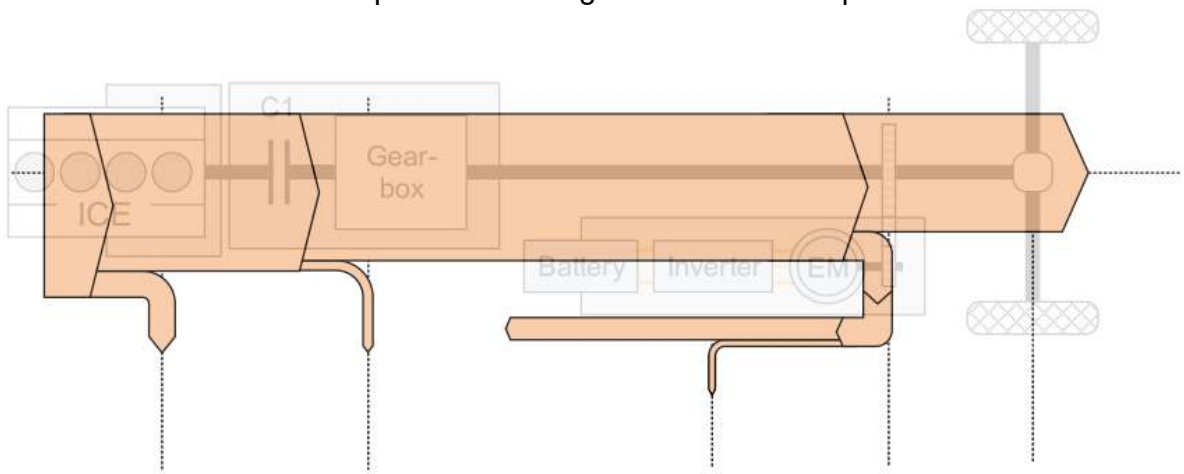
Power flow diagrams

FE.6. Consider the powertrain model seen in the image below.



In this exercise you are to identify which mode each power flow diagram describes.

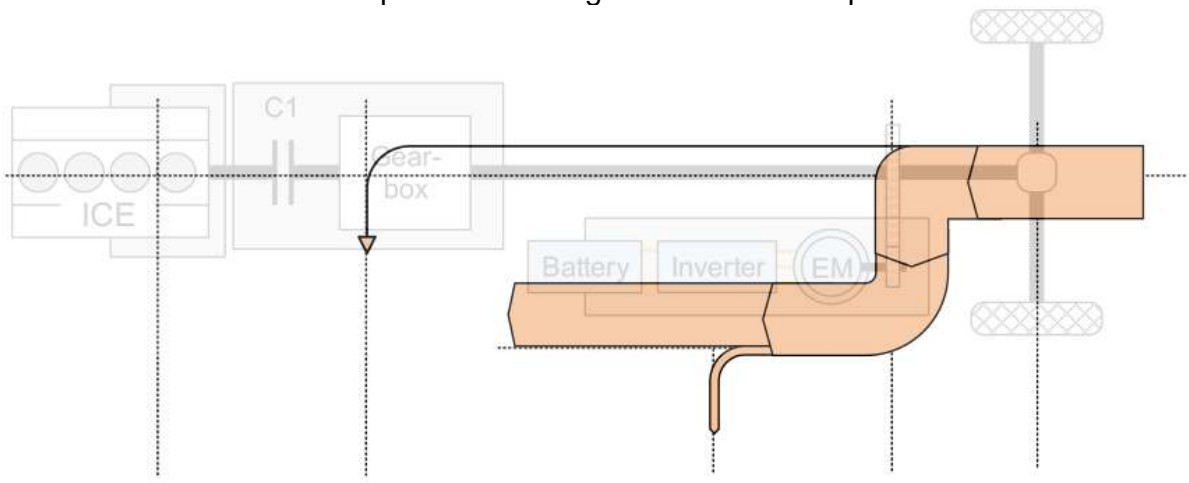
FE.6a. Which mode does the power flow diagram below correspond to?



ICEonly ; ICE +Battery ; ICE +Charge ; Battery only ; Engine Braking ; Regeneration

Select the correct mode in the above -list.

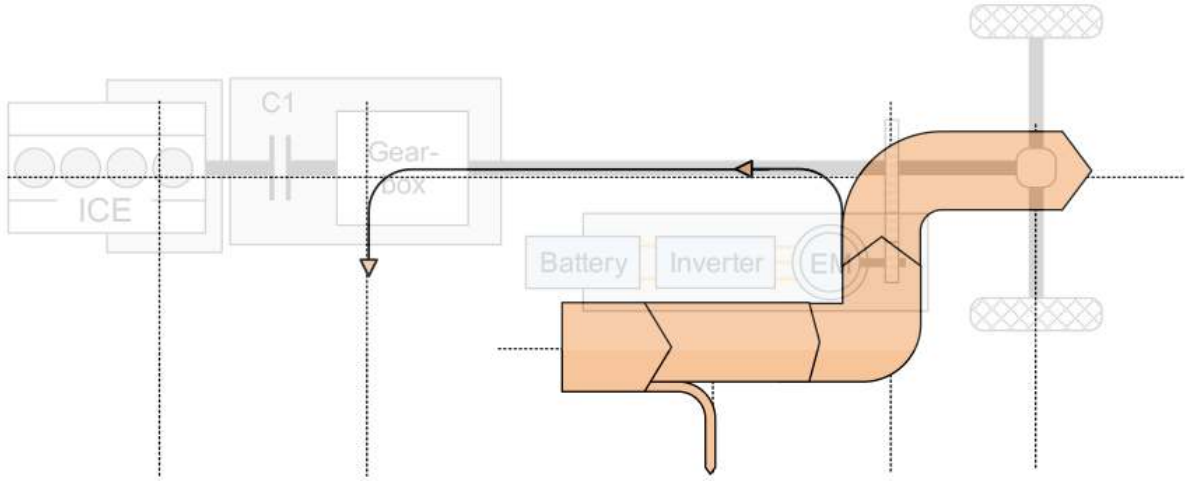
FE.6b. Which mode does the power flow diagram below correspond to?



Select the correct mode in the above -list..

Select an option

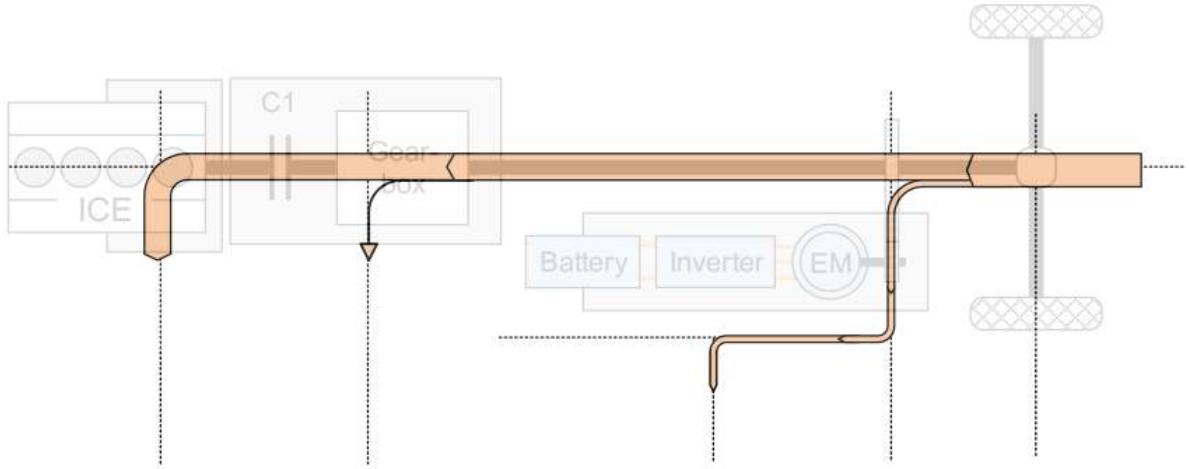
FE.6c. Which mode does the power flow diagram below correspond to?



Select the correct mode in the above -list.

Select an option

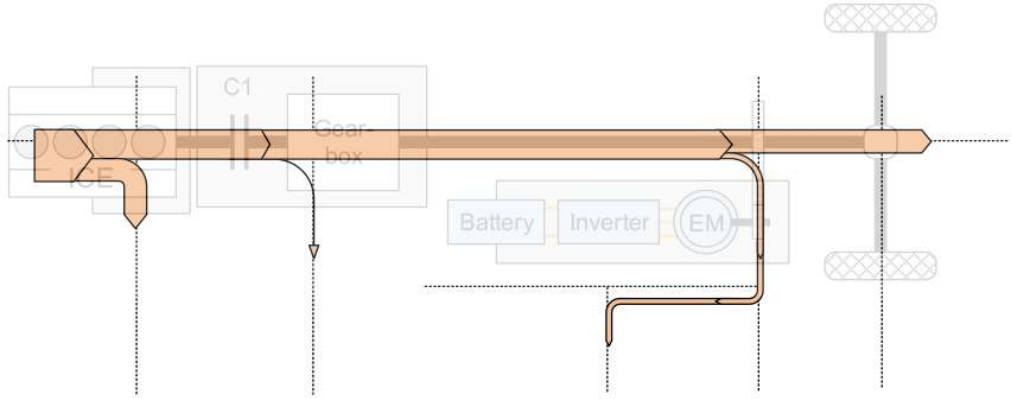
FE.6d. Which mode does the power flow diagram below correspond to?



Select the correct mode in the above -list.

Select an option

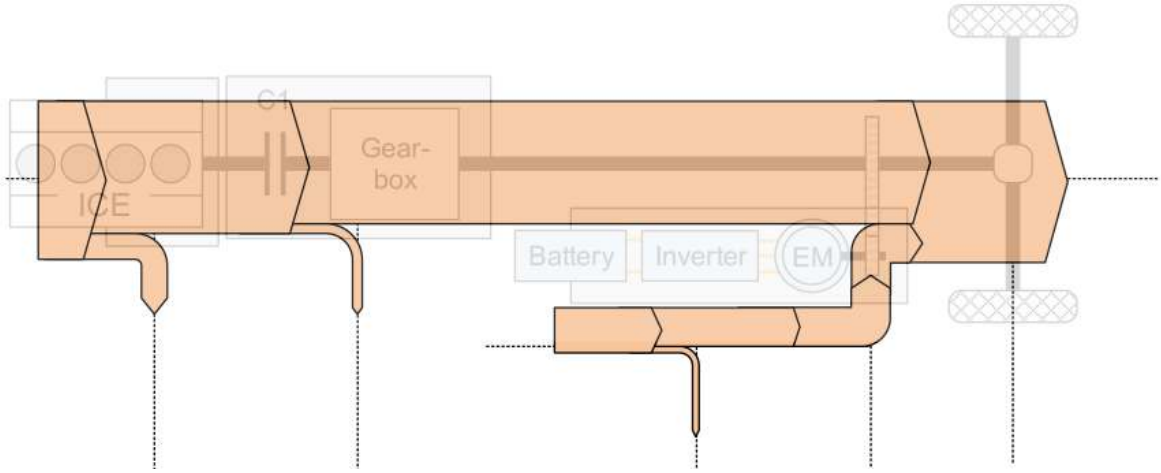
FE.6e. Which mode does the power flow diagram below correspond to?



Select the correct mode in the above -list..

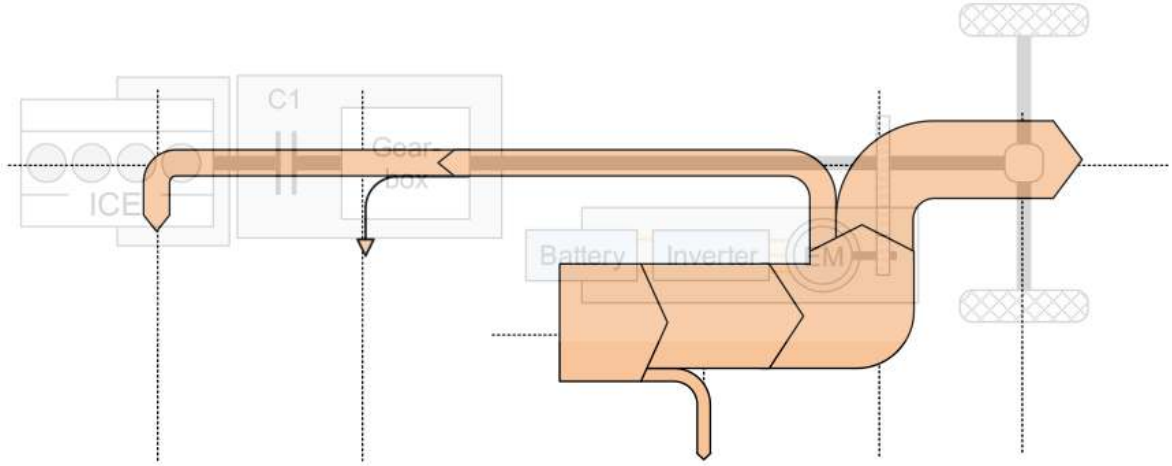
Select an option

FE.6f. Which mode does the power flow diagram below correspond to?



Select the correct mode in the above -list.

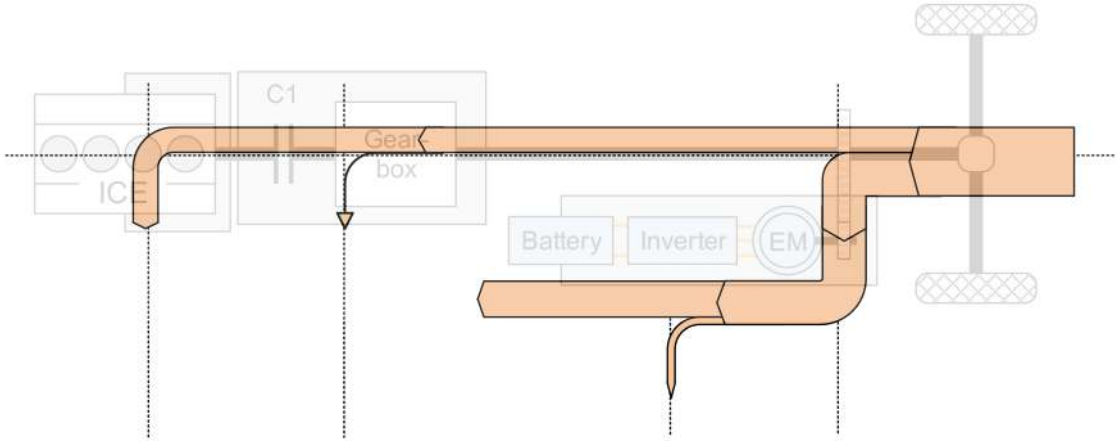
FE.6g. Which mode does the power flow diagram below correspond to?



Select the correct mode in the above -list.

Select an option

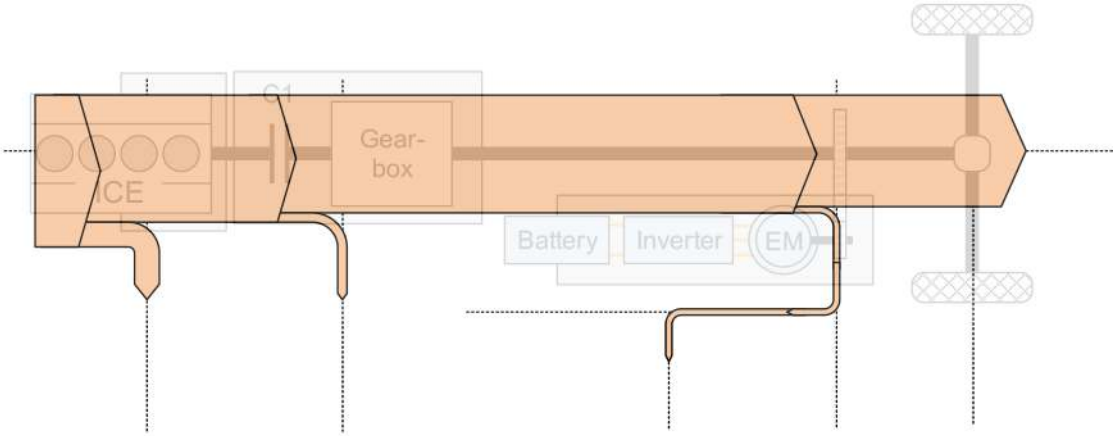
FE.6h. Which mode does the power flow diagram below correspond to?



Select the correct mode in the above -list.

Select an option

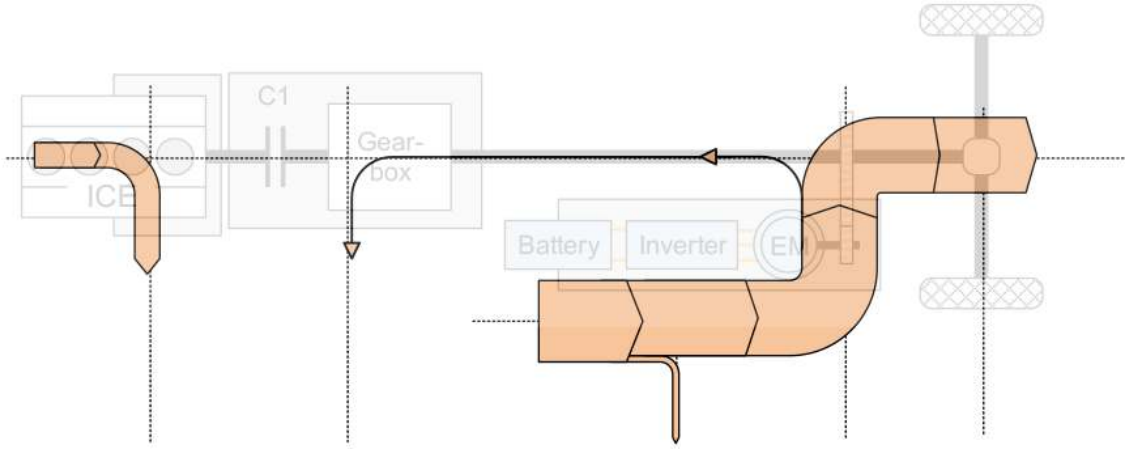
FE.6i. Which mode does the power flow diagram below correspond to?



Select the correct mode in the above -list.

Select an option

FE.6j. Which mode does the power flow diagram below correspond to?



Select the correct mode in the above -list.

Select an option

FE.6k. For which one of the situations described in the above power flow diagrams (i.e. in FE.6a-6j) is it possible to reduce the required fuel power by turning the engine off without requiring any additional battery power?

Select the correct situation in the drop-down-list. [a,b,c,d,e,f,g,h,i,j]

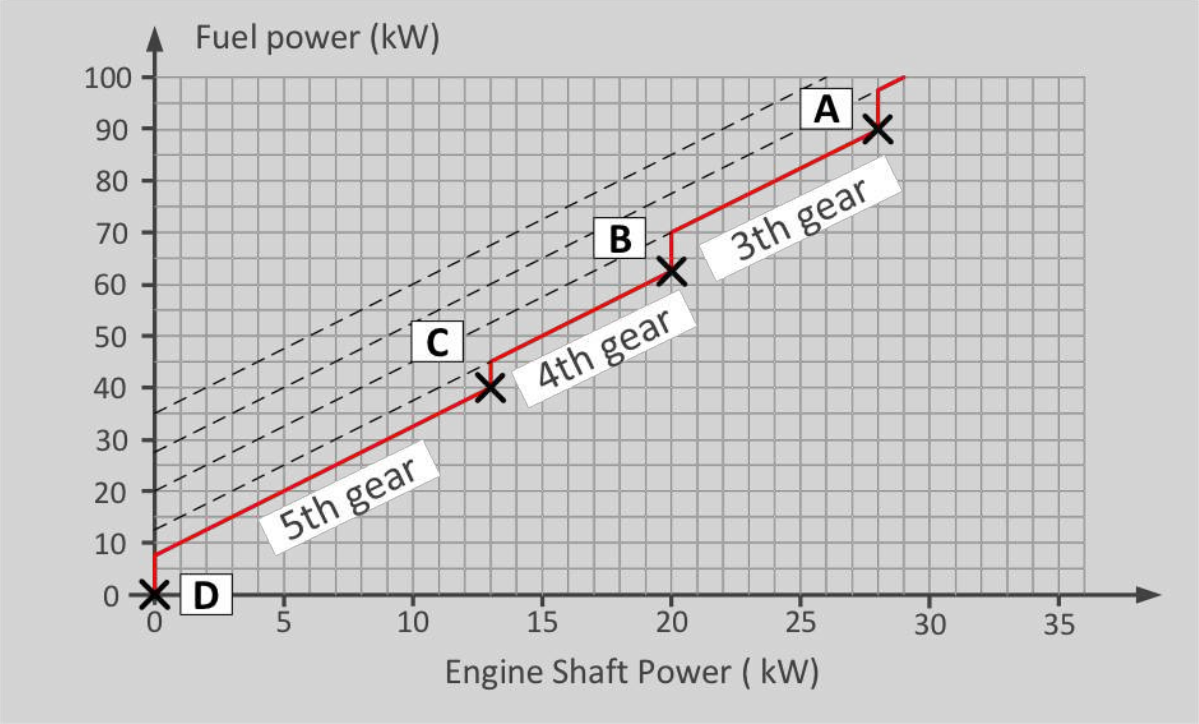
Select an option

FE.6l. For which of the situations described in the above power flow diagrams (i.e. in FE.6a-6j) is it possible to charge the battery more, or to discharge it less, if the engine is turned off, without requiring any increase in fuel power? **Note**: Three of the situations are correct.

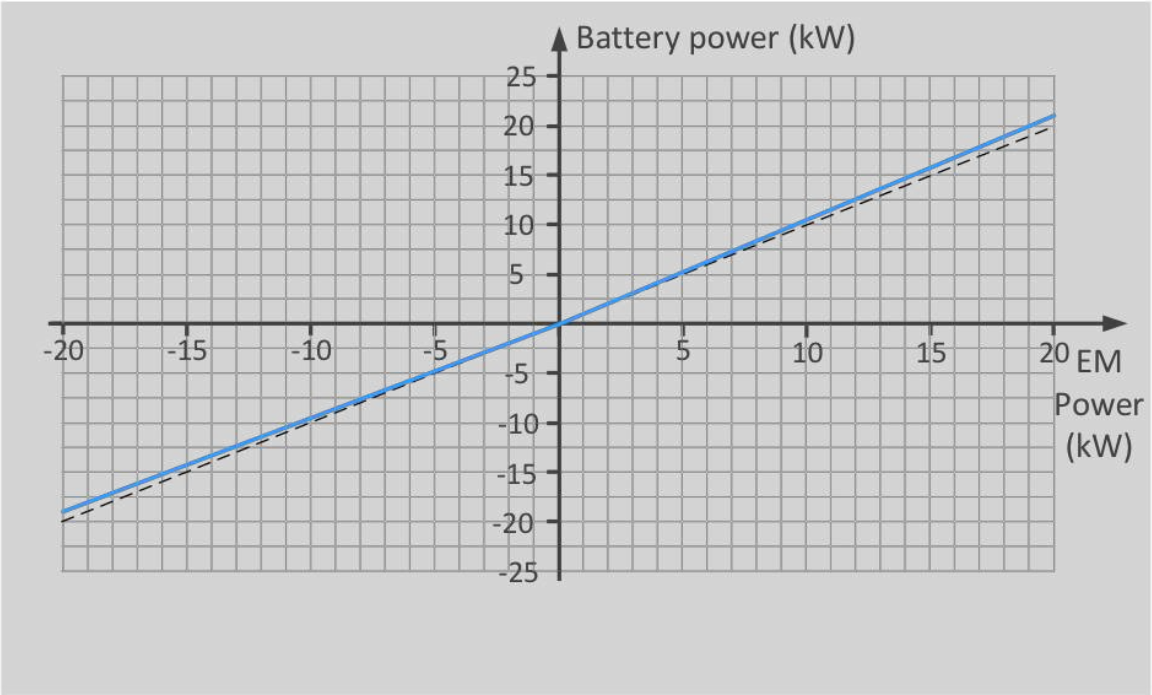
Select the three situations that are correct. [a,b,c,d,e,f,g,h,i,j]

- [ ] a
- [ ] b
- [ ] c
- [ ] d
- [ ] e
- [ ] f
- [ ] g
- [ ] h
- [ ] i
- [ ] j

FE.7. The fuel power as a function of engine power for an engine in a parallel hybrid is shown in the diagram below. In this exercise you are to analyse an ECMS control of this powertrain for one specific driving situation. The vehicle speed is 72 km/h and the traction force is 750 N. At this speed and when using the most fuel efficient gears, the lowest fuel consumption as a function of engine power follows the red line seen in the fuel power diagram.



The relation between shaft power and internal battery power for this EM, inverter and battery is shown in the diagram below, and it corresponds to an efficiency of 90% both when charging and discharging. The no-load losses of the EM and inverter are assumed to be zero.



FE.7a. What is the fuel power if the battery power is zero?

Enter your answer in the input field below, as an integer number.

kW

Still consider a vehicle speed of 72 km/h and a traction force of 750 N and calculate the *equivalent fuel consumption* when the engine operates in the operating points A-D in the fuel power diagram above. The price for battery energy is 3.0 fuel kW per battery kW.

Please note that, when answering the following questions, battery power shall be positive when discharging and negative when charging.

FE.7b. What is the battery power in operating point A?

Enter your answer in the input field below, with one correct decimal.

kW

FE.7c. What is the equivalent fuel consumption in point A?

Enter your answer in the input field below, with one correct decimal.

kW

FE.7d. What is the battery power in operating point B?

Enter your answer in the input field below, with one correct decimal.

kW

FE.7e. What is the equivalent fuel consumption in point B?

Enter your answer in the input field below, as an integer number.

kW

FE.7f. What is the battery power in operating point C?

Enter your answer in the input field below, with one correct decimal.

kW

FE.7g. What is the equivalent fuel consumption in point C?

Enter your answer in the input field below, with one correct decimal.

kW

FE.7h. What is the battery power in operating point D?

Enter your answer in the input field below, with one correct decimal.

kW

FE.7i. What is the equivalent fuel consumption in point D?

Enter your answer in the input field below, as an integer number.

kW

Assume that the ECMS only selects between the four operating points A-D.

FE.7j. Which one of operating points A to D will the ECMS controller select in this case?

Select the correct operating point in the drop-down-list.

Select an option