Power Electronics and Fuel Cell Assignment - 1

Tasks To Be Performed:

1. Draw the circuit diagram of Buck Converter, Boost Converter and Buck Boost Converter and compare between the construction of them

Ans:- Here are the circuit diagrams for a Buck Converter, Boost Converter, and Buck-Boost Converter, along with a comparison of their construction.

Buck Converter

A Buck Converter steps down the input voltage to a lower output voltage.

Circuit Diagram

```
Vin ----+---+---- L ---+----+---- Vout
        |   |          |    |
       SW   D          C    Rload
        |   |          |    |
       GND  |          |    GND
            |
           GND
```

- **Vin**: Input Voltage
- **L**: Inductor
- **SW**: Switch (typically a transistor)
- **D**: Diode
- **C**: Capacitor
- **Rload**: Load Resistor

Boost Converter

A Boost Converter steps up the input voltage to a higher output voltage.

Circuit Diagram

```
Vin ----+---- L ----+----+---- Vout
        |          SW    |
       GND          |    C
                    |    |
                    D   Rload
                    |    |
                   GND  GND
```

- **Vin**: Input Voltage
- **L**: Inductor
- **SW**: Switch (typically a transistor)
- **D**: Diode
- **C**: Capacitor
- **Rload**: Load Resistor

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Buck-Boost Converter

A Buck-Boost Converter can either step up or step down the input voltage, producing an output voltage that is either greater or less than the input voltage, and can also invert the polarity of the output.

Circuit Diagram

```
Vin ----+---- L ----+----+---- Vout (negative)
        |           SW   |
       GND          |    C
                    |    |
                    D   Rload
                    |    |
                   GND  GND
```

- **Vin**: Input Voltage
- **L**: Inductor
- **SW**: Switch (typically a transistor)
- **D**: Diode
- **C**: Capacitor
- **Rload**: Load Resistor

Comparison of Construction

1. **Buck Converter**:
    - **Purpose**: Steps down voltage.
    - **Components**: Inductor (L), switch (SW), diode (D), capacitor (C), and load resistor (Rload).
    - **Operation**: When the switch is on, the inductor charges and the output capacitor provides current to the load. When the switch is off, the inductor discharges through the diode and capacitor to the load.
2. **Boost Converter**:
    - **Purpose**: Steps up voltage.
    - **Components**: Inductor (L), switch (SW), diode (D), capacitor (C), and load resistor (Rload).
    - **Operation**: When the switch is on, the inductor charges. When the switch is off, the inductor discharges through the diode and into the capacitor, increasing the voltage to the load.
3. **Buck-Boost Converter**:
    - **Purpose**: Steps up or steps down and inverts voltage.
    - **Components**: Inductor (L), switch (SW), diode (D), capacitor (C), and load resistor (Rload).
    - **Operation**: When the switch is on, the inductor charges. When the switch is off, the inductor discharges through the diode to the capacitor and load, with the output voltage inverted in polarity compared to the input.

Differences Keypoints:

- **Buck Converter**: Used for stepping down voltage. Simple construction with one inductor and one diode.

- **Boost Converter**: Used for stepping up voltage. Similar construction but the inductor and switch placement differs.
- **Buck-Boost Converter**: Flexible for stepping up or down voltage and inverting polarity. Similar components but different topology, enabling more versatile voltage conversion.

These converters each use similar components but differ in their topologies to achieve their respective voltage transformations.

2. Determine the power density and the efficiencies of the fuel cell and plant at full load if the balance of the plant consumes 20% of the fuel cell output power (η_{bop} equals 80%).

Ans:- To determine the power density and the efficiencies of a fuel cell and plant at full load, we'll start with some basic definitions and calculations. We'll assume that the balance of plant (BoP) consumes 20% of the fuel cell's output power, which means the BoP efficiency (η_{bop}) is 80%.

Definitions

1. **Fuel Cell Efficiency (η_{fc})**: The ratio of the useful electrical power output to the chemical energy input from the fuel.
2. **Balance of Plant Efficiency (η_{bop})**: The ratio of the power available after the BoP consumption to the total power output of the fuel cell.
3. **Overall Plant Efficiency (η_{plant})**: The combined efficiency of the fuel cell and the BoP.
4. **Power Density**: The power output per unit volume or mass of the fuel cell.

Given

- η_{bop}=0.80 (BoP consumes 20% of the fuel cell output power)
- Let's denote the output power of the fuel cell by P_{fc}.
- The power consumed by the BoP is 0.20·Pfc .
- The useful power output of the plant (Pplant) is 0.80·P_{fc}

Calculations

Power Density

Power density is typically given in terms of power per unit volume or mass. Assuming we know the volume (V) or mass (M) of the fuel cell, the power density (D) can be calculated as:

$$D = \frac{Pfc}{V} \quad \text{or} \quad D = \frac{Pfc}{M}$$

Fuel Cell Efficiency (ηfc)

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Assuming we know the chemical energy input E$input$ to the fuel cell, the efficiency can be calculated as:

$$\eta fc = \frac{Pfc}{Einput}$$

Overall Plant Efficiency (ηplant)

The overall efficiency of the plant (ηplant) takes into account both the fuel cell efficiency and the BoP efficiency:

$$\eta plant = \eta fc \times \eta bop$$

$$Since\ \eta bop = 0.80:$$

$$\eta plant = \eta fc \times 0.80$$

Example Calculation

Let's use an example to illustrate the calculation. Suppose the fuel cell has an output power (Pfc) of 1000 W (1 kW) and the chemical energy input is 1200 W (1.2 kW). Let's also assume the volume of the fuel cell is 0.01 m^3 (10 liters).

1. Power Density

$D = \frac{Pfc}{V} = \frac{1000W}{0.01m3}$ =100,000 W/m^3

2. Fuel Cell Efficiency (ηfc)

$\eta fc = \frac{Pfc}{Einput} = \frac{1000W}{1200W}$=0.833 or 83.3%

3. Overall Plant Efficiency (ηplant)

$\eta plant = \eta fc \times \eta bop$ =0.833×0.80=0.666 or 66.6

Summary

1. **Power Density**: 100,000 W/m^3
2. **Fuel Cell Efficiency (η_{fc})**: 83.3%
3. **Overall Plant Efficiency (η_{plant})**: 66.6%

These calculations provide an understanding of the power density and efficiencies of a fuel cell and its associated plant at full load, considering the balance of plant consumption.

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3. The parameters of a fuel cell are provided in the table. For simplicity, the effects of temperature and pressure are ignored.

4. Determine: (i) the no-load voltage (ii) the full-load voltage at 15,000 A/m^2

Description	Parameter	Value	Units
Change in Gibbs free energy	ΔG°	-180 x 10^3	J/mole
Faraday's constant	F	96485	J/V-mol
Fuel cell area specific resistance	R_Ω	1.5 x 10^{-5}	Ωm^2
Activation loss coefficient	A	5 x 10^{-3}	V
Exchange current density	i_o	20	A/m2
Concentration loss coefficient	m	3 x 10^{-5}	V
Concentration loss exponent	n	0.5 x 10^{-3}	m^2/A
Cell thickness	t_{fc}	1.34	mm

Ans:- To determine the no-load voltage ($V_{no-load}$) and the full-load voltage ($V_{full-load}$) for the fuel cell given the parameters in the table, we will perform the calculations as follows:

Parameters Given

1. Change in Gibbs free energy (ΔG): -180,000 J/mole
2. Faraday's constant (F): 96,485 J/V-mole
3. Fuel cell area specific resistance (R_Ω): 1.5×10^{-5} $\Omega\cdot m^2$
4. Activation loss coefficient (A): 5×10^{-3} V
5. Exchange current density (i_o): 20 A/m^2
6. Concentration loss coefficient (m): 3×10^{-5} V
7. Concentration loss exponent (n): 0.5×10^{-3} m^2/A
8. Cell thickness (t_{fc}): 1.34 mm
9. Current density (J): 15,000 A/m^2

1. No-Load Voltage ($V_{no-load}$)

The no-load voltage is the open-circuit voltage (E_0), which can be calculated using the change in Gibbs free energy and Faraday's constant:

$$E0 = -\frac{\Delta \mathring{G}}{F}$$

$$E0 = -\frac{-180 \times 103}{96{,}485} \approx 1.866$$

2. Full-Load Voltage ($V_{full-load}$)

The full-load voltage is calculated by accounting for the activation loss, ohmic loss, and concentration loss. The formula is:

$V_{full-load}=E_0-\eta_{act}-\eta_{ohm}-\eta_{conc}$

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a. Activation Loss (η_{act})

Activation loss is calculated using the Tafel equation:

$$\eta_{act} = A \ln\left(\frac{J}{i_o}\right)$$

$$\eta_{act} = 5 \times 10^{-3} \ln\left(\frac{15,000}{20}\right)$$

$$\eta_{act} = 5 \times 10^{-3} \ln(750) \approx 5 \times 10^{-3} \times 6.620 \approx 0.0331\,\mathrm{V}$$

b. Ohmic Loss (η_{ohm})

Ohmic loss is determined by the area specific resistance and the current density:

$$\eta_{ohm} = J \cdot R_{\Omega}$$

$$\eta_{ohm} = 15,000 \times 1.5 \times 10^{-5} = 0.225\,\mathrm{V}$$

c. Concentration Loss (η_{conc})

Concentration loss can be modeled using the given coefficients:

$$\eta_{conc} = m \exp\left(n \cdot J\right)$$

$$\eta_{conc} = 3 \times 10^{-5} \exp\left(0.5 \times 10^{-3} \times 15,000\right)$$

$$\eta_{conc} = 3 \times 10^{-5} \exp(7.5) \approx 3 \times 10^{-5} \times 1,808 \approx 0.0542\,\mathrm{V}$$

Full-Load Voltage Calculation

Now, summing all the components:

$V_{full-load} = E_0 - \eta_{act} - \eta_{ohm} - \eta_{conc}$

$V_{full-load} = 1.866V - 0.0331V - 0.225V - 0.0542V$

$V_{full-load} \approx 1.5537\ V$

Summary

- **No-Load Voltage ($V_{no-load}$)**: 1.866 V
- **Full-Load Voltage ($V_{full-load}$)**: 1.5537 V