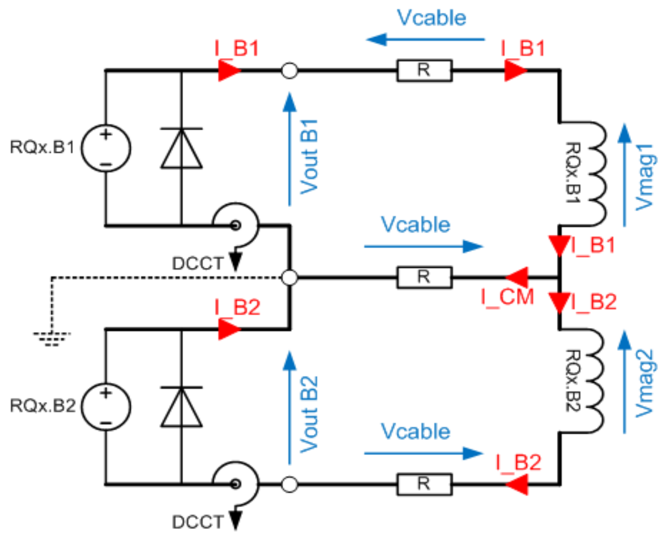
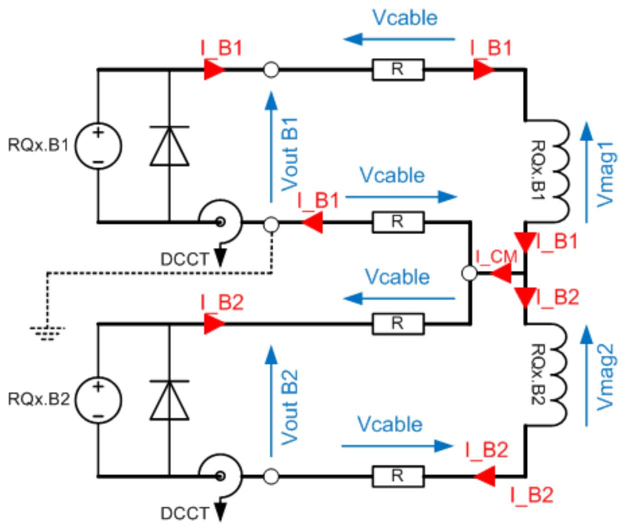
IPQ CIRCUIT POWERING USING 3 OR 4 CABLES

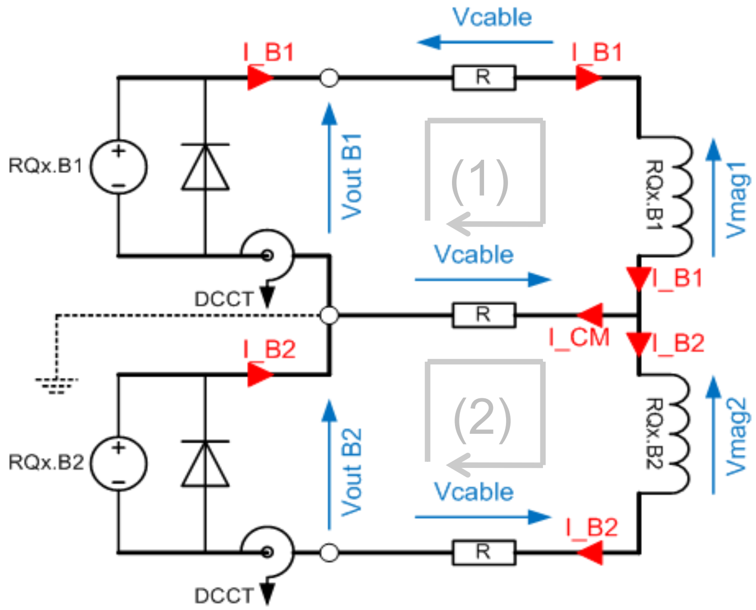
2012-03-29

3 CABLES



4 CABLES





IPQ Circuit Analyze [3 cables - 2012 configuration]

The resistance of all cables is assumed to be equal:

$$R_{Cable1} = R_{Cable2} = R_{Cable3} = R$$

The voltage of each converter determined by equations:

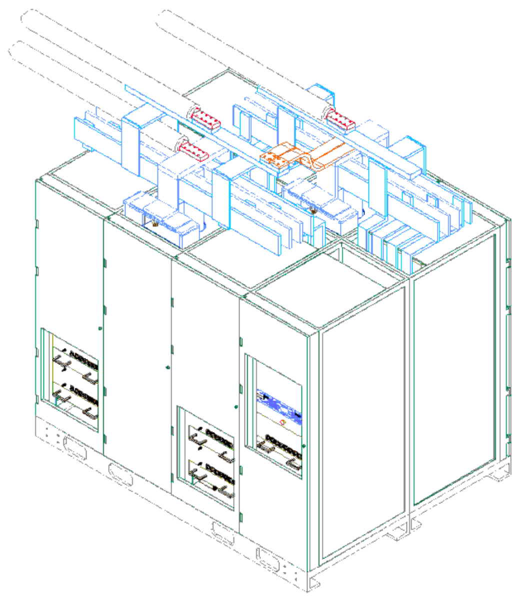
$$V_{outB1} = R \times (2 \times I_{B1} - I_{B2}) + \left(L_{B1} \times \frac{dI_{B1}}{dt}\right) \quad (1)$$

$$V_{outB2} = R \times (2 \times I_{B2} - I_{B1}) + \left(L_{B2} \times \frac{dI_{B2}}{dt}\right) \quad (2)$$

To maintain full control of both limited current & limited voltage 1-Quadrant converters, the following condition shall be verified:

$V_{outB1.MAX} > V_{outB1} > 0$ and $V_{outB2.MAX} > V_{outB2} > 0$

$I_{B1.MAX} > I_{B1} > I_{STBY}$ and $I_{B2.MAX} > I_{B2} > I_{STBY}$



Using (1) and (2), we found the following condition:

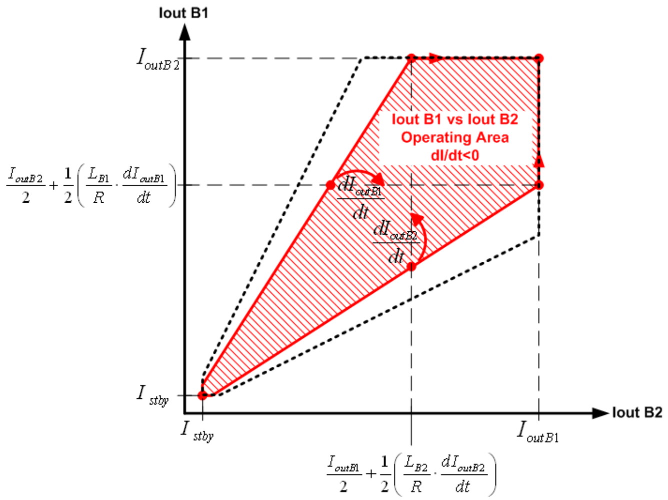
$2 \times I_{B2} + \frac{L_{B2}}{R} \cdot \frac{dI_{B2}}{dt} > I_{B1} > I_{STBY} \quad (3a)$ and $I_{B1.MAX} > I_{B1} \quad (3b)$

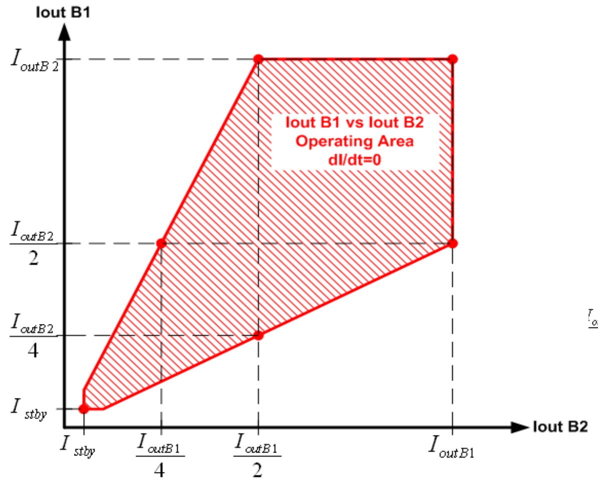
$2 \times I_{B1} + \frac{L_{B1}}{R} \cdot \frac{dI_{B1}}{dt} > I_{B2} > I_{STBY} \quad (4a)$ and $I_{B2.MAX} > I_{B2} \quad (3b)$

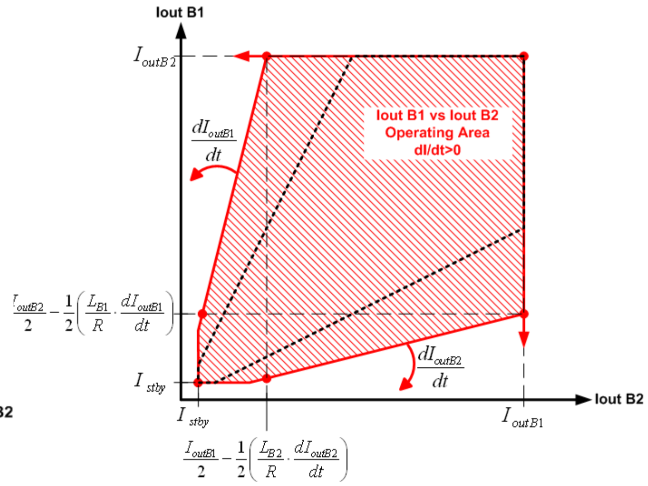
Operating area: IB1 Current versus IB2 Current

This following graph shown the operating area when :

$$\frac{dI}{dt} < 0 \qquad \frac{dI}{dt} = 0 \qquad \frac{dI}{dt} > 0$$







$$I_{B2} > \frac{I_{B1}}{2} + \frac{1}{2}\left(\frac{L_{B2}}{R}\cdot\frac{dI_{B2}}{dt}\right) > I_{STBY} \quad (3c)$$

$$I_{B1} > \frac{I_{B2}}{2} + \frac{1}{2}\left(\frac{L_{B1}}{R}\cdot\frac{dI_{B1}}{dt}\right) > I_{STBY} \quad (4c)$$

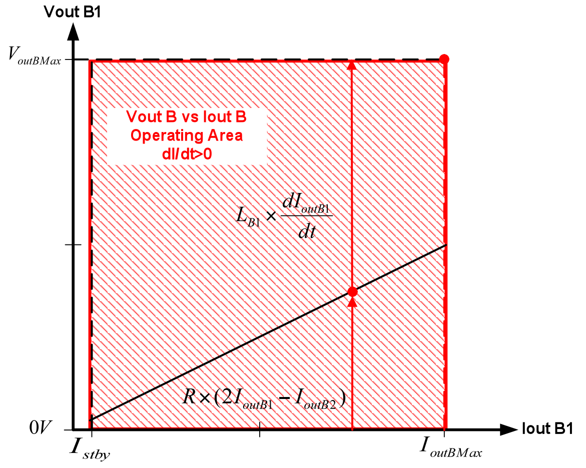
$$I_{B2} > \frac{I_{B1}}{2} > I_{STBY} \quad (3e)$$

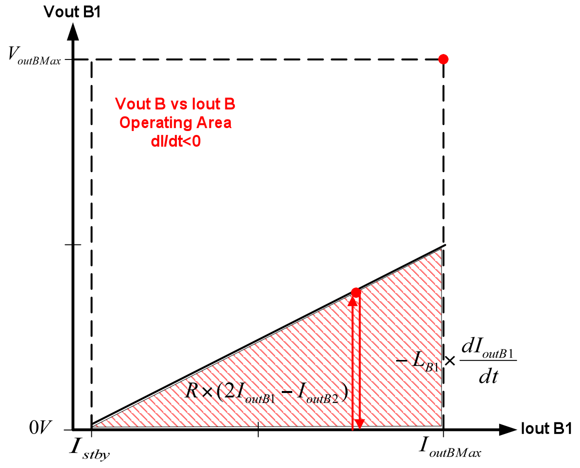
$$I_{B1} > \frac{I_{B2}}{2} > I_{STBY} \quad (4e)$$

$$I_{B2} > \frac{I_{B1}}{2} - \frac{1}{2}\left(\frac{L_{B2}}{R}\cdot\frac{dI_{B2}}{dt}\right) > I_{STBY} \quad (3d)$$

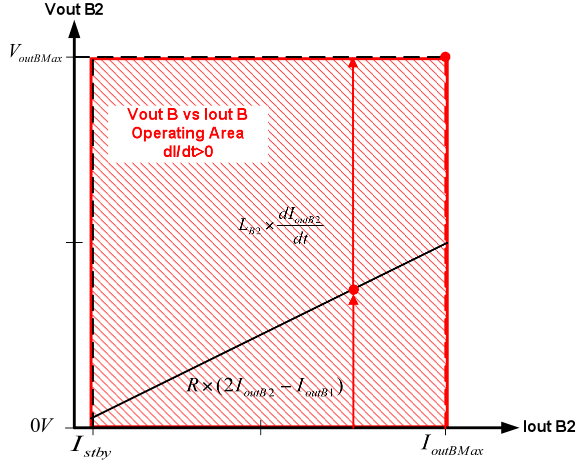
$$I_{B1} > \frac{I_{B2}}{2} - \frac{1}{2}\left(\frac{L_{B1}}{R}\cdot\frac{dI_{B1}}{dt}\right) > I_{STBY} \quad (4d)$$

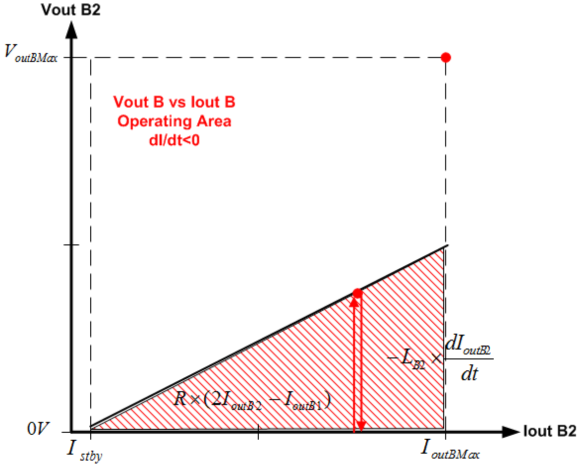
- <u>Operating area: IB Current versus Voltage</u>
- Iout B1 versus Vout B1





- Iout B2 versus Vout B2





IPQ Circuit Analyze [4 cables - Additonnal Cable in the return path]

The resistance of all cables is assumed to be equal:

$$R_{Cable1} = R_{Cable2} = R_{Cable3} = R_{Cable4} = R$$

The voltage of each converter determined by equations:

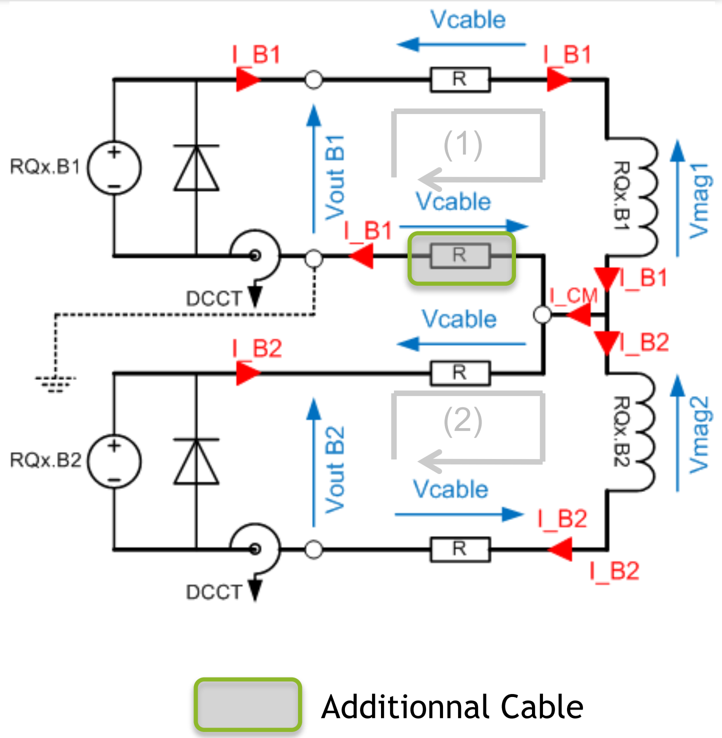
$$V_{outB1} = 2 \times R \times I_{B1} + \left(L_{B1} \times \frac{dI_{B1}}{dt} \right) \quad (1)$$

$$V_{outB2} = 2 \times R \times I_{B2} + \left(L_{B2} \times \frac{dI_{B2}}{dt} \right) \quad (2)$$

To maintain full control of both limited current & limited voltage 1-Quadrant converters, the following condition shall be verified:

$V_{outB1.MAX} > V_{outB1} > 0$ **and** $V_{outB2.MAX} > V_{outB2} > 0$

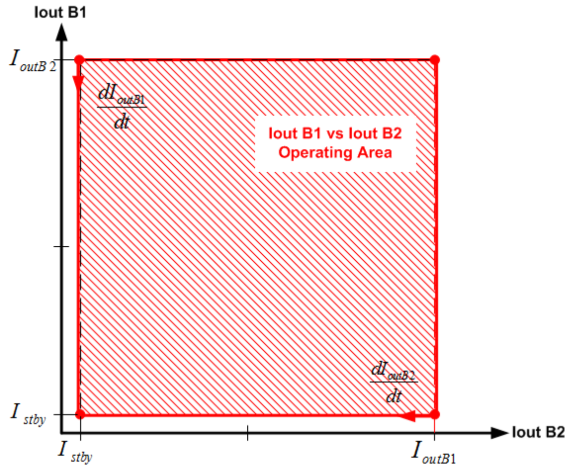
$I_{B1} > I_{STBY}$ **and** $I_{B2} > I_{STBY}$



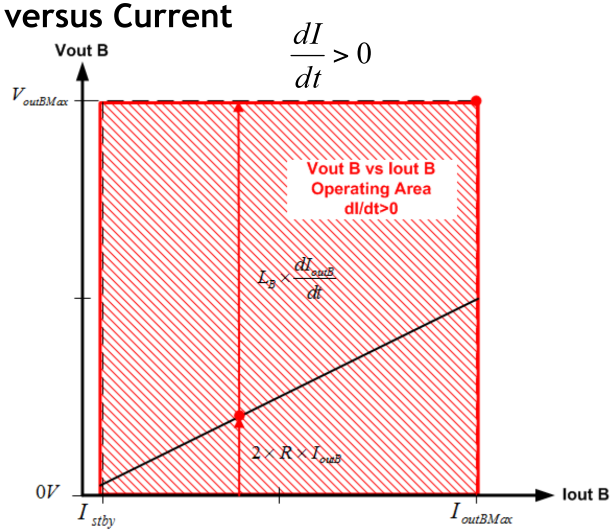
Operating area

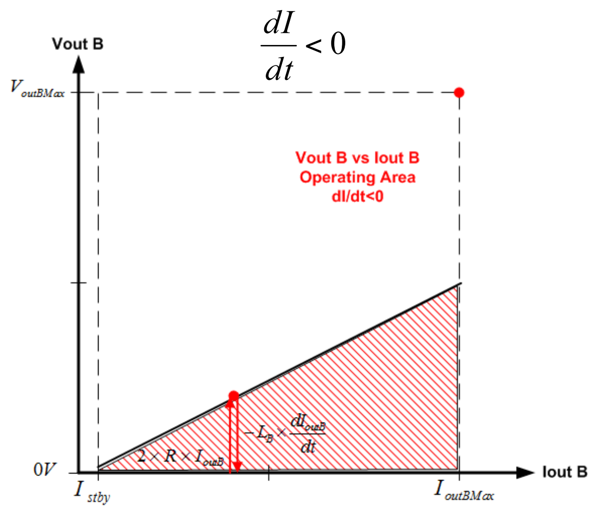
This following graph shown the operating area when :

IB1 Current versus IB2 Current

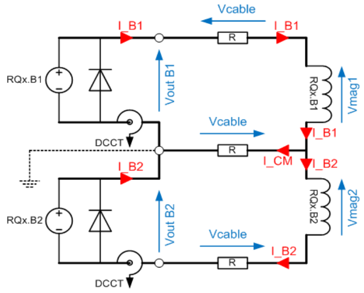


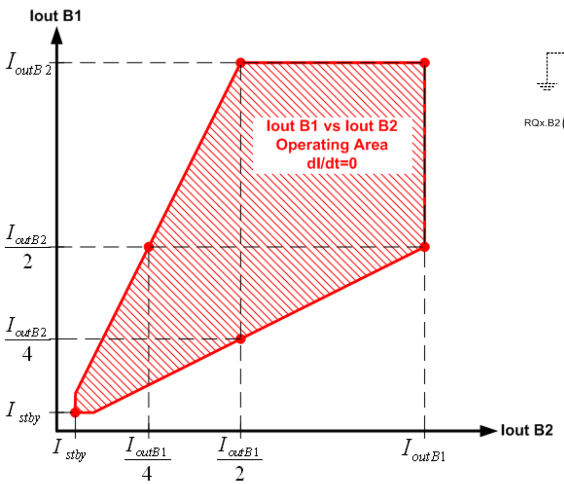
Voltage versus Current





3 CABLES





$$\frac{dI}{dt} = 0$$

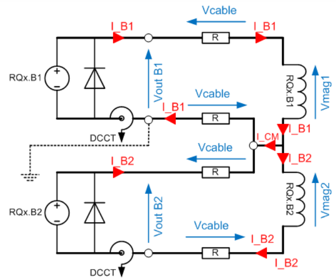
$$V_{outB1} = R \times \left(2 \times I_{B1} - I_{B2}\right) \quad (1)$$

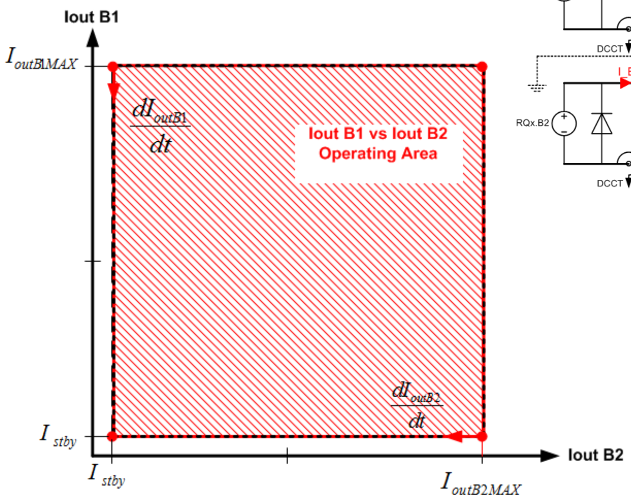
$$V_{outB2} = R \times \left(2 \times I_{B2} - I_{B1}\right) \quad (2)$$

$$I_{B1} > \frac{I_{B2}}{2} > I_{Stby}$$

$$I_{B2} > \frac{I_{B1}}{2} > I_{Stby}$$

4 CABLES





$$V'_{outB1} = 2 \times R \times I_{B1} \quad (1)$$

$$V'_{outB2} = 2 \times R \times I_{B2} \quad (2)$$

$$I_{B1} > I_{Stby}$$

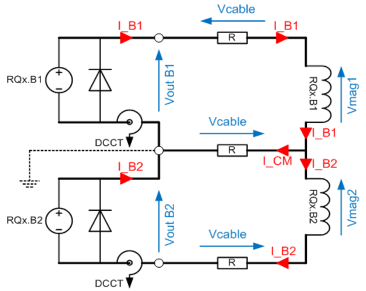
$$I_{B2} > I_{Stby}$$

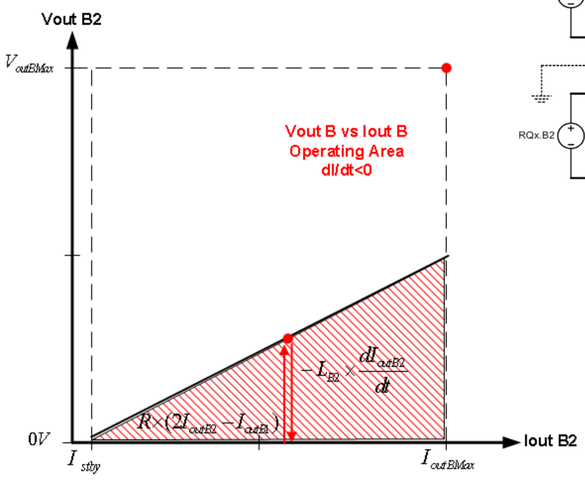
Need more voltage at the output of the converters with 4 cables at same currents

$$V'_{outB1} - V_{outB1} = R \times I_{B2}$$

$$V'_{outB2} - V_{outB2} = R \times I_{B1}$$

3 CABLES

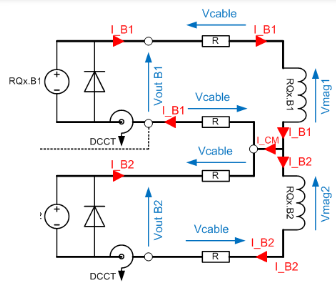


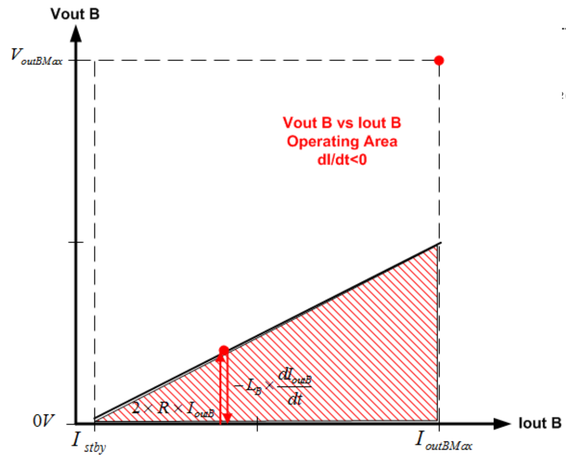


$$L_{B1}\times\frac{dI_{B1}}{dt}=V_{outB1}-R\times\left(2\times I_{B1}-I_{B2}\right)\quad(1)$$

$$L_{B2}\times\frac{dI_{B2}}{dt}=V_{outB2}-R\times\left(2\times I_{B2}-I_{B1}\right)\quad(2)$$

4 CABLES





$$L_{B1}\times\frac{dI_{B1}}{dt}=V_{outB1}-2\times R\times I_{B1}\quad(1)$$

$$L_{B2}\times\frac{dI_{B2}}{dt}=V_{outB2}-2\times R\times I_{B2}\quad(2)$$

DIDT > 0 $\frac{dI_B}{dt}$ **with 4 cables** $<$ $\frac{dI_B}{dt}$ **with 3 cables at same currents**

DIDT < 0 $\left|\frac{dI_B}{dt}\right|$ **with 4 cables** $>$ $\left|\frac{dI_B}{dt}\right|$ **with 3 cables at same currents**

<u>CONCLUSIONS:</u> IPQ with 4 cables versus IPQ with 3 cables

1. No more limitations between I_{B1} and I_{B2}

2. Nevertheless due to the converter topology, the following conditions shall be still verified:

$$I_{MAX} > I_B > I_{Stby} \quad \text{with} \quad I_{Stby} = 3\% \times I_{MAX}$$

$$V_{outMAX} > V_{outB} > 0V$$ which limits the DIDT during ramp-down

3. The output voltage of the converter will be 2 times higher at $I_{B1} = I_{B2} = I_{MAX}$

4. During ramp-up, $\left|\frac{dI_B}{dt}\right|$ with 4 cables < $\left|\frac{dI_B}{dt}\right|$ with 3 cables

5. During ramp-down, $\left|\frac{dI_B}{dt}\right|$ with 4 cables > $\left|\frac{dI_B}{dt}\right|$ with 3 cables

6. The power consumption will be 2 times higher at $I_{B1} = I_{B2} = I_{MAX}$ with 4 cables

7. The water flow needed for the cooling of the cables will be 2 times higher at $I_{B1} = I_{B2} = I_{MAX}$