Appendix A. Methodology and Detailed Calculations

A.1. Methodology

$\overrightarrow{dB_1}$ from Infinitesimal dx_1 Is perpendicular to plane of L_1 and M(x,y,z) Choosing M on the y0z plane Is not disturbing the generality of the problem

Biot-Savart Law states:

$$\overrightarrow{dB_1} = \blacksquare \cdot \frac{\mu \cdot I \cdot \overrightarrow{dr} \times \vec{r}}{4 \cdot \pi \cdot r^3}$$

L//x axis

$$dB_1 := \frac{\mu \cdot I \cdot dx \cdot \sin\theta}{4 \cdot \pi \cdot r^2} \qquad (1)$$

$$r := \sqrt{x^2 + r_1^2} \qquad (2)$$

$$\sin\theta := \sin(\theta - \pi) = \blacksquare \cdot \frac{r_1}{r} = \blacksquare \cdot \frac{r_1}{\sqrt{x^2 + r_1^2}} \qquad (3)$$

(1),(2),(3)

$$dB_1 := \frac{\mu \cdot I \cdot \frac{r_1}{\sqrt{x^2 + r_1^2}}}{4 \cdot \pi \cdot \left(x^2 + r_1^2\right)} \cdot dx$$

$$dB_1 := \frac{\mu \cdot I \cdot r_1}{4 \cdot \pi \cdot \left(x^2 + r_1^2\right)^{\frac{3}{2}}} \cdot dx$$

$$B_1 := \int_{x_1}^{x_2} \frac{\mu \cdot I \cdot r_1}{4 \cdot \pi \cdot \left(x^2 + r_1^2\right)^{\frac{3}{2}}} \, dx$$

$$B_1 := \frac{(\mu \cdot I \cdot r_1)}{4\pi} \cdot \left[\int_{x_1}^{x_2} \frac{1}{\left(x^2 + r_1^2\right)^{\frac{3}{2}}} \, dx \right]$$

$$B_1 := \frac{(\mu \cdot I \cdot r_1)}{(4\pi)} \cdot \left(\frac{x}{r_1^2 \cdot \sqrt{x^2 + r_1^2}} \right) \Bigg|_{x_1}^{x_2}$$

$$B_1 := \frac{(\mu \cdot I \cdot r_1)}{(4\pi)} \cdot \left(\frac{x_2}{r_1^2 \cdot \sqrt{x_2^2 + r_1^2}} - \frac{x_1}{r_1^2 \cdot \sqrt{x_{.1}^2 + r_1^2}} \right)$$

$$B_1 := \frac{(\mu \cdot I)}{(4\pi \cdot r_1)} \cdot \left(\frac{x_2}{\sqrt{x_2^2 + r_1^2}} - \frac{x_1}{\sqrt{x_{.1}^2 + r_1^2}} \right) \quad \text{or} \qquad B_1 := \frac{(\mu \cdot I)}{(4\pi \cdot r_1)} \cdot \left(\cos\theta_2 - \cos\theta_1\right)$$

$$r_1 := \sqrt{y_1^2 + z_1^2} \qquad z_1 := z - z_0$$

$$B_1 := \frac{(\mu \cdot I)}{\left(4\pi \cdot \sqrt{y_1^2 + z_1^2}\right)} \cdot \left[\frac{x_2}{\sqrt{x_2^2 + \left(y_1^2 + z_1^2\right)}} - \frac{x_1}{\sqrt{x_{.1}^2 + \left(y_1^2 + z_1^2\right)}} \right]$$

$$B_{1z} := B_1 \cdot \cos(\phi) \qquad \cos(\varphi) = \blacksquare \cdot \frac{y_1}{r_1} = \blacksquare \cdot \frac{y_1}{\sqrt{y_1^2 + z_1^2}}$$

$$B_{1y} := B_1 \cdot \sin(\varphi) \qquad \sin(\varphi) = \blacksquare \cdot \frac{z_1}{r_1} = \blacksquare \cdot \frac{z_1}{\sqrt{y_1^2 + z_1^2}}$$

Similar for B_2, B_3, B_4, B_5, B_6, B_7, B_8, B_9….

But B_{4y}, B_{5y}, B_{6y} rotated relative to B_{1y} by angle θ_1 and B_{7y}, B_{8y}, B_{9y}…. by angle θ_2
Consequently must be referred to B_{1y} xyz axis so they must be analysed to their relative y and x components in order perform the vector addition

The equations calculate the magnitude of the relative magnetic fields. The directions of the vectors **are defined by the right hand rule**. It must be noted that the B vectors are perpendicular to the plane of the conductor and the point of interest. The current flow through the cross bonds is considered negligible and not taken into account. The relative distances and dimensions are featured on the following 3-D drawing.

$$\overrightarrow{B_{totz}} = \overrightarrow{B_{1z}} + \overrightarrow{B_{2z}} + \overrightarrow{B_{3z}} + \overrightarrow{B_{4z}} + \overrightarrow{B_{5z}} + \overrightarrow{B_{6z}} + \overrightarrow{B_{7z}} + \overrightarrow{B_{8z}} + \overrightarrow{B_{9z}} + \ldots\ldots$$

$$\overrightarrow{B_{toty}} = \overrightarrow{B_{1y}} + \overrightarrow{B_{2y}} + \overrightarrow{B_{3y}} + \overrightarrow{B_{4yy}} + \overrightarrow{B_{5yy}} + \overrightarrow{B_{6yy}} + \overrightarrow{B_{7yy}} + \overrightarrow{B_{8yy}} + \overrightarrow{B_{9yy}} + \ldots..$$

$$\overrightarrow{B_{totx}} = \overrightarrow{B_{4yx}} + \overrightarrow{B_{5yx}} + \overrightarrow{B_{6yx}} + \overrightarrow{B_{7yx}} + \overrightarrow{B_{8yx}} + \overrightarrow{B_{9yx}} + \ldots\ldots$$

$$\left|B_{tot}\right| := \sqrt{\left|B_{totz}\right|^2 + \left|B_{toty}\right|^2 + \left|B_{totx}\right|^2}$$

A.2. Indicative 3-D Model

The system is modelled as three sets of continuous straight conductors with their relative rotations. Although this is not the exact system configuration it can very accurately calculate the associated magnetic fields while reducing the complexity of the calculations. The following drawing demonstrates a scaled part of the system showing the direction of the field produce by one conductor and how the associated distances are measured.

A.3. Normal Operation

Case 1: Resulting magnetic field from standard infrastructure layout at the most sensitive point of the building. (21min 57 sec of simulation, Normal operation train at chainage 50, regenerating)

$$I_1 := 959 \qquad I_2 := \frac{959}{2} \qquad I_3 := \frac{959}{2} \qquad \Delta_d := 1.435$$

$h := 5$

$\mu := 4\pi \cdot 10^{-7}$

$$\frac{\Delta_d}{2} = 7.175 \times 10^{-1}$$

$x_a := 100 \qquad x_b := 150$

$$y_1 := 105 \qquad y_2 := y_1 - \frac{\Delta_d}{2} \qquad y_2 = 1.043 \times 10^2 \qquad y_3 := y_1 + \frac{\Delta_d}{2} \qquad y_3 = 1.057 \times 10^2$$

$z_1 := 4 \qquad z_2 := 1 \qquad z_3 := 1$

$$B_{1z} := \left[\frac{\mu \cdot I_1 \cdot y_1}{4 \cdot \pi \cdot \left(y_1^2 + z_1^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_1^2 + z_1^2 + x_b^2}} - \frac{x_a}{\sqrt{y_1^2 + z_1^2 + x_a^2}}\right) \qquad B_{1z} = 1.182 \times 10^{-7}$$

$$B_{1y} := \left[\frac{\mu \cdot I_1 \cdot z_1}{4 \cdot \pi \cdot \left(y_1^2 + z_1^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_1^2 + z_1^2 + x_b^2}} - \frac{x_a}{\sqrt{y_1^2 + z_1^2 + x_a^2}}\right) \qquad B_{1y} = 4.504 \times 10^{-9}$$

$$B_{2z} := \left[\frac{\mu \cdot I_2 \cdot y_2}{4 \cdot \pi \cdot \left(y_2^2 + z_2^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_2^2 + z_2^2 + x_b^2}} - \frac{x_a}{\sqrt{y_2^2 + z_2^2 + x_a^2}}\right) \qquad B_{2z} = 5.928 \times 10^{-8}$$

$$B_{2y} := \left[\frac{\mu \cdot I_2 \cdot z_2}{4 \cdot \pi \cdot \left(y_2^2 + z_2^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_2^2 + z_2^2 + x_b^2}} - \frac{x_a}{\sqrt{y_2^2 + z_2^2 + x_a^2}}\right) \qquad B_{2y} = 5.685 \times 10^{-10}$$

$$B_{3z} := \left[\frac{\mu \cdot I_3 \cdot y_3}{4 \cdot \pi \cdot \left(y_3^2 + z_3^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_3^2 + z_3^2 + x_b^2}} - \frac{x_a}{\sqrt{y_3^2 + z_3^2 + x_a^2}}\right) \qquad B_{3z} = 5.905 \times 10^{-8}$$

$$B_{3y} := \left[\frac{\mu \cdot I_3 \cdot z_3}{4 \cdot \pi \cdot \left(y_3^2 + z_3^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_3^2 + z_3^2 + x_b^2}} - \frac{x_a}{\sqrt{y_3^2 + z_3^2 + x_a^2}}\right) \qquad B_{3y} = 5.586 \times 10^{-10}$$

$I_4 := 959$ $\quad I_5 := \frac{959}{2}$ $\quad I_6 := \frac{959}{2}$

$x_c := 75$ $\quad x_d := 175$

$y_4 := 158$ $\quad y_5 := y_4 - \frac{\Delta_d}{2}$ $\quad y_5 = 1.573\times 10^2$ $\quad y_6 := y_4 + \frac{\Delta_d}{2}$ $\quad y_6 = 1.587\times 10^2$

$z_4 := 4$ $\quad z_5 := 1$ $\quad z_6 := 1$

$$B_{4z} := \left[\frac{\mu\cdot I_4\cdot y_4}{4\cdot\pi\cdot\left(y_4^2 + z_4^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_4^2 + z_4^2 + x_d^2}} - \frac{x_c}{\sqrt{y_4^2 + z_4^2 + x_c^2}}\right) \qquad B_{4z} = 1.901\times 10^{-7}$$

$$B_{4y} := \left[\frac{\mu\cdot I_4\cdot z_4}{4\cdot\pi\cdot\left(y_4^2 + z_4^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_4^2 + z_4^2 + x_d^2}} - \frac{x_c}{\sqrt{y_4^2 + z_4^2 + x_c^2}}\right) \qquad B_{4y} = 4.813\times 10^{-9}$$

$$B_{5z} := \left[\frac{\mu\cdot I_5\cdot y_5}{4\cdot\pi\cdot\left(y_5^2 + z_5^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_5^2 + z_5^2 + x_d^2}} - \frac{x_c}{\sqrt{y_5^2 + z_5^2 + x_c^2}}\right) \qquad B_{5z} = 9.552\times 10^{-8}$$

$$B_{5y} := \left[\frac{\mu\cdot I_5\cdot z_5}{4\cdot\pi\cdot\left(y_5^2 + z_5^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_5^2 + z_5^2 + x_d^2}} - \frac{x_c}{\sqrt{y_5^2 + z_5^2 + x_c^2}}\right) \qquad B_{5y} = 6.073\times 10^{-10}$$

$$B_{6z} := \left[\frac{\mu\cdot I_6\cdot y_6}{4\cdot\pi\cdot\left(y_6^2 + z_6^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_6^2 + z_6^2 + x_d^2}} - \frac{x_c}{\sqrt{y_6^2 + z_6^2 + x_c^2}}\right) \qquad B_{6z} = 9.47\times 10^{-8}$$

$$B_{6y} := \left[\frac{\mu\cdot I_6\cdot z_6}{4\cdot\pi\cdot\left(y_6^2 + z_6^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_6^2 + z_6^2 + x_d^2}} - \frac{x_c}{\sqrt{y_6^2 + z_6^2 + x_c^2}}\right) \qquad B_{6y} = 5.967\times 10^{-10}$$

$I_7 := 461$ $\quad I_8 := \frac{479}{2}$ $\quad I_9 := \frac{479}{2}$

$x_e := -12.5$ $\quad x_f := 1670$

$y_7 := 242$ $\quad y_8 := y_7 - \frac{\Delta_d}{2}$ $\quad y_8 = 2.413\times 10^2$ $\quad y_9 := y_7 + \frac{\Delta_d}{2}$ $\quad y_9 = 2.427\times 10^2$

$z_7 := 4$ $\quad z_8 := 1$ $\quad z_9 := 1$

$$B_{7z} := \left[\frac{\mu\cdot I_7\cdot y_7}{4\cdot\pi\cdot\left(y_7^2 + z_7^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_7^2 + z_7^2 + x_f^2}} - \frac{x_e}{\sqrt{y_7^2 + z_7^2 + x_e^2}}\right) \qquad B_{7z} = 1.983\times 10^{-7}$$

$$B_{7y} := \left[\frac{\mu\cdot I_7\cdot z_7}{4\cdot\pi\cdot\left(y_7^2 + z_7^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_7^2 + z_7^2 + x_f^2}} - \frac{x_e}{\sqrt{y_7^2 + z_7^2 + x_e^2}}\right) \qquad B_{7y} = 3.278\times 10^{-9}$$

$$B_{8z} := \left[\frac{\mu\cdot I_8\cdot y_8}{4\cdot\pi\cdot\left(y_8^2 + z_8^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_8^2 + z_8^2 + x_f^2}} - \frac{x_e}{\sqrt{y_8^2 + z_8^2 + x_e^2}}\right) \qquad B_{8z} = 1.034\times 10^{-7}$$

$$B_{8y} := \left[\frac{\mu\cdot I_8\cdot z_8}{4\cdot\pi\cdot\left(y_8^2 + z_8^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_8^2 + z_8^2 + x_f^2}} - \frac{x_e}{\sqrt{y_8^2 + z_8^2 + x_e^2}}\right) \qquad B_{8y} = 4.284\times 10^{-10}$$

$$B_{9z} := \left[\frac{\mu\cdot I_9\cdot y_9}{4\cdot\pi\cdot\left(y_9^2 + z_9^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_9^2 + z_9^2 + x_f^2}} - \frac{x_e}{\sqrt{y_9^2 + z_9^2 + x_e^2}}\right) \qquad B_{9z} = 1.027\times 10^{-7}$$

$$B_{9y} := \left[\frac{\mu\cdot I_9\cdot z_9}{4\cdot\pi\cdot\left(y_9^2 + z_9^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_9^2 + z_9^2 + x_f^2}} - \frac{x_e}{\sqrt{y_9^2 + z_9^2 + x_e^2}}\right) \qquad B_{9y} = 4.232\times 10^{-10}$$

$I_{10} := 497 \qquad I_{11} := \frac{479}{2} \qquad I_{12} := \frac{479}{2}$

$x_e := -12.5 \qquad x_f := 1670$

$y_{10} := y_7 + 2 \qquad y_{11} := y_8 + 2 \qquad y_{12} := y_9 + 2$

$z_{10} := 4 \qquad z_{11} := 1 \qquad z_{12} := 1$

$$B_{10z} := \left[\frac{\mu \cdot I_{10} \cdot y_{10}}{4 \cdot \pi \cdot \left(y_{10}^{2} + z_{10}^{2}\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{10}^{2} + z_{10}^{2} + x_f^{2}}} - \frac{x_e}{\sqrt{y_{10}^{2} + z_{10}^{2} + x_e^{2}}}\right) \qquad B_{10z} = 2.119 \times 10^{-7}$$

$$B_{10y} := \left[\frac{\mu \cdot I_{10} \cdot z_{10}}{4 \cdot \pi \cdot \left(y_{10}^{2} + z_{10}^{2}\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{10}^{2} + z_{10}^{2} + x_f^{2}}} - \frac{x_e}{\sqrt{y_{10}^{2} + z_{10}^{2} + x_e^{2}}}\right) \qquad B_{10y} = 3.474 \times 10^{-9}$$

$$B_{11z} := \left[\frac{\mu \cdot I_{11} \cdot y_{11}}{4 \cdot \pi \cdot \left(y_{11}^{2} + z_{11}^{2}\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{11}^{2} + z_{11}^{2} + x_f^{2}}} - \frac{x_e}{\sqrt{y_{11}^{2} + z_{11}^{2} + x_e^{2}}}\right) \qquad B_{11z} = 1.025 \times 10^{-7}$$

$$B_{11y} := \left[\frac{\mu \cdot I_{11} \cdot z_{11}}{4 \cdot \pi \cdot \left(y_{11}^{2} + z_{11}^{2}\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{11}^{2} + z_{11}^{2} + x_f^{2}}} - \frac{x_e}{\sqrt{y_{11}^{2} + z_{11}^{2} + x_e^{2}}}\right) \qquad B_{11y} = 4.212 \times 10^{-10}$$

$$B_{12z} := \left[\frac{\mu \cdot I_{12} \cdot y_{12}}{4 \cdot \pi \cdot \left(y_{12}^{2} + z_{12}^{2}\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{12}^{2} + z_{12}^{2} + x_f^{2}}} - \frac{x_e}{\sqrt{y_{12}^{2} + z_{12}^{2} + x_e^{2}}}\right) \qquad B_{12z} = 1.018 \times 10^{-7}$$

$$B_{12y} := \left[\frac{\mu \cdot I_{12} \cdot z_{12}}{4 \cdot \pi \cdot \left(y_{12}^{2} + z_{12}^{2}\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{12}^{2} + z_{12}^{2} + x_f^{2}}} - \frac{x_e}{\sqrt{y_{12}^{2} + z_{12}^{2} + x_e^{2}}}\right) \qquad B_{12y} = 4.161 \times 10^{-10}$$

$B_{totz} := B_{1z} + B_{4z} + B_{7z} + B_{10z} - B_{2z} - B_{3z} - B_{5z} - B_{6z} - B_{8z} - B_{9z} - B_{11z} - B_{12z}$

$B_{totz} = -3.928\times 10^{-10}$

Refer to a common xyz axis, first conductor as a reference

$\theta_1 := \frac{\pi}{6}$ $\qquad$ $\theta_2 := 0.44\cdot\pi$

$B_{4yy} := B_{4y}\cdot\cos(\theta_1)$ $\qquad$ $B_{4yy} = 4.168\times 10^{-9}$

$B_{5yy} := B_{5y}\cdot\cos(\theta_1)$ $\qquad$ $B_{5yy} = 5.26\times 10^{-10}$

$B_{6yy} := B_{6y}\cdot\cos(\theta_1)$ $\qquad$ $B_{6yy} = 5.167\times 10^{-10}$

$B_{7yy} := B_{7y}\cdot\cos(\theta_2)$ $\qquad$ $B_{7yy} = 6.142\times 10^{-10}$

$B_{8yy} := B_{8y}\cdot\cos(\theta_2)$ $\qquad$ $B_{8yy} = 8.028\times 10^{-11}$

$B_{9yy} := B_{9y}\cdot\cos(\theta_2)$ $\qquad$ $B_{9yy} = 7.93\times 10^{-11}$

$B_{10yy} := B_{10y}\cdot\cos(\theta_2)$ $\qquad$ $B_{10yy} = 6.51\times 10^{-10}$

$B_{11yy} := B_{11y}\cdot\cos(\theta_2)$ $\qquad$ $B_{11yy} = 7.892\times 10^{-11}$

$B_{12yy} := B_{12y}\cdot\cos(\theta_2)$ $\qquad$ $B_{12yy} = 7.797\times 10^{-11}$

$B_{4yx} := B_{4y}\cdot\sin(\theta_1)$ $\qquad$ $B_{4yx} = 2.406\times 10^{-9}$

$B_{5yx} := B_{5y}\cdot\sin(\theta_1)$ $\qquad$ $B_{5yx} = 3.037\times 10^{-10}$

$B_{6yx} := B_{6y}\cdot\sin(\theta_1)$ $\qquad$ $B_{6yx} = 2.983\times 10^{-10}$

$B_{7yx} := B_{7y}\cdot\sin(\theta_2)$ $\qquad$ $B_{7yx} = 3.22\times 10^{-9}$

$B_{8yx} := B_{8y}\cdot\sin(\theta_2)$ $\qquad$ $B_{8yx} = 4.209\times 10^{-10}$

$B_{9yx} := B_{9y}\cdot\sin(\theta_2)$ $\qquad$ $B_{9yx} = 4.157\times 10^{-10}$

$B_{10yx} := B_{10y}\cdot\sin(\theta_2)$ $\qquad$ $B_{10yx} = 3.412\times 10^{-9}$

$B_{11yx} := B_{11y}\cdot\sin(\theta_2)$ $\qquad$ $B_{11yx} = 4.137\times 10^{-10}$

$B_{12yx} := B_{12y}\cdot\sin(\theta_2)$ $\qquad$ $B_{12yx} = 4.087\times 10^{-10}$

$$B_{toty} := B_{1y} + B_{2y} + B_{3y} + B_{4yy} + B_{5yy} + B_{6yy} + B_{7yy} + B_{8yy} + B_{9yy} + B_{10yy} + B_{11yy} + B_{12yy}$$

$$B_{toty} = 1.242 \times 10^{-8}$$

$$B_{totx} := B_{4yx} + B_{5yx} + B_{6yx} + B_{7yx} + B_{8yx} + B_{9yx} + B_{10yx} + B_{11yx} + B_{12yx}$$

$$B_{totx} = 1.13 \times 10^{-8}$$

$$B_{tot} := \sqrt{B_{totz}^{2} + B_{toty}^{2} + B_{totx}^{2}}$$

$$B_{tot} = 1.68 \times 10^{-8}$$

B.tot=17 nT

A.4. Outage at 1 Substation

Case 2: Resulting magnetic field from standard infrastructure layout at the most sensitive point of the building. (46min 7sec of simulation, train motoring, westbound at chainage 60, Substation 1 out)

$I_1 := 1083 \qquad I_2 := \frac{1083}{2} \qquad I_3 := \frac{1083}{2} \qquad \Delta_d := 1.435$

$h := 5$

$\mu := 4\pi \cdot 10^{-7} \qquad \frac{\Delta_d}{2} = 7.175 \times 10^{-1}$

$x_a := 106 \qquad x_b := 150$

$y_1 := 105 \qquad y_2 := y_1 - \frac{\Delta_d}{2} \qquad y_2 = 1.043 \times 10^2 \qquad y_3 := y_1 + \frac{\Delta_d}{2} \qquad y_3 = 1.057 \times 10^2$

$z_1 := 4 \qquad z_2 := 1 \qquad z_3 := 1$

$$B_{1z} := \left[\frac{\mu \cdot I_1 \cdot y_1}{4 \cdot \pi \cdot \left(y_1^2 + z_1^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_1^2 + z_1^2 + x_b^2}} - \frac{x_a}{\sqrt{y_1^2 + z_1^2 + x_a^2}}\right) \qquad B_{1z} = 1.121 \times 10^{-7}$$

$$B_{1y} := \left[\frac{\mu \cdot I_1 \cdot z_1}{4 \cdot \pi \cdot \left(y_1^2 + z_1^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_1^2 + z_1^2 + x_b^2}} - \frac{x_a}{\sqrt{y_1^2 + z_1^2 + x_a^2}}\right) \qquad B_{1y} = 4.27 \times 10^{-9}$$

$$B_{2z} := \left[\frac{\mu \cdot I_2 \cdot y_2}{4 \cdot \pi \cdot \left(y_2^2 + z_2^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_2^2 + z_2^2 + x_b^2}} - \frac{x_a}{\sqrt{y_2^2 + z_2^2 + x_a^2}}\right) \qquad B_{2z} = 5.619 \times 10^{-8}$$

$$B_{2y} := \left[\frac{\mu \cdot I_2 \cdot z_2}{4 \cdot \pi \cdot \left(y_2^2 + z_2^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_2^2 + z_2^2 + x_b^2}} - \frac{x_a}{\sqrt{y_2^2 + z_2^2 + x_a^2}}\right) \qquad B_{2y} = 5.388 \times 10^{-10}$$

$$B_{3z} := \left[\frac{\mu \cdot I_3 \cdot y_3}{4 \cdot \pi \cdot \left(y_3^2 + z_3^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_3^2 + z_3^2 + x_b^2}} - \frac{x_a}{\sqrt{y_3^2 + z_3^2 + x_a^2}}\right) \qquad B_{3z} = 5.6 \times 10^{-8}$$

$$B_{3y} := \left[\frac{\mu \cdot I_3 \cdot z_3}{4 \cdot \pi \cdot \left(y_3^2 + z_3^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_3^2 + z_3^2 + x_b^2}} - \frac{x_a}{\sqrt{y_3^2 + z_3^2 + x_a^2}}\right) \qquad B_{3y} = 5.297 \times 10^{-10}$$

$I_4 := 108\text{ʒ}$ $\quad I_5 := \frac{1083}{2}$ $\quad I_6 := \frac{1083}{2}$

$x_c := 75$ $\quad x_d := 17\text{ʒ}$

$y_4 := 158$ $\quad y_5 := y_4 - \frac{\Delta_d}{2}$ $\quad y_5 = 1.573\times 10^2$ $\quad y_6 := y_4 + \frac{\Delta_d}{2}$ $\quad y_6 = 1.587\times 10^2$

$z_4 := 4$ $\quad z_5 := 1$ $\quad z_6 := 1$

$$B_{4z} := \left[\frac{\mu \cdot I_4 \cdot y_4}{4\cdot\pi\cdot\left(y_4^{\,2} + z_4^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_4^{\,2} + z_4^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_4^{\,2} + z_4^{\,2} + x_c^{\,2}}}\right) \qquad B_{4z} = 2.147\times 10^{-7}$$

$$B_{4y} := \left[\frac{\mu \cdot I_4 \cdot z_4}{4\cdot\pi\cdot\left(y_4^{\,2} + z_4^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_4^{\,2} + z_4^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_4^{\,2} + z_4^{\,2} + x_c^{\,2}}}\right) \qquad B_{4y} = 5.435\times 10^{-9}$$

$$B_{5z} := \left[\frac{\mu \cdot I_5 \cdot y_5}{4\cdot\pi\cdot\left(y_5^{\,2} + z_5^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_5^{\,2} + z_5^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_5^{\,2} + z_5^{\,2} + x_c^{\,2}}}\right) \qquad B_{5z} = 1.079\times 10^{-7}$$

$$B_{5y} := \left[\frac{\mu \cdot I_5 \cdot z_5}{4\cdot\pi\cdot\left(y_5^{\,2} + z_5^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_5^{\,2} + z_5^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_5^{\,2} + z_5^{\,2} + x_c^{\,2}}}\right) \qquad B_{5y} = 6.859\times 10^{-10}$$

$$B_{6z} := \left[\frac{\mu \cdot I_6 \cdot y_6}{4\cdot\pi\cdot\left(y_6^{\,2} + z_6^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_6^{\,2} + z_6^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_6^{\,2} + z_6^{\,2} + x_c^{\,2}}}\right) \qquad B_{6z} = 1.069\times 10^{-7}$$

$$B_{6y} := \left[\frac{\mu \cdot I_6 \cdot z_6}{4\cdot\pi\cdot\left(y_6^{\,2} + z_6^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_6^{\,2} + z_6^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_6^{\,2} + z_6^{\,2} + x_c^{\,2}}}\right) \qquad B_{6y} = 6.738\times 10^{-10}$$

$I_7 := 540 \qquad I_8 := \frac{541}{2} \qquad I_9 := \frac{541}{2}$

$x_e := -12.5 \qquad x_f := 1670$

$y_7 := 242 \qquad y_8 := y_7 - \frac{\Delta_d}{2} \qquad y_8 = 2.413\times 10^2 \qquad y_9 := y_7 + \frac{\Delta_d}{2} \qquad y_9 = 2.427\times 10^2$

$z_7 := 4 \qquad z_8 := 1 \qquad z_9 := 1$

$$B_{7z} := \left[\frac{\mu\cdot I_7\cdot y_7}{4\cdot\pi\cdot\left(y_7^2 + z_7^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_7^2 + z_7^2 + x_f^2}} - \frac{x_e}{\sqrt{y_7^2 + z_7^2 + x_e^2}}\right) \qquad B_{7z} = 2.323\times 10^{-7}$$

$$B_{7y} := \left[\frac{\mu\cdot I_7\cdot z_7}{4\cdot\pi\cdot\left(y_7^2 + z_7^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_7^2 + z_7^2 + x_f^2}} - \frac{x_e}{\sqrt{y_7^2 + z_7^2 + x_e^2}}\right) \qquad B_{7y} = 3.839\times 10^{-9}$$

$$B_{8z} := \left[\frac{\mu\cdot I_8\cdot y_8}{4\cdot\pi\cdot\left(y_8^2 + z_8^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_8^2 + z_8^2 + x_f^2}} - \frac{x_e}{\sqrt{y_8^2 + z_8^2 + x_e^2}}\right) \qquad B_{8z} = 1.168\times 10^{-7}$$

$$B_{8y} := \left[\frac{\mu\cdot I_8\cdot z_8}{4\cdot\pi\cdot\left(y_8^2 + z_8^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_8^2 + z_8^2 + x_f^2}} - \frac{x_e}{\sqrt{y_8^2 + z_8^2 + x_e^2}}\right) \qquad B_{8y} = 4.839\times 10^{-10}$$

$$B_{9z} := \left[\frac{\mu\cdot I_9\cdot y_9}{4\cdot\pi\cdot\left(y_9^2 + z_9^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_9^2 + z_9^2 + x_f^2}} - \frac{x_e}{\sqrt{y_9^2 + z_9^2 + x_e^2}}\right) \qquad B_{9z} = 1.16\times 10^{-7}$$

$$B_{9y} := \left[\frac{\mu\cdot I_9\cdot z_9}{4\cdot\pi\cdot\left(y_9^2 + z_9^2\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_9^2 + z_9^2 + x_f^2}} - \frac{x_e}{\sqrt{y_9^2 + z_9^2 + x_e^2}}\right) \qquad B_{9y} = 4.78\times 10^{-10}$$

$I_{10} := 543$ $\quad I_{11} := \frac{541}{2}$ $\quad I_{12} := \frac{541}{2}$

$x_e := -12.5$ $\quad x_f := 1670$

$y_{10} := y_7 + 2$ $\quad y_{11} := y_8 + 2$ $\quad y_{12} := y_9 + 2$

$z_{10} := 4$ $\quad z_{11} := 1$ $\quad z_{12} := 1$

$$B_{10z} := \left[\frac{\mu \cdot I_{10} \cdot y_{10}}{4 \cdot \pi \cdot \left(y_{10}^2 + z_{10}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{10}^2 + z_{10}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{10}^2 + z_{10}^2 + x_e^2}}\right)$$

$B_{10z} = 2.315 \times 10^{-7}$

$$B_{10y} := \left[\frac{\mu \cdot I_{10} \cdot z_{10}}{4 \cdot \pi \cdot \left(y_{10}^2 + z_{10}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{10}^2 + z_{10}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{10}^2 + z_{10}^2 + x_e^2}}\right)$$

$B_{10y} = 3.795 \times 10^{-9}$

$$B_{11z} := \left[\frac{\mu \cdot I_{11} \cdot y_{11}}{4 \cdot \pi \cdot \left(y_{11}^2 + z_{11}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{11}^2 + z_{11}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{11}^2 + z_{11}^2 + x_e^2}}\right)$$

$B_{11z} = 1.157 \times 10^{-7}$

$$B_{11y} := \left[\frac{\mu \cdot I_{11} \cdot z_{11}}{4 \cdot \pi \cdot \left(y_{11}^2 + z_{11}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{11}^2 + z_{11}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{11}^2 + z_{11}^2 + x_e^2}}\right)$$

$B_{11y} = 4.757 \times 10^{-10}$

$$B_{12z} := \left[\frac{\mu \cdot I_{12} \cdot y_{12}}{4 \cdot \pi \cdot \left(y_{12}^2 + z_{12}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{12}^2 + z_{12}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{12}^2 + z_{12}^2 + x_e^2}}\right)$$

$B_{12z} = 1.15 \times 10^{-7}$

$$B_{12y} := \left[\frac{\mu \cdot I_{12} \cdot z_{12}}{4 \cdot \pi \cdot \left(y_{12}^2 + z_{12}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{12}^2 + z_{12}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{12}^2 + z_{12}^2 + x_e^2}}\right)$$

$B_{12y} = 4.699 \times 10^{-10}$

$$B_{totz} := -B_{1z} - B_{4z} - B_{7z} - B_{10z} + B_{2z} + B_{3z} + B_{5z} + B_{6z} + B_{8z} + B_{9z} + B_{11z} + B_{12z}$$

$$B_{totz} = -7.755\times 10^{-11}$$

Refer to a common xyz axis, first conductor as a reference

$$\theta_1 := \frac{\pi}{6} \qquad \theta_2 := 0.44\cdot\pi$$

$$B_{4yy} := B_{4y}\cdot\cos(\theta_1) \qquad B_{4yy} = 4.707\times 10^{-9}$$

$$B_{5yy} := B_{5y}\cdot\cos(\theta_1) \qquad B_{5yy} = 5.94\times 10^{-10}$$

$$B_{6yy} := B_{6y}\cdot\cos(\theta_1) \qquad B_{6yy} = 5.836\times 10^{-10}$$

$$B_{7yy} := B_{7y}\cdot\cos(\theta_2) \qquad B_{7yy} = 7.194\times 10^{-10}$$

$$B_{8yy} := B_{8y}\cdot\cos(\theta_2) \qquad B_{8yy} = 9.067\times 10^{-11}$$

$$B_{9yy} := B_{9y}\cdot\cos(\theta_2) \qquad B_{9yy} = 8.957\times 10^{-11}$$

$$B_{10yy} := B_{10y}\cdot\cos(\theta_2) \qquad B_{10yy} = 7.112\times 10^{-10}$$

$$B_{11yy} := B_{11y}\cdot\cos(\theta_2) \qquad B_{11yy} = 8.914\times 10^{-11}$$

$$B_{12yy} := B_{12y}\cdot\cos(\theta_2) \qquad B_{12yy} = 8.806\times 10^{-11}$$

$$B_{4yx} := B_{4y}\cdot\sin(\theta_1) \qquad B_{4yx} = 2.718\times 10^{-9}$$

$$B_{5yx} := B_{5y}\cdot\sin(\theta_1) \qquad B_{5yx} = 3.429\times 10^{-10}$$

$$B_{6yx} := B_{6y}\cdot\sin(\theta_1) \qquad B_{6yx} = 3.369\times 10^{-10}$$

$$B_{7yx} := B_{7y}\cdot\sin(\theta_2) \qquad B_{7yx} = 3.771\times 10^{-9}$$

$$B_{8yx} := B_{8y}\cdot\sin(\theta_2) \qquad B_{8yx} = 4.753\times 10^{-10}$$

$$B_{9yx} := B_{9y}\cdot\sin(\theta_2) \qquad B_{9yx} = 4.695\times 10^{-10}$$

$$B_{10yx} := B_{10y}\cdot\sin(\theta_2) \qquad B_{10yx} = 3.728\times 10^{-9}$$

$$B_{11yx} := B_{11y}\cdot\sin(\theta_2) \qquad B_{11yx} = 4.673\times 10^{-10}$$

$$B_{12yx} := B_{12y}\cdot\sin(\theta_2) \qquad B_{12yx} = 4.616\times 10^{-10}$$

$B_{toty} := B_{1y} + B_{2y} + B_{3y} + B_{4yy} + B_{5yy} + B_{6yy} + B_{7yy} + B_{8yy} + B_{9yy} + B_{10yy} + B_{11yy} + B_{12yy}$

$B_{toty} = 1.301\times 10^{-8}$

$B_{totx} := B_{4yx} + B_{5yx} + B_{6yx} + B_{7yx} + B_{8yx} + B_{9yx} + B_{10yx} + B_{11yx} + B_{12yx}$

$B_{totx} = 1.277\times 10^{-8}$

$B_{tot} := \sqrt{B_{totz}^{2} + B_{toty}^{2} + B_{totx}^{2}}$

$B_{tot} = 1.823\times 10^{-8}$

B.tot=18.2 nT

A.5. Outage at 2nd Substation

Case 3: Resulting magnetic field from standard infrastructure layout at the most sensitive point of the building. (22min 6sec of simulation, outage at 2S/S, train at chainage 50, regenerating)

$I_1 := 871$ $\quad I_2 := \frac{871}{2}$ $\quad I_3 := \frac{871}{2}$ $\quad \Delta_d := 1.435$

$h := 5$

$\mu := 4\pi \cdot 10^{-7}$ $\quad \frac{\Delta_d}{2} = 7.175 \times 10^{-1}$

$x_a := 100$ $\quad x_b := 150$

$y_1 := 105$ $\quad y_2 := y_1 - \frac{\Delta_d}{2}$ $\quad y_2 = 1.043 \times 10^{2}$ $\quad y_3 := y_1 + \frac{\Delta_d}{2}$ $\quad y_3 = 1.057 \times 10^{2}$

$z_1 := 4$ $\quad z_2 := 1$ $\quad z_3 := 1$

$$B_{1z} := \left[\frac{\mu \cdot I_1 \cdot y_1}{4\cdot\pi\cdot\left(y_1^2 + z_1^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_1^2 + z_1^2 + x_b^2}} - \frac{x_a}{\sqrt{y_1^2 + z_1^2 + x_a^2}}\right) \qquad B_{1z} = 1.074 \times 10^{-7}$$

$$B_{1y} := \left[\frac{\mu \cdot I_1 \cdot z_1}{4\cdot\pi\cdot\left(y_1^2 + z_1^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_1^2 + z_1^2 + x_b^2}} - \frac{x_a}{\sqrt{y_1^2 + z_1^2 + x_a^2}}\right) \qquad B_{1y} = 4.091 \times 10^{-9}$$

$$B_{2z} := \left[\frac{\mu \cdot I_2 \cdot y_2}{4\cdot\pi\cdot\left(y_2^2 + z_2^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_2^2 + z_2^2 + x_b^2}} - \frac{x_a}{\sqrt{y_2^2 + z_2^2 + x_a^2}}\right) \qquad B_{2z} = 5.384 \times 10^{-8}$$

$$B_{2y} := \left[\frac{\mu \cdot I_2 \cdot z_2}{4\cdot\pi\cdot\left(y_2^2 + z_2^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_2^2 + z_2^2 + x_b^2}} - \frac{x_a}{\sqrt{y_2^2 + z_2^2 + x_a^2}}\right) \qquad B_{2y} = 5.163 \times 10^{-10}$$

$$B_{3z} := \left[\frac{\mu \cdot I_3 \cdot y_3}{4\cdot\pi\cdot\left(y_3^2 + z_3^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_3^2 + z_3^2 + x_b^2}} - \frac{x_a}{\sqrt{y_3^2 + z_3^2 + x_a^2}}\right) \qquad B_{3z} = 5.363 \times 10^{-8}$$

$$B_{3y} := \left[\frac{\mu \cdot I_3 \cdot z_3}{4\cdot\pi\cdot\left(y_3^2 + z_3^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_3^2 + z_3^2 + x_b^2}} - \frac{x_a}{\sqrt{y_3^2 + z_3^2 + x_a^2}}\right) \qquad B_{3y} = 5.073 \times 10^{-10}$$

$I_4 := 871 \qquad I_5 := \frac{871}{2} \qquad I_6 := \frac{871}{2}$

$x_c := 75 \qquad x_d := 175$

$y_4 := 158 \qquad y_5 := y_4 - \frac{\Delta_d}{2} \qquad y_5 = 1.573\times 10^{2} \qquad y_6 := y_4 + \frac{\Delta_d}{2} \qquad y_6 = 1.587\times 10^{2}$

$z_4 := 4 \qquad z_5 := 1 \qquad z_6 := 1$

$$B_{4z} := \left[\frac{\mu\cdot I_4\cdot y_4}{4\cdot\pi\cdot\left(y_4^{\,2} + z_4^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_4^{\,2} + z_4^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_4^{\,2} + z_4^{\,2} + x_c^{\,2}}}\right) \qquad B_{4z} = 1.727\times 10^{-7}$$

$$B_{4y} := \left[\frac{\mu\cdot I_4\cdot z_4}{4\cdot\pi\cdot\left(y_4^{\,2} + z_4^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_4^{\,2} + z_4^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_4^{\,2} + z_4^{\,2} + x_c^{\,2}}}\right) \qquad B_{4y} = 4.371\times 10^{-9}$$

$$B_{5z} := \left[\frac{\mu\cdot I_5\cdot y_5}{4\cdot\pi\cdot\left(y_5^{\,2} + z_5^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_5^{\,2} + z_5^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_5^{\,2} + z_5^{\,2} + x_c^{\,2}}}\right) \qquad B_{5z} = 8.676\times 10^{-8}$$

$$B_{5y} := \left[\frac{\mu\cdot I_5\cdot z_5}{4\cdot\pi\cdot\left(y_5^{\,2} + z_5^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_5^{\,2} + z_5^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_5^{\,2} + z_5^{\,2} + x_c^{\,2}}}\right) \qquad B_{5y} = 5.516\times 10^{-10}$$

$$B_{6z} := \left[\frac{\mu\cdot I_6\cdot y_6}{4\cdot\pi\cdot\left(y_6^{\,2} + z_6^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_6^{\,2} + z_6^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_6^{\,2} + z_6^{\,2} + x_c^{\,2}}}\right) \qquad B_{6z} = 8.601\times 10^{-8}$$

$$B_{6y} := \left[\frac{\mu\cdot I_6\cdot z_6}{4\cdot\pi\cdot\left(y_6^{\,2} + z_6^{\,2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_6^{\,2} + z_6^{\,2} + x_d^{\,2}}} - \frac{x_c}{\sqrt{y_6^{\,2} + z_6^{\,2} + x_c^{\,2}}}\right) \qquad B_{6y} = 5.419\times 10^{-10}$$

$I_7 := 630$ $\quad I_8 := \frac{697}{2}$ $\quad I_9 := \frac{697}{2}$

$x_e := -12.5$ $\quad x_f := 1670$

$y_7 := 242$ $\quad y_8 := y_7 - \frac{\Delta_d}{2}$ $\quad y_8 = 2.413 \times 10^2$ $\quad y_9 := y_7 + \frac{\Delta_d}{2}$ $\quad y_9 = 2.427 \times 10^2$

$z_7 := 4$ $\quad z_8 := 1$ $\quad z_9 := 1$

$$B_{7z} := \left[\frac{\mu \cdot I_7 \cdot y_7}{4 \cdot \pi \cdot \left(y_7^2 + z_7^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_7^2 + z_7^2 + x_f^2}} - \frac{x_e}{\sqrt{y_7^2 + z_7^2 + x_e^2}}\right) \qquad B_{7z} = 2.71 \times 10^{-7}$$

$$B_{7y} := \left[\frac{\mu \cdot I_7 \cdot z_7}{4 \cdot \pi \cdot \left(y_7^2 + z_7^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_7^2 + z_7^2 + x_f^2}} - \frac{x_e}{\sqrt{y_7^2 + z_7^2 + x_e^2}}\right) \qquad B_{7y} = 4.479 \times 10^{-9}$$

$$B_{8z} := \left[\frac{\mu \cdot I_8 \cdot y_8}{4 \cdot \pi \cdot \left(y_8^2 + z_8^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_8^2 + z_8^2 + x_f^2}} - \frac{x_e}{\sqrt{y_8^2 + z_8^2 + x_e^2}}\right) \qquad B_{8z} = 1.504 \times 10^{-7}$$

$$B_{8y} := \left[\frac{\mu \cdot I_8 \cdot z_8}{4 \cdot \pi \cdot \left(y_8^2 + z_8^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_8^2 + z_8^2 + x_f^2}} - \frac{x_e}{\sqrt{y_8^2 + z_8^2 + x_e^2}}\right) \qquad B_{8y} = 6.234 \times 10^{-10}$$

$$B_{9z} := \left[\frac{\mu \cdot I_9 \cdot y_9}{4 \cdot \pi \cdot \left(y_9^2 + z_9^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_9^2 + z_9^2 + x_f^2}} - \frac{x_e}{\sqrt{y_9^2 + z_9^2 + x_e^2}}\right) \qquad B_{9z} = 1.495 \times 10^{-7}$$

$$B_{9y} := \left[\frac{\mu \cdot I_9 \cdot z_9}{4 \cdot \pi \cdot \left(y_9^2 + z_9^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_9^2 + z_9^2 + x_f^2}} - \frac{x_e}{\sqrt{y_9^2 + z_9^2 + x_e^2}}\right) \qquad B_{9y} = 6.158 \times 10^{-10}$$

$I_{10} := 764 \qquad I_{11} := \frac{697}{2} \qquad I_{12} := \frac{697}{2}$

$x_g := -12.5 \qquad x_h := 1670$

$y_{10} := y_7 + 2 \qquad y_{11} := y_8 + 2 \qquad y_{12} := y_9 + 2$

$z_{10} := 4 \qquad z_{11} := 1 \qquad z_{12} := 1$

$$B_{10z} := \left[\frac{\mu \cdot I_{10} \cdot y_{10}}{4 \cdot \pi \cdot \left(y_{10}^2 + z_{10}^2\right)}\right] \cdot \left(\frac{x_h}{\sqrt{y_{10}^2 + z_{10}^2 + x_h^2}} - \frac{x_g}{\sqrt{y_{10}^2 + z_{10}^2 + x_g^2}}\right) \qquad B_{10z} = 3.258 \times 10^{-7}$$

$$B_{10y} := \left[\frac{\mu \cdot I_{10} \cdot z_{10}}{4 \cdot \pi \cdot \left(y_{10}^2 + z_{10}^2\right)}\right] \cdot \left(\frac{x_h}{\sqrt{y_{10}^2 + z_{10}^2 + x_h^2}} - \frac{x_g}{\sqrt{y_{10}^2 + z_{10}^2 + x_g^2}}\right) \qquad B_{10y} = 5.34 \times 10^{-9}$$

$$B_{11z} := \left[\frac{\mu \cdot I_{11} \cdot y_{11}}{4 \cdot \pi \cdot \left(y_{11}^2 + z_{11}^2\right)}\right] \cdot \left(\frac{x_h}{\sqrt{y_{11}^2 + z_{11}^2 + x_h^2}} - \frac{x_g}{\sqrt{y_{11}^2 + z_{11}^2 + x_g^2}}\right) \qquad B_{11z} = 1.491 \times 10^{-7}$$

$$B_{11y} := \left[\frac{\mu \cdot I_{11} \cdot z_{11}}{4 \cdot \pi \cdot \left(y_{11}^2 + z_{11}^2\right)}\right] \cdot \left(\frac{x_h}{\sqrt{y_{11}^2 + z_{11}^2 + x_h^2}} - \frac{x_g}{\sqrt{y_{11}^2 + z_{11}^2 + x_h^2}}\right) \qquad B_{11y} = 5.87 \times 10^{-10}$$

$$B_{12z} := \left[\frac{\mu \cdot I_{12} \cdot y_{12}}{4 \cdot \pi \cdot \left(y_{12}^2 + z_{12}^2\right)}\right] \cdot \left(\frac{x_h}{\sqrt{y_{12}^2 + z_{12}^2 + x_h^2}} - \frac{x_g}{\sqrt{y_{12}^2 + z_{12}^2 + x_g^2}}\right) \qquad B_{12z} = 1.482 \times 10^{-7}$$

$$B_{12y} := \left[\frac{\mu \cdot I_{12} \cdot z_{12}}{4 \cdot \pi \cdot \left(y_{12}^2 + z_{12}^2\right)}\right] \cdot \left(\frac{x_h}{\sqrt{y_{12}^2 + z_{12}^2 + x_h^2}} - \frac{x_g}{\sqrt{y_{12}^2 + z_{12}^2 + x_g^2}}\right) \qquad B_{12y} = 6.055 \times 10^{-10}$$

$B_{totz} := B_{1z} + B_{4z} + B_{7z} + B_{10z} - B_{2z} - B_{3z} - B_{5z} - B_{6z} - B_{8z} - B_{9z} - B_{11z} - B_{12z}$

$B_{totz} = -6.086\times 10^{-10}$

Refer to a common xyz axis, first conductor as a reference

$\theta_1 := \frac{\pi}{6}$ $\qquad$ $\theta_2 := 0.44\pi$

$B_{4yy} := B_{4y}\cdot\cos(\theta_1)$ $\qquad$ $B_{4yy} = 3.786\times 10^{-9}$

$B_{5yy} := B_{5y}\cdot\cos(\theta_1)$ $\qquad$ $B_{5yy} = 4.777\times 10^{-10}$

$B_{6yy} := B_{6y}\cdot\cos(\theta_1)$ $\qquad$ $B_{6yy} = 4.693\times 10^{-10}$

$B_{7yy} := B_{7y}\cdot\cos(\theta_2)$ $\qquad$ $B_{7yy} = 8.393\times 10^{-10}$

$B_{8yy} := B_{8y}\cdot\cos(\theta_2)$ $\qquad$ $B_{8yy} = 1.168\times 10^{-10}$

$B_{9yy} := B_{9y}\cdot\cos(\theta_2)$ $\qquad$ $B_{9yy} = 1.154\times 10^{-10}$

$B_{10yy} := B_{10y}\cdot\cos(\theta_2)$ $\qquad$ $B_{10yy} = 1.001\times 10^{-9}$

$B_{11yy} := B_{11y}\cdot\cos(\theta_2)$ $\qquad$ $B_{11yy} = 1.1\times 10^{-10}$

$B_{12yy} := B_{12y}\cdot\cos(\theta_2)$ $\qquad$ $B_{12yy} = 1.135\times 10^{-10}$

$B_{4yx} := B_{4y}\cdot\sin(\theta_1)$ $\qquad$ $B_{4yx} = 2.186\times 10^{-9}$

$B_{5yx} := B_{5y}\cdot\sin(\theta_1)$ $\qquad$ $B_{5yx} = 2.758\times 10^{-10}$

$B_{6yx} := B_{6y}\cdot\sin(\theta_1)$ $\qquad$ $B_{6yx} = 2.71\times 10^{-10}$

$B_{7yx} := B_{7y}\cdot\sin(\theta_2)$ $\qquad$ $B_{7yx} = 4.4\times 10^{-9}$

$B_{8yx} := B_{8y}\cdot\sin(\theta_2)$ $\qquad$ $B_{8yx} = 6.124\times 10^{-10}$

$B_{9yx} := B_{9y}\cdot\sin(\theta_2)$ $\qquad$ $B_{9yx} = 6.049\times 10^{-10}$

$B_{10yx} := B_{10y}\cdot\sin(\theta_2)$ $\qquad$ $B_{10yx} = 5.246\times 10^{-9}$

$B_{11yx} := B_{11y}\cdot\sin(\theta_2)$ $\qquad$ $B_{11yx} = 5.766\times 10^{-10}$

$B_{12yx} := B_{12y}\cdot\sin(\theta_2)$ $\qquad$ $B_{12yx} = 5.947\times 10^{-10}$

$B_{toty} := B_{1y} + B_{2y} + B_{3y} + B_{4yy} + B_{5yy} + B_{6yy} + B_{7yy} + B_{8yy} + B_{9yy} + B_{10yy} + B_{11yy} + B_{12yy}$

$B_{toty} = 1.214 \times 10^{-8}$

$B_{totx} := B_{4yx} + B_{5yx} + B_{6yx} + B_{7yx} + B_{8yx} + B_{9yx} + B_{10yx} + B_{11yx} + B_{12yx}$

$B_{totx} = 1.477 \times 10^{-8}$

$B_{tot} := \sqrt{B_{totz}^2 + B_{toty}^2 + B_{totx}^2}$

$B_{tot} = 1.913 \times 10^{-8}$

B.tot=19.1 nT

A.6. Normal operation- Reduced current

Case 4: Resulting magnetic field from standard infrastructure layout at the most sensitive point of the building, reduced current. (21min 57 sec of simulation, Normal operation train at chainage 50, regenerating)

$I_1 := 300 \qquad I_2 := \frac{300}{2} \qquad I_3 := \frac{300}{2} \qquad \Delta_d := 1.435$

$h := 5$

$\mu := 4\pi \cdot 10^{-7} \qquad \frac{\Delta_d}{2} = 7.175 \times 10^{-1}$

$x_a := 100 \qquad x_b := 150$

$y_1 := 105 \qquad y_2 := y_1 - \frac{\Delta_d}{2} \qquad y_2 = 1.043 \times 10^{2} \qquad y_3 := y_1 + \frac{\Delta_d}{2} \qquad y_3 = 1.057 \times 10^{2}$

$z_1 := 4 \qquad z_2 := 1 \qquad z_3 := 1$

$$B_{1z} := \left[\frac{\mu \cdot I_1 \cdot y_1}{4 \cdot \pi \cdot \left(y_1^2 + z_1^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_1^2 + z_1^2 + x_b^2}} - \frac{x_a}{\sqrt{y_1^2 + z_1^2 + x_a^2}}\right) \qquad B_{1z} = 3.699 \times 10^{-8}$$

$$B_{1y} := \left[\frac{\mu \cdot I_1 \cdot z_1}{4 \cdot \pi \cdot \left(y_1^2 + z_1^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_1^2 + z_1^2 + x_b^2}} - \frac{x_a}{\sqrt{y_1^2 + z_1^2 + x_a^2}}\right) \qquad B_{1y} = 1.409 \times 10^{-9}$$

$$B_{2z} := \left[\frac{\mu \cdot I_2 \cdot y_2}{4 \cdot \pi \cdot \left(y_2^2 + z_2^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_2^2 + z_2^2 + x_b^2}} - \frac{x_a}{\sqrt{y_2^2 + z_2^2 + x_a^2}}\right) \qquad B_{2z} = 1.855 \times 10^{-8}$$

$$B_{2y} := \left[\frac{\mu \cdot I_2 \cdot z_2}{4 \cdot \pi \cdot \left(y_2^2 + z_2^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_2^2 + z_2^2 + x_b^2}} - \frac{x_a}{\sqrt{y_2^2 + z_2^2 + x_a^2}}\right) \qquad B_{2y} = 1.778 \times 10^{-10}$$

$$B_{3z} := \left[\frac{\mu \cdot I_3 \cdot y_3}{4 \cdot \pi \cdot \left(y_3^2 + z_3^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_3^2 + z_3^2 + x_b^2}} - \frac{x_a}{\sqrt{y_3^2 + z_3^2 + x_a^2}}\right) \qquad B_{3z} = 1.847 \times 10^{-8}$$

$$B_{3y} := \left[\frac{\mu \cdot I_3 \cdot z_3}{4 \cdot \pi \cdot \left(y_3^2 + z_3^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_3^2 + z_3^2 + x_b^2}} - \frac{x_a}{\sqrt{y_3^2 + z_3^2 + x_a^2}}\right) \qquad B_{3y} = 1.747 \times 10^{-10}$$

$I_4 := 300 \qquad I_5 := \frac{300}{2} \qquad I_6 := \frac{300}{2}$

$x_c := 75 \qquad x_d := 175$

$y_4 := 158 \qquad y_5 := y_4 - \frac{\Delta_d}{2} \qquad y_5 = 1.573\times 10^{2} \qquad y_6 := y_4 + \frac{\Delta_d}{2} \qquad y_6 = 1.587\times 10^{2}$

$z_4 := 4 \qquad z_5 := 1 \qquad z_6 := 1$

$$B_{4z} := \left[\frac{\mu\cdot I_4\cdot y_4}{4\cdot\pi\cdot\left(y_4^{2}+z_4^{2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_4^{2}+z_4^{2}+x_d^{2}}}-\frac{x_c}{\sqrt{y_4^{2}+z_4^{2}+x_c^{2}}}\right) \qquad B_{4z} = 5.947\times 10^{-8}$$

$$B_{4y} := \left[\frac{\mu\cdot I_4\cdot z_4}{4\cdot\pi\cdot\left(y_4^{2}+z_4^{2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_4^{2}+z_4^{2}+x_d^{2}}}-\frac{x_c}{\sqrt{y_4^{2}+z_4^{2}+x_c^{2}}}\right) \qquad B_{4y} = 1.506\times 10^{-9}$$

$$B_{5z} := \left[\frac{\mu\cdot I_5\cdot y_5}{4\cdot\pi\cdot\left(y_5^{2}+z_5^{2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_5^{2}+z_5^{2}+x_d^{2}}}-\frac{x_c}{\sqrt{y_5^{2}+z_5^{2}+x_c^{2}}}\right) \qquad B_{5z} = 2.988\times 10^{-8}$$

$$B_{5y} := \left[\frac{\mu\cdot I_5\cdot z_5}{4\cdot\pi\cdot\left(y_5^{2}+z_5^{2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_5^{2}+z_5^{2}+x_d^{2}}}-\frac{x_c}{\sqrt{y_5^{2}+z_5^{2}+x_c^{2}}}\right) \qquad B_{5y} = 1.9\times 10^{-10}$$

$$B_{6z} := \left[\frac{\mu\cdot I_6\cdot y_6}{4\cdot\pi\cdot\left(y_6^{2}+z_6^{2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_6^{2}+z_6^{2}+x_d^{2}}}-\frac{x_c}{\sqrt{y_6^{2}+z_6^{2}+x_c^{2}}}\right) \qquad B_{6z} = 2.963\times 10^{-8}$$

$$B_{6y} := \left[\frac{\mu\cdot I_6\cdot z_6}{4\cdot\pi\cdot\left(y_6^{2}+z_6^{2}\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_6^{2}+z_6^{2}+x_d^{2}}}-\frac{x_c}{\sqrt{y_6^{2}+z_6^{2}+x_c^{2}}}\right) \qquad B_{6y} = 1.867\times 10^{-10}$$

$I_7 := 150$ $\quad I_8 := \frac{150}{2}$ $\quad I_9 := \frac{150}{2}$

$x_e := -12.5$ $\quad x_f := 1670$

$y_7 := 242$ $\quad y_8 := y_7 - \frac{\Delta_d}{2}$ $\quad y_8 = 2.413\times 10^2$ $\quad y_9 := y_7 + \frac{\Delta_d}{2}$ $\quad y_9 = 2.427\times 10^2$

$z_7 := 4$ $\quad z_8 := 1$ $\quad z_9 := 1$

$$B_{7z} := \left[\frac{\mu\cdot I_7\cdot y_7}{4\cdot\pi\cdot\left(y_7^{\,2} + z_7^{\,2}\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_7^{\,2} + z_7^{\,2} + x_f^{\,2}}} - \frac{x_e}{\sqrt{y_7^{\,2} + z_7^{\,2} + x_e^{\,2}}}\right) \qquad B_{7z} = 6.452\times 10^{-8}$$

$$B_{7y} := \left[\frac{\mu\cdot I_7\cdot z_7}{4\cdot\pi\cdot\left(y_7^{\,2} + z_7^{\,2}\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_7^{\,2} + z_7^{\,2} + x_f^{\,2}}} - \frac{x_e}{\sqrt{y_7^{\,2} + z_7^{\,2} + x_e^{\,2}}}\right) \qquad B_{7y} = 1.066\times 10^{-9}$$

$$B_{8z} := \left[\frac{\mu\cdot I_8\cdot y_8}{4\cdot\pi\cdot\left(y_8^{\,2} + z_8^{\,2}\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_8^{\,2} + z_8^{\,2} + x_f^{\,2}}} - \frac{x_e}{\sqrt{y_8^{\,2} + z_8^{\,2} + x_e^{\,2}}}\right) \qquad B_{8z} = 3.237\times 10^{-8}$$

$$B_{8y} := \left[\frac{\mu\cdot I_8\cdot z_8}{4\cdot\pi\cdot\left(y_8^{\,2} + z_8^{\,2}\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_8^{\,2} + z_8^{\,2} + x_f^{\,2}}} - \frac{x_e}{\sqrt{y_8^{\,2} + z_8^{\,2} + x_e^{\,2}}}\right) \qquad B_{8y} = 1.342\times 10^{-10}$$

$$B_{9z} := \left[\frac{\mu\cdot I_9\cdot y_9}{4\cdot\pi\cdot\left(y_9^{\,2} + z_9^{\,2}\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_9^{\,2} + z_9^{\,2} + x_f^{\,2}}} - \frac{x_e}{\sqrt{y_9^{\,2} + z_9^{\,2} + x_e^{\,2}}}\right) \qquad B_{9z} = 3.217\times 10^{-8}$$

$$B_{9y} := \left[\frac{\mu\cdot I_9\cdot z_9}{4\cdot\pi\cdot\left(y_9^{\,2} + z_9^{\,2}\right)}\right]\cdot\left(\frac{x_f}{\sqrt{y_9^{\,2} + z_9^{\,2} + x_f^{\,2}}} - \frac{x_e}{\sqrt{y_9^{\,2} + z_9^{\,2} + x_e^{\,2}}}\right) \qquad B_{9y} = 1.325\times 10^{-10}$$

$I_{10} := 150 \qquad I_{11} := \frac{150}{2} \qquad I_{12} := \frac{150}{2}$

$x_e := -12.5 \qquad x_f := 1670$

$y_{10} := y_7 + 2 \qquad y_{11} := y_8 + 2 \qquad y_{12} := y_9 + 2$

$z_{10} := 4 \qquad z_{11} := 1 \qquad z_{12} := 1$

$$B_{10z} := \left[\frac{\mu \cdot I_{10} \cdot y_{10}}{4 \cdot \pi \cdot \left(y_{10}^2 + z_{10}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{10}^2 + z_{10}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{10}^2 + z_{10}^2 + x_e^2}}\right) \qquad B_{10z} = 6.396 \times 10^{-8}$$

$$B_{10y} := \left[\frac{\mu \cdot I_{10} \cdot z_{10}}{4 \cdot \pi \cdot \left(y_{10}^2 + z_{10}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{10}^2 + z_{10}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{10}^2 + z_{10}^2 + x_e^2}}\right) \qquad B_{10y} = 1.048 \times 10^{-9}$$

$$B_{11z} := \left[\frac{\mu \cdot I_{11} \cdot y_{11}}{4 \cdot \pi \cdot \left(y_{11}^2 + z_{11}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{11}^2 + z_{11}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{11}^2 + z_{11}^2 + x_e^2}}\right) \qquad B_{11z} = 3.209 \times 10^{-8}$$

$$B_{11y} := \left[\frac{\mu \cdot I_{11} \cdot z_{11}}{4 \cdot \pi \cdot \left(y_{11}^2 + z_{11}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{11}^2 + z_{11}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{11}^2 + z_{11}^2 + x_e^2}}\right) \qquad B_{11y} = 1.319 \times 10^{-10}$$

$$B_{12z} := \left[\frac{\mu \cdot I_{12} \cdot y_{12}}{4 \cdot \pi \cdot \left(y_{12}^2 + z_{12}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{12}^2 + z_{12}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{12}^2 + z_{12}^2 + x_e^2}}\right) \qquad B_{12z} = 3.189 \times 10^{-8}$$

$$B_{12y} := \left[\frac{\mu \cdot I_{12} \cdot z_{12}}{4 \cdot \pi \cdot \left(y_{12}^2 + z_{12}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{12}^2 + z_{12}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{12}^2 + z_{12}^2 + x_e^2}}\right) \qquad B_{12y} = 1.303 \times 10^{-10}$$

$$B_{totz} := B_{1z} + B_{4z} + B_{7z} + B_{10z} - B_{2z} - B_{3z} - B_{5z} - B_{6z} - B_{8z} - B_{9z} - B_{11z} - B_{12z}$$

$$B_{totz} = -1.017 \times 10^{-10}$$

Refer to a common xyz axis, first conductor as a reference

$$\theta_1 := \frac{\pi}{6} \qquad \theta_2 := 0.44 \cdot \pi$$

$$B_{4yy} := B_{4y} \cdot \cos(\theta_1) \qquad B_{4yy} = 1.304 \times 10^{-9}$$

$$B_{5yy} := B_{5y} \cdot \cos(\theta_1) \qquad B_{5yy} = 1.645 \times 10^{-10}$$

$$B_{6yy} := B_{6y} \cdot \cos(\theta_1) \qquad B_{6yy} = 1.616 \times 10^{-10}$$

$$B_{7yy} := B_{7y} \cdot \cos(\theta_2) \qquad B_{7yy} = 1.998 \times 10^{-10}$$

$$B_{8yy} := B_{8y} \cdot \cos(\theta_2) \qquad B_{8yy} = 2.514 \times 10^{-11}$$

$$B_{9yy} := B_{9y} \cdot \cos(\theta_2) \qquad B_{9yy} = 2.483 \times 10^{-11}$$

$$B_{10yy} := B_{10y} \cdot \cos(\theta_2) \qquad B_{10yy} = 1.965 \times 10^{-10}$$

$$B_{11yy} := B_{11y} \cdot \cos(\theta_2) \qquad B_{11yy} = 2.471 \times 10^{-11}$$

$$B_{12yy} := B_{12y} \cdot \cos(\theta_2) \qquad B_{12yy} = 2.442 \times 10^{-11}$$

$$B_{4yx} := B_{4y} \cdot \sin(\theta_1) \qquad B_{4yx} = 7.528 \times 10^{-10}$$

$$B_{5yx} := B_{5y} \cdot \sin(\theta_1) \qquad B_{5yx} = 9.499 \times 10^{-11}$$

$$B_{6yx} := B_{6y} \cdot \sin(\theta_1) \qquad B_{6yx} = 9.333 \times 10^{-11}$$

$$B_{7yx} := B_{7y} \cdot \sin(\theta_2) \qquad B_{7yx} = 1.048 \times 10^{-9}$$

$$B_{8yx} := B_{8y} \cdot \sin(\theta_2) \qquad B_{8yx} = 1.318 \times 10^{-10}$$

$$B_{9yx} := B_{9y} \cdot \sin(\theta_2) \qquad B_{9yx} = 1.302 \times 10^{-10}$$

$$B_{10yx} := B_{10y} \cdot \sin(\theta_2) \qquad B_{10yx} = 1.03 \times 10^{-9}$$

$$B_{11yx} := B_{11y} \cdot \sin(\theta_2) \qquad B_{11yx} = 1.296 \times 10^{-10}$$

$$B_{12yx} := B_{12y} \cdot \sin(\theta_2) \qquad B_{12yx} = 1.28 \times 10^{-10}$$

$B_{toty} := B_{1y} + B_{2y} + B_{3y} + B_{4yy} + B_{5yy} + B_{6yy} + B_{7yy} + B_{8yy} + B_{9yy} + B_{10yy} + B_{11yy} + B_{12yy}$

$B_{toty} = 3.887\times 10^{-9}$

$B_{totx} := B_{4yx} + B_{5yx} + B_{6yx} + B_{7yx} + B_{8yx} + B_{9yx} + B_{10yx} + B_{11yx} + B_{12yx}$

$B_{totx} = 3.538\times 10^{-9}$

$B_{tot} := \sqrt{B_{totz}^{2} + B_{toty}^{2} + B_{totx}^{2}}$

$B_{tot} = 5.257\times 10^{-9}$

B.tot =5.2 nT

A.7. Normal operation- Trolley type OLE

Case 5: Resulting magnetic field from trolley type infrastructure layout at the most sensitive point of the building. (Normal operation, insulated block joints at rails, return via one conductor next to OCS)

$I_1 := 959 \qquad I_2 := 959 \qquad I_3 := 0 \qquad \Delta_d := 1.435$

$h := 5$

$\mu := 4\pi \cdot 10^{-7} \qquad \frac{\Delta_d}{2} = 7.175 \times 10^{-1}$

$x_a := 100 \qquad x_b := 150$

$y_1 := 105 \qquad y_2 := y_1 - 0.5 \qquad y_2 = 1.045 \times 10^{2} \qquad y_3 := 0 \qquad y_3 = 0 \times 10^{0}$

$z_1 := 4 \qquad z_2 := 4 \qquad z_3 := 1$

$$B_{1z} := \left[\frac{\mu \cdot I_1 \cdot y_1}{4 \cdot \pi \cdot \left(y_1^2 + z_1^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_1^2 + z_1^2 + x_b^2}} - \frac{x_a}{\sqrt{y_1^2 + z_1^2 + x_a^2}}\right) \qquad B_{1z} = 1.182 \times 10^{-7}$$

$$B_{1y} := \left[\frac{\mu \cdot I_1 \cdot z_1}{4 \cdot \pi \cdot \left(y_1^2 + z_1^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_1^2 + z_1^2 + x_b^2}} - \frac{x_a}{\sqrt{y_1^2 + z_1^2 + x_a^2}}\right) \qquad B_{1y} = 4.504 \times 10^{-9}$$

$$B_{2z} := \left[\frac{\mu \cdot I_2 \cdot y_2}{4 \cdot \pi \cdot \left(y_2^2 + z_2^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_2^2 + z_2^2 + x_b^2}} - \frac{x_a}{\sqrt{y_2^2 + z_2^2 + x_a^2}}\right) \qquad B_{2z} = 1.184 \times 10^{-7}$$

$$B_{2y} := \left[\frac{\mu \cdot I_2 \cdot z_2}{4 \cdot \pi \cdot \left(y_2^2 + z_2^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_2^2 + z_2^2 + x_b^2}} - \frac{x_a}{\sqrt{y_2^2 + z_2^2 + x_a^2}}\right) \qquad B_{2y} = 4.532 \times 10^{-9}$$

$$B_{3z} := \left[\frac{\mu \cdot I_3 \cdot y_3}{4 \cdot \pi \cdot \left(y_3^2 + z_3^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_3^2 + z_3^2 + x_b^2}} - \frac{x_a}{\sqrt{y_3^2 + z_3^2 + x_a^2}}\right) \qquad B_{3z} = 0 \times 10^{0}$$

$$B_{3y} := \left[\frac{\mu \cdot I_3 \cdot z_3}{4 \cdot \pi \cdot \left(y_3^2 + z_3^2\right)}\right] \cdot \left(\frac{x_b}{\sqrt{y_3^2 + z_3^2 + x_b^2}} - \frac{x_a}{\sqrt{y_3^2 + z_3^2 + x_a^2}}\right) \qquad B_{3y} = 0 \times 10^{0}$$

$I_4 := 959$ $\quad I_5 := 959$ $\quad I_6 := 0$

$x_c := 75$ $\quad x_d := 175$

$y_4 := 158$ $\quad y_5 := y_4 - 0.5$ $\quad y_5 = 1.575\times 10^2$ $\quad y_6 := 0$ $\quad y_6 = 0\times 10^0$

$z_4 := 4$ $\quad z_5 := 4$ $\quad z_6 := 0$

$$B_{4z} := \left[\frac{\mu\cdot I_4\cdot y_4}{4\cdot\pi\cdot\left(y_4^2 + z_4^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_4^2 + z_4^2 + x_d^2}} - \frac{x_c}{\sqrt{y_4^2 + z_4^2 + x_c^2}}\right) \qquad B_{4z} = 1.901\times 10^{-7}$$

$$B_{4y} := \left[\frac{\mu\cdot I_4\cdot z_4}{4\cdot\pi\cdot\left(y_4^2 + z_4^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_4^2 + z_4^2 + x_d^2}} - \frac{x_c}{\sqrt{y_4^2 + z_4^2 + x_c^2}}\right) \qquad B_{4y} = 4.813\times 10^{-9}$$

$$B_{5z} := \left[\frac{\mu\cdot I_5\cdot y_5}{4\cdot\pi\cdot\left(y_5^2 + z_5^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_5^2 + z_5^2 + x_d^2}} - \frac{x_c}{\sqrt{y_5^2 + z_5^2 + x_c^2}}\right) \qquad B_{5z} = 1.907\times 10^{-7}$$

$$B_{5y} := \left[\frac{\mu\cdot I_5\cdot z_5}{4\cdot\pi\cdot\left(y_5^2 + z_5^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_5^2 + z_5^2 + x_d^2}} - \frac{x_c}{\sqrt{y_5^2 + z_5^2 + x_c^2}}\right) \qquad B_{5y} = 4.843\times 10^{-9}$$

$$B_{6z} := \left[\frac{\mu\cdot I_6\cdot y_6}{4\cdot\pi\cdot\left(y_6^2 + z_6^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_6^2 + z_6^2 + x_d^2}} - \frac{x_c}{\sqrt{y_6^2 + z_6^2 + x_c^2}}\right) \qquad B_{6z} = 0\times 10^0$$

$$B_{6y} := \left[\frac{\mu\cdot I_6\cdot z_6}{4\cdot\pi\cdot\left(y_6^2 + z_6^2\right)}\right]\cdot\left(\frac{x_d}{\sqrt{y_6^2 + z_6^2 + x_d^2}} - \frac{x_c}{\sqrt{y_6^2 + z_6^2 + x_c^2}}\right) \qquad B_{6y} = 0\times 10^0$$

$I_7 := 461 \qquad I_8 := 461 \qquad I_9 := 461$

$x_e := -12.5 \qquad x_f := 1670$

$y_7 := 242 \qquad y_8 := y_7 - 0.5 \qquad y_8 = 2.415 \times 10^2 \qquad y_9 := 0 \qquad y_9 = 0 \times 10^0$

$z_7 := 4 \qquad z_8 := 4 \qquad z_9 := 0$

$$B_{7z} := \left[\frac{\mu \cdot I_7 \cdot y_7}{4 \cdot \pi \cdot \left(y_7^2 + z_7^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_7^2 + z_7^2 + x_f^2}} - \frac{x_e}{\sqrt{y_7^2 + z_7^2 + x_e^2}}\right) \qquad B_{7z} = 1.983 \times 10^{-7}$$

$$B_{7y} := \left[\frac{\mu \cdot I_7 \cdot z_7}{4 \cdot \pi \cdot \left(y_7^2 + z_7^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_7^2 + z_7^2 + x_f^2}} - \frac{x_e}{\sqrt{y_7^2 + z_7^2 + x_e^2}}\right) \qquad B_{7y} = 3.278 \times 10^{-9}$$

$$B_{8z} := \left[\frac{\mu \cdot I_8 \cdot y_8}{4 \cdot \pi \cdot \left(y_8^2 + z_8^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_8^2 + z_8^2 + x_f^2}} - \frac{x_e}{\sqrt{y_8^2 + z_8^2 + x_e^2}}\right) \qquad B_{8z} = 1.987 \times 10^{-7}$$

$$B_{8y} := \left[\frac{\mu \cdot I_8 \cdot z_8}{4 \cdot \pi \cdot \left(y_8^2 + z_8^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_8^2 + z_8^2 + x_f^2}} - \frac{x_e}{\sqrt{y_8^2 + z_8^2 + x_e^2}}\right) \qquad B_{8y} = 3.292 \times 10^{-9}$$

$$B_{9z} := \left[\frac{\mu \cdot I_9 \cdot y_9}{4 \cdot \pi \cdot \left(y_9^2 + z_9^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_9^2 + z_9^2 + x_f^2}} - \frac{x_e}{\sqrt{y_9^2 + z_9^2 + x_e^2}}\right) \qquad B_{9z} = 0 \times 10^{0}$$

$$B_{9y} := \left[\frac{\mu \cdot I_9 \cdot z_9}{4 \cdot \pi \cdot \left(y_9^2 + z_9^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_9^2 + z_9^2 + x_f^2}} - \frac{x_e}{\sqrt{y_9^2 + z_9^2 + x_e^2}}\right) \qquad B_{9y} = 0 \times 10^{0}$$

$I_{10} := 497$ $\quad I_{11} := 497$ $\quad I_{12} := 0$

$x_e := -12.5$ $\quad x_f := 1670$

$y_{10} := y_7 + 2$ $\quad y_{11} := y_8 + 2$ $\quad y_{12} := 0$

$z_{10} := 4$ $\quad z_{11} := 4$ $\quad z_{12} := 1$

$$B_{10z} := \left[\frac{\mu \cdot I_{10} \cdot y_{10}}{4 \cdot \pi \cdot \left(y_{10}^2 + z_{10}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{10}^2 + z_{10}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{10}^2 + z_{10}^2 + x_e^2}}\right) \qquad B_{10z} = 2.119 \times 10^{-7}$$

$$B_{10y} := \left[\frac{\mu \cdot I_{10} \cdot z_{10}}{4 \cdot \pi \cdot \left(y_{10}^2 + z_{10}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{10}^2 + z_{10}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{10}^2 + z_{10}^2 + x_e^2}}\right) \qquad B_{10y} = 3.474 \times 10^{-9}$$

$$B_{11z} := \left[\frac{\mu \cdot I_{11} \cdot y_{11}}{4 \cdot \pi \cdot \left(y_{11}^2 + z_{11}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{11}^2 + z_{11}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{11}^2 + z_{11}^2 + x_e^2}}\right) \qquad B_{11z} = 2.124 \times 10^{-7}$$

$$B_{11y} := \left[\frac{\mu \cdot I_{11} \cdot z_{11}}{4 \cdot \pi \cdot \left(y_{11}^2 + z_{11}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{11}^2 + z_{11}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{11}^2 + z_{11}^2 + x_e^2}}\right) \qquad B_{11y} = 3.489 \times 10^{-9}$$

$$B_{12z} := \left[\frac{\mu \cdot I_{12} \cdot y_{12}}{4 \cdot \pi \cdot \left(y_{12}^2 + z_{12}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{12}^2 + z_{12}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{12}^2 + z_{12}^2 + x_e^2}}\right) \qquad B_{12z} = 0 \times 10^{0}$$

$$B_{12y} := \left[\frac{\mu \cdot I_{12} \cdot z_{12}}{4 \cdot \pi \cdot \left(y_{12}^2 + z_{12}^2\right)}\right] \cdot \left(\frac{x_f}{\sqrt{y_{12}^2 + z_{12}^2 + x_f^2}} - \frac{x_e}{\sqrt{y_{12}^2 + z_{12}^2 + x_e^2}}\right) \qquad B_{12y} = 0 \times 10^{0}$$

$B_{totz} := B_{1z} + B_{4z} + B_{7z} + B_{10z} - B_{2z} - B_{3z} - B_{5z} - B_{6z} - B_{8z} - B_{9z} - B_{11z} - B_{12z}$

$B_{totz} = -1.634\times 10^{-9}$

Refer to a common xyz axis, first conductor as a reference

$\theta_1 := \frac{\pi}{6}$ $\qquad$ $\theta_2 := 0.44\cdot\pi$

$B_{4yy} := B_{4y}\cdot\cos(\theta_1)$ $\qquad$ $B_{4yy} = 4.168\times 10^{-9}$

$B_{5yy} := B_{5y}\cdot\cos(\theta_1)$ $\qquad$ $B_{5yy} = 4.194\times 10^{-9}$

$B_{6yy} := B_{6y}\cdot\cos(\theta_1)$ $\qquad$ $B_{6yy} = 0\times 10^{0}$

$B_{7yy} := B_{7y}\cdot\cos(\theta_2)$ $\qquad$ $B_{7yy} = 6.142\times 10^{-10}$

$B_{8yy} := B_{8y}\cdot\cos(\theta_2)$ $\qquad$ $B_{8yy} = 6.168\times 10^{-10}$

$B_{9yy} := B_{9y}\cdot\cos(\theta_2)$ $\qquad$ $B_{9yy} = 0\times 10^{0}$

$B_{10yy} := B_{10y}\cdot\cos(\theta_2)$ $\qquad$ $B_{10yy} = 6.51\times 10^{-10}$

$B_{11yy} := B_{11y}\cdot\cos(\theta_2)$ $\qquad$ $B_{11yy} = 6.537\times 10^{-10}$

$B_{12yy} := B_{12y}\cdot\cos(\theta_2)$ $\qquad$ $B_{12yy} = 0\times 10^{0}$

$B_{4yx} := B_{4y}\cdot\sin(\theta_1)$ $\qquad$ $B_{4yx} = 2.406\times 10^{-9}$

$B_{5yx} := B_{5y}\cdot\sin(\theta_1)$ $\qquad$ $B_{5yx} = 2.421\times 10^{-9}$

$B_{6yx} := B_{6y}\cdot\sin(\theta_1)$ $\qquad$ $B_{6yx} = 0\times 10^{0}$

$B_{7yx} := B_{7y}\cdot\sin(\theta_2)$ $\qquad$ $B_{7yx} = 3.22\times 10^{-9}$

$B_{8yx} := B_{8y}\cdot\sin(\theta_2)$ $\qquad$ $B_{8yx} = 3.233\times 10^{-9}$

$B_{9yx} := B_{9y}\cdot\sin(\theta_2)$ $\qquad$ $B_{9yx} = 0\times 10^{0}$

$B_{10yx} := B_{10y}\cdot\sin(\theta_2)$ $\qquad$ $B_{10yx} = 3.412\times 10^{-9}$

$B_{11yx} := B_{11y}\cdot\sin(\theta_2)$ $\qquad$ $B_{11yx} = 3.427\times 10^{-9}$

$B_{12yx} := B_{12y}\cdot\sin(\theta_2)$ $\qquad$ $B_{12yx} = 0\times 10^{0}$

$$B_{toty} := B_{1y} - B_{2y} - B_{3y} + B_{4yy} - B_{5yy} - B_{6yy} + B_{7yy} - B_{8yy} - B_{9yy} + B_{10yy} - B_{11yy} - B_{12yy}$$

$$B_{toty} = -5.886 \times 10^{-11}$$

$$B_{totx} := B_{4yx} - B_{5yx} - B_{6yx} + B_{7yx} - B_{8yx} - B_{9yx} + B_{10yx} - B_{11yx} - B_{12yx}$$

$$B_{totx} = -4.319 \times 10^{-11}$$

$$B_{tot} := \sqrt{B_{totz}^{2} + B_{toty}^{2} + B_{totx}^{2}}$$

$$B_{tot} = 1.635 \times 10^{-9}$$

B.tot=1.6 nT

Appendix B. TRAIN Input Data

B.1. General

Hatch Mott MacDonald has modeled the western end of the proposed “B” Line extension up to the 3rd substation of the system and the adjacent MacNab station based on the limited existing information and some logical assumptions based on relative LRT projects and experience. The traction power is supplied at the nominal voltage of 750V DC through an overhead conductor rail and returned through the running rails. An operational headway of 4 minutes is modeled

B.2. Electrical Model

A single overhead conductor rail with resistance of 0.052542 (Ohm/km) per track is modeled [2]. Although reference [2] suggest that a messenger wire is taken into consideration, there is no relevant information for its relative position and characteristics and consequently a single overhead conductor is used for the magnetic field calculations

The running rails are Standard 100lb ARAA or 115lb AREMA rails with 10% wear and cable bonding between E/B & W/B tracks every 100m and a resistance of 0.017444 (Ohm/km) per track.

Track feeder cables and negative return cables are both 2 x 500kcm copper cables in duct with a resistance of 0.041257 (Ohm/km)

The typical rail-to-earth resistance for LRT systems of 10 Ohm.km is modeled with a floating system.

B.3. LRT vehicle Characteristics

The LRT vehicle characteristics are taken from [2] and are summarized in the following table:

Item	Description	Vehicle Data
	Vehicle Make and Type	Make:____________ Type:____________
1	Number of Cars per Train	1
2	Number of Motor per Car	4 x 125kW Motors = 1 x 500kW (for continuous duty)
3	Number of Axles per Car	6
4	Length per Car (m) / Length per Train (m)	32.000m / 32.000m
5	Weight of Empty Car (tonnes) / Weight of Empty Train (tonnes)	49.500tonnes / 49.500tonnes
6	Number of Passengers per Car (AW 2 Load, 4 pass./m^2))	178 (50 Seated + 128 Standing Pass.)
7	Number of Seats per Car	50
8	Weight of Each Passenger (kg)	?? kg
9	Full Weight per Car (tonnes) / Full Weight per Train (tonnes) (AW 2 Load)	70.100tonnes / 70.100tonnes
10	Normal Acceleration Jerk Rate Limit (m/s^3)	
	Normal Deceleration Jerk Rate Limit (m/s^3)	
11	Maximum Acceleration Rate can be Achieved (m/s^2)	1.2000(m/s^2)
12	Maximum Deceleration Rate can be Achieved (m/s^2)	1.3400(m/s^2)
13	Normal Acceleration Rate during Operation (m/s^2)	1.0000(m/s^2)
14	Normal Dcceleration Rate during Operation (m/s^2)	0.8000(m/s^2)
15	Maximum Service Speed can be Achieved (km/h)	70km/h
16	Maximum Service Speed during Operation (km/h)	60km/h
17	Nominal Train Operating Voltage (Vdc)	750VDC

Figure 10: LRT vehicle Characteristics

Source:Hamilton Rapid Transit Preliminary Design and Feasibility Study

The system has been simulated with regenerative braking switched on.

B.4. Motor Characteristics

Reference [2] does not provide any motor characteristics. Our rolling stock experts advised that the motor characteristics of a similar LRT vehicle can be used that will draw similar currents and consequently relevant magnetic fields. Based on the LRT vehicle description on [2], our rolling stock experts advised that the Bombardier Flexity 2 LRT vehicle has very similar characteristics and these characteristics were modelled for the simulations. The motor characteristics and regenerated braking characteristics are shown below.

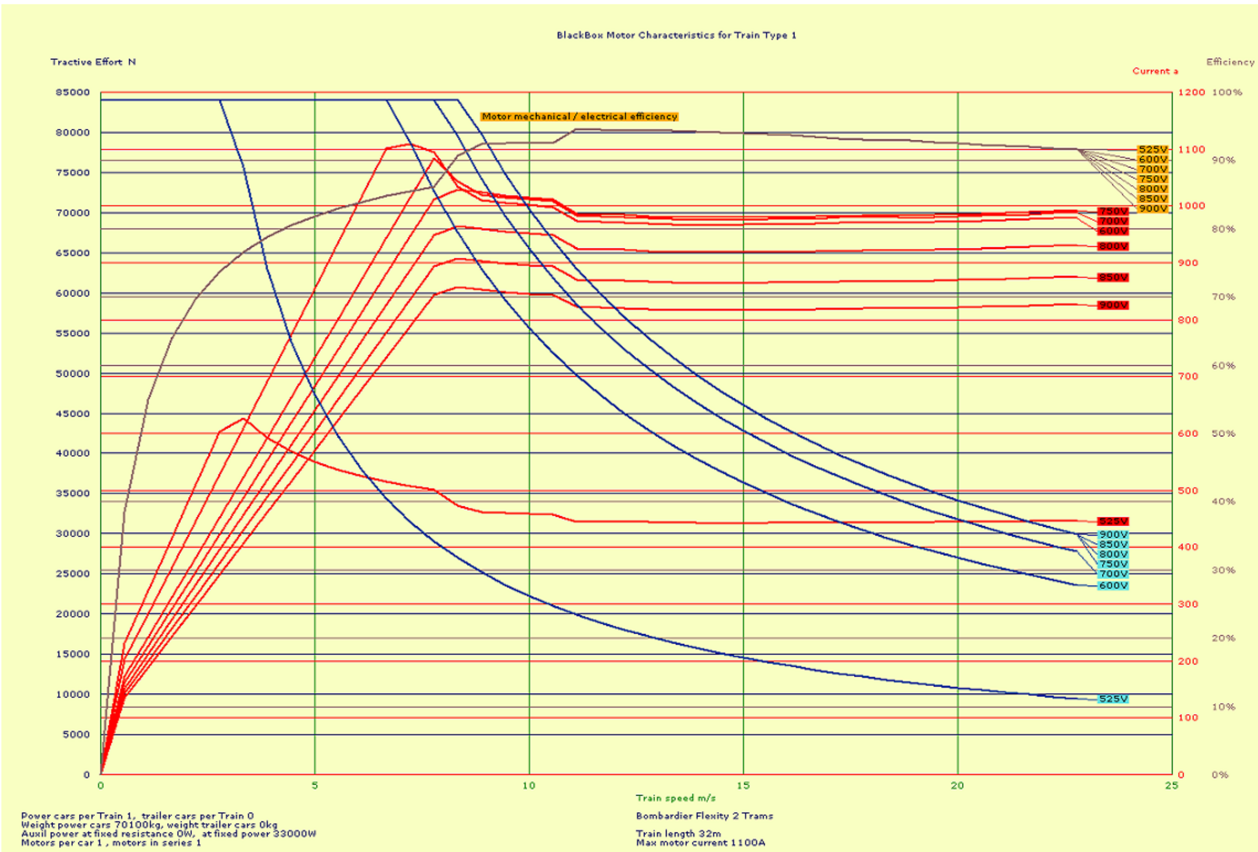

Figure 11: Motor Characteristics and Tractive Effort

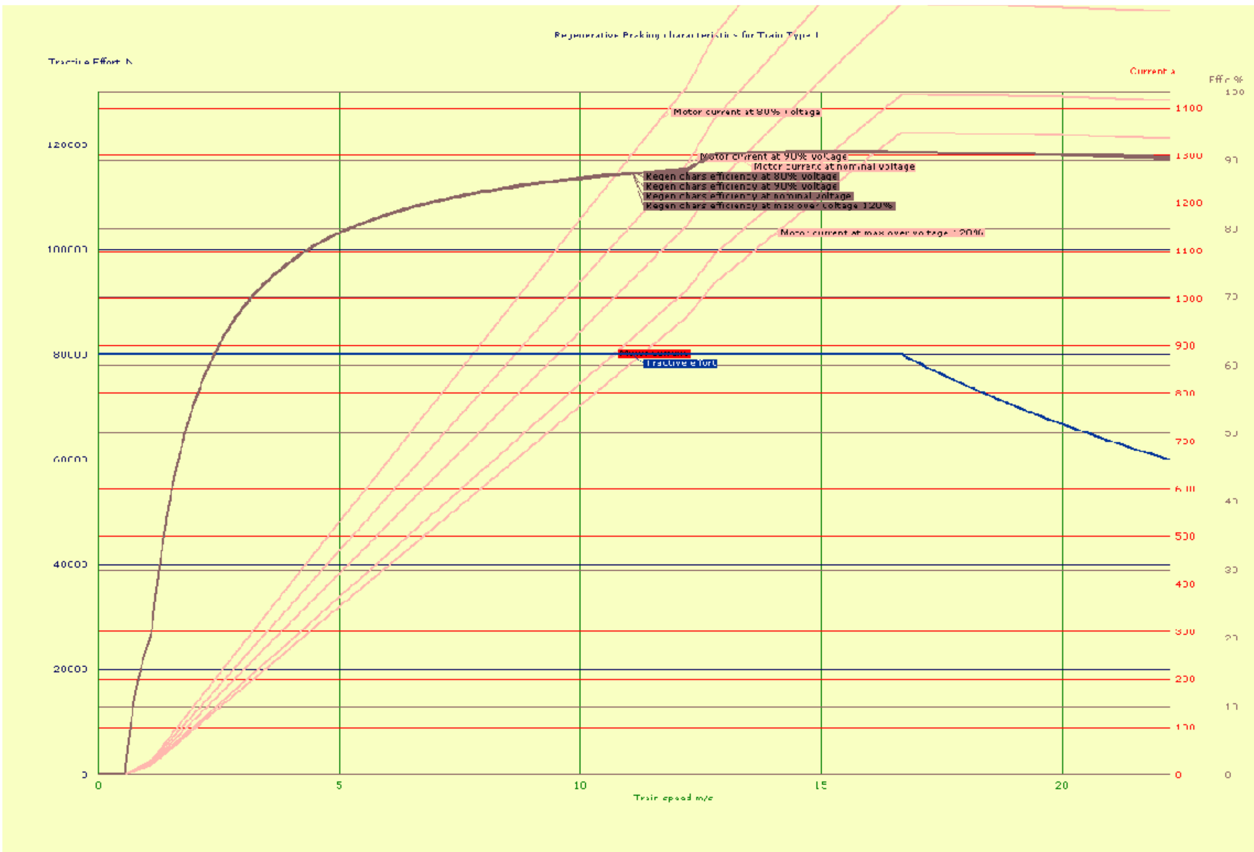

Figure 12: Regenerative Braking Characteristics

B.5. Traction Substations

Three traction substations were modeled between McMaster University station and MacNab station. The rating and locations were obtained from reference [2] (Appendix E)

Substation Location	Chainage (m)	Number and Rating of TRU (kW)
Adjacent to McMaster Uni. Station	210	1x1000
Adjacent to Longwood Stop	2100	1x1000
Adjacent to McNab Stop	4600	1x1000

B.6. Speed Restrictions

The speed restriction data are taken from reference [2]. The maximum speed is set to 60km/h in the entire route for both directions.

B.7. Timetable

An operational headway of 4 min is modeled according to [2]

B.8. Gradients

The route gradients were obtained from drawings Hamilton LRT 'B' Line- Preliminary Design Plan and Profile sheets 1-10 from the TPAP package.

B.9. Assumptions

The key assumptions are listed below:

- A standard single conductor catenary and standard gauge rail track (1435mm) are considered.
- Return current is equally distributed between the two running rails (50% current on each rail)
- The height of the catenary is assumed to be 5m
- Distance between the tracks is considered to be the standard 2m separation distance
- The 1st substation is located 210m western of the end of the line (McMaster University station). It must be noted that this is a preliminary suggestion [2] and the location might change during the next phases of the more detailed design, resulting in different current levels and length of current carrying conductors.
- The tracks are cross-bonded every 100m. It is assumed that there are cross-bonds on the ends of the line.
- The motor and traction characteristics of Bombardier Flexity 2 LRT vehicle were used during the simulation based on its similarity to the proposed LRT vehicle system according to reference [2]