Modelling of Electromagnetic Fields Produced by High Voltage Submarine Cables

J. Rzempołuch[1]*, K. F. Goddard[1], S. Chaudhary[1], G. Callender[1], J. Dix[1], P. Lewin[1]

[1]University of Southampton, Southampton, United Kingdom

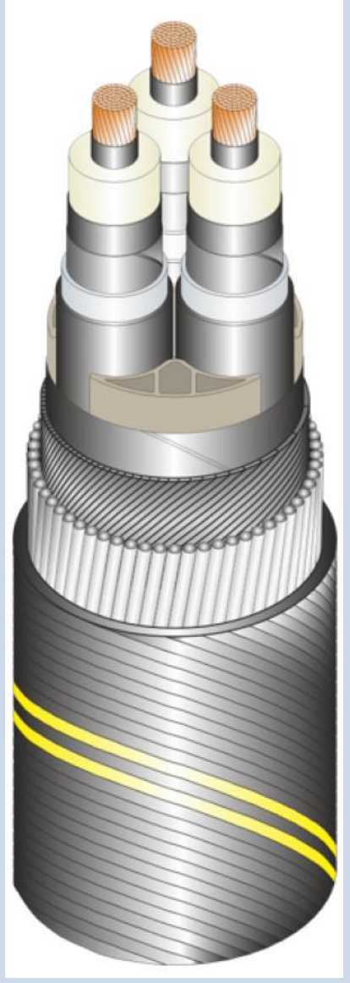
Introduction

Accurate modelling of EMFs associated with HV submarine cables is required to conduct biological experiments that aim to reproduce similar EMF conditions to a real-life submarine cable and is a necessary part of the licensing process. In this work, a methodology for HV (high voltage) cable modelling is presented. Initial computations utilise COMSOL Multiphysics, a Finite Element Analysis software. A less computationally complex and more accessible computational techniques are developed, and their accuracy is assessed through comparison with computational models.

Types of HV cable systems

Two main cable systems include HVAC (Fig.1) and HVDC (Fig.2). The modelling approach differs in geometry and implementation depending on the cable type.

HVAC



- Mostly used in offshore windfarms as either export or inter-array
- Consist of three helically twisted conductors
- Produce both AC magnetic and electric fields

Figure 1: An example HVAC 3-core submarine export cable [1].

HVDC

- Mostly used as interconnectors
- Produce DC magnetic fields that perturb the geomagnetic field
- Most commonly operate in a bipolar configuration

Figure 2: An example HVDC submarine cable [1].

Numerical methods

Some of the cable characteristics introduce complexity to the system making it difficult to calculate the electromagnetic fields analytically. In such cases, numerical models can be employed to arrive at a solution or validate analytical solutions.

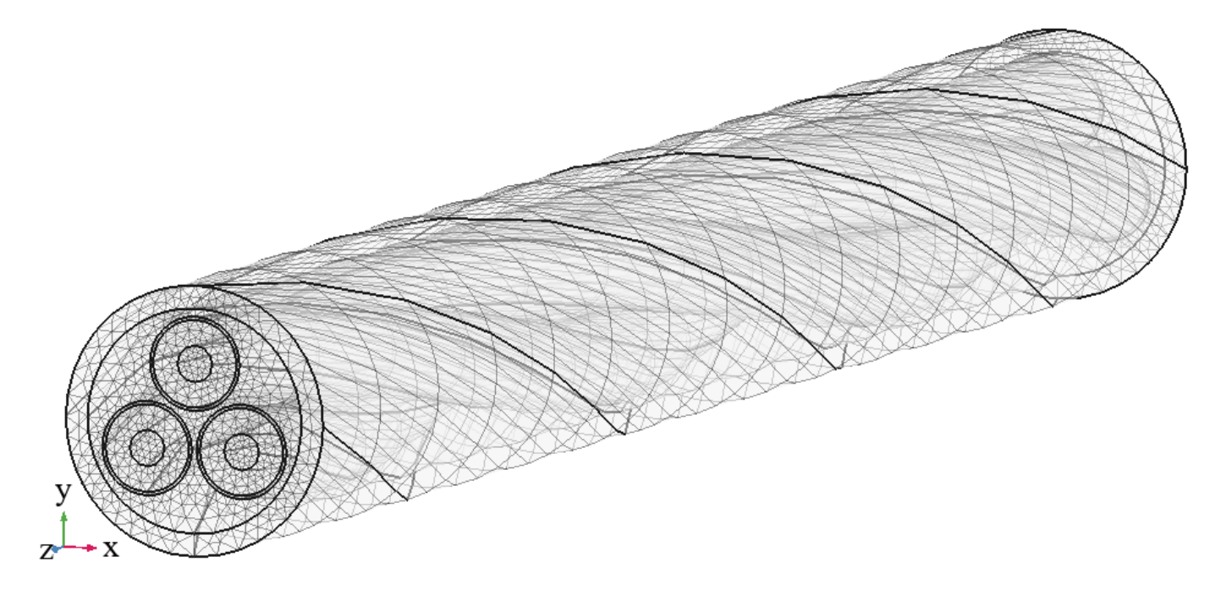


Figure 3: A geometry of an HVAC three phase export cable in COMSOL Multiphysics. The cable includes metallic sheaths and a twist.

When solving for HVAC systems, this method allows for inclusion of eddy currents induced in conductive components of the system which improves the accuracy of the solution. Figs. 4 and 5 show the magnetic field norm including these effects and the electric field norm which is a result of the time-varying magnetic vector potential ($-\frac{\partial A}{\partial t}$).

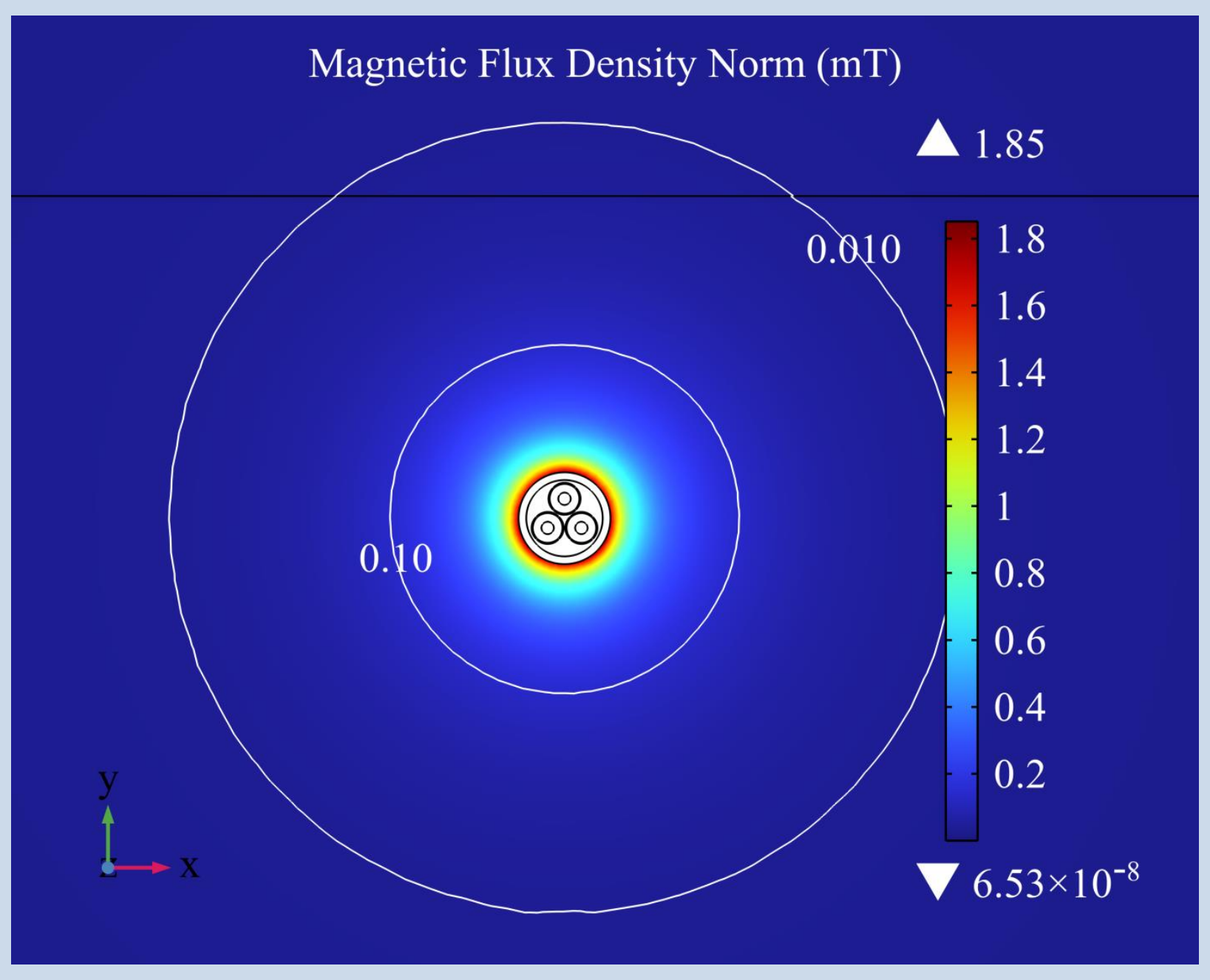


Figure 4: The magnetic field norm produced by an example HVAC cable.

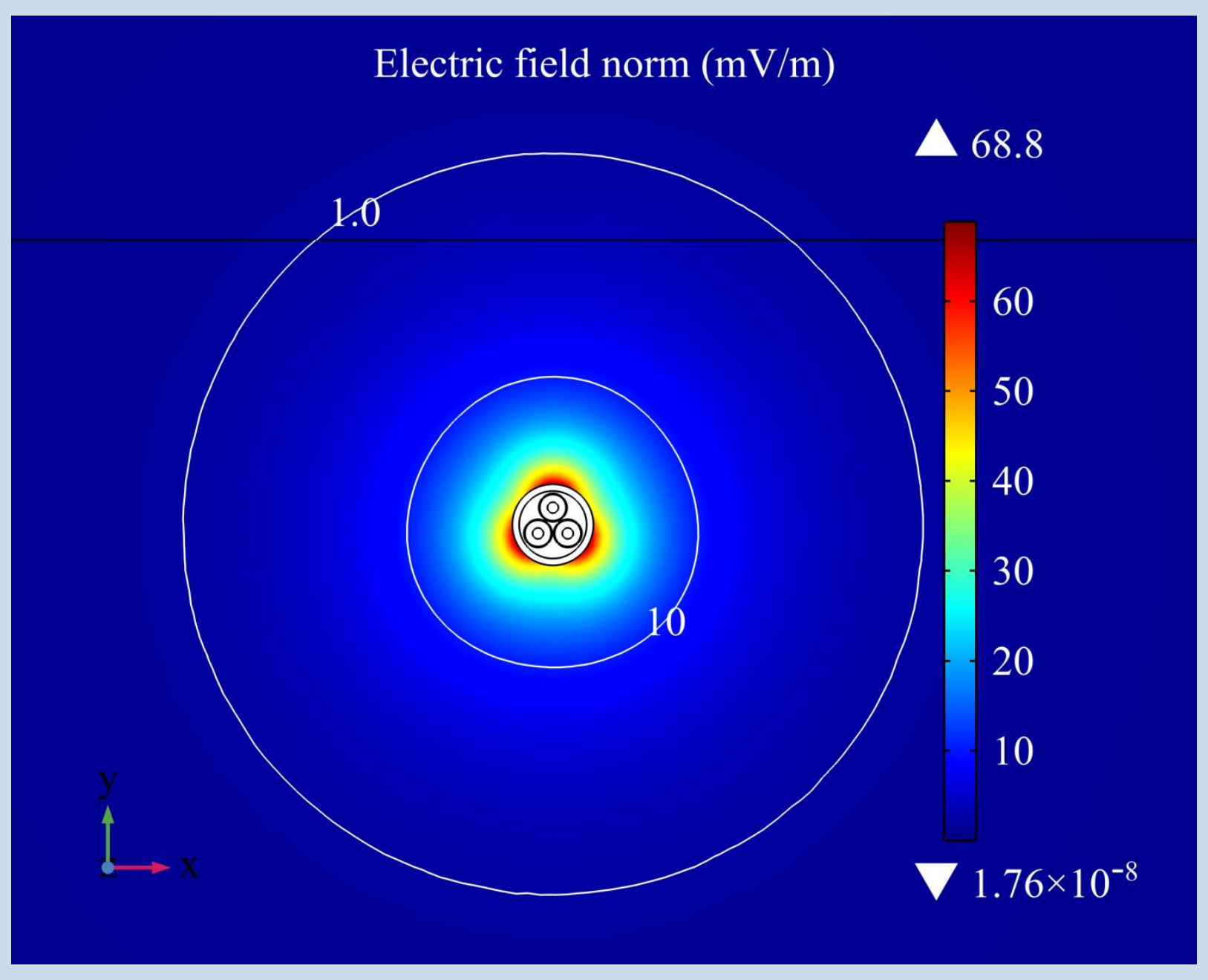


Figure 5: An electric field norm produced by an example HVAC cable.

Analytical methods

Depending on the degree of simplification, different analytical models can be developed to calculate the EMFs. Analytical methods are often advantageous as they do not require much computational power or specialist software.

In this work, a code for calculation of magnetic and electric field due to three helically twisted line currents was developed, following the expressions described in [2]. (1)-(3) are equations which have been used to compute the magnetic flux density components.

$$B_r = -\frac{\mu_0 I}{\pi} a\,\Omega^2 \sum_{n=1}^{\infty} n\, I_n'(an\Omega)K_n'(rn\Omega) \cdot \sin\big(n(\varphi_0 - \varphi + \Omega z)\big) \quad (1)$$

$$B_\phi = \frac{\mu_0 I}{2\pi r} + \frac{\mu_0 a I}{\pi r}\Omega \sum_{n=1}^{\infty} n\, I_n'(an\Omega)K_n(rn\Omega) \cdot \cos\big(n(\phi_0 - \phi + \Omega z)\big) \quad (2)$$

$$B_z = -\frac{\mu_0 I}{\pi} a\Omega^2 \sum_{n=1}^{\infty} n\, I_n'(an\Omega)K_n(rn\Omega) \cdot \cos\big(n(\phi_0 - \phi + \Omega z)\big) \quad (3)$$

This approximation for an HVAC system does not assume that the currents are parallel and thus includes the cancellation due to the twist resulting in more accuracy than previously adopted approaches. Example plots produced using this method are presented in Figs. 6 and 7. The method was validated by a numerical solution (Figs. 8 and 9)

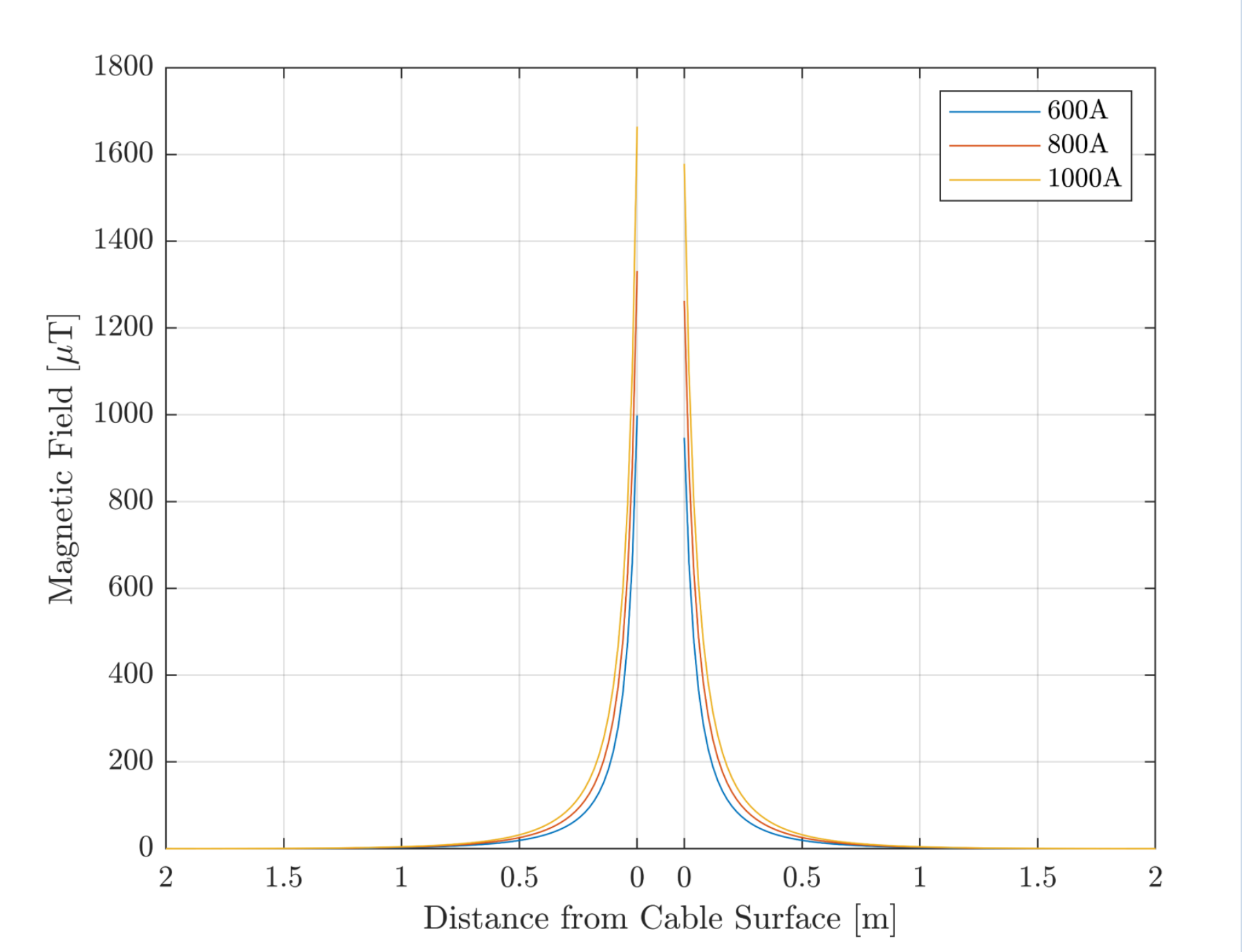


Figure 6: A line plot of the magnetic field norm as a function of distance from the cable.

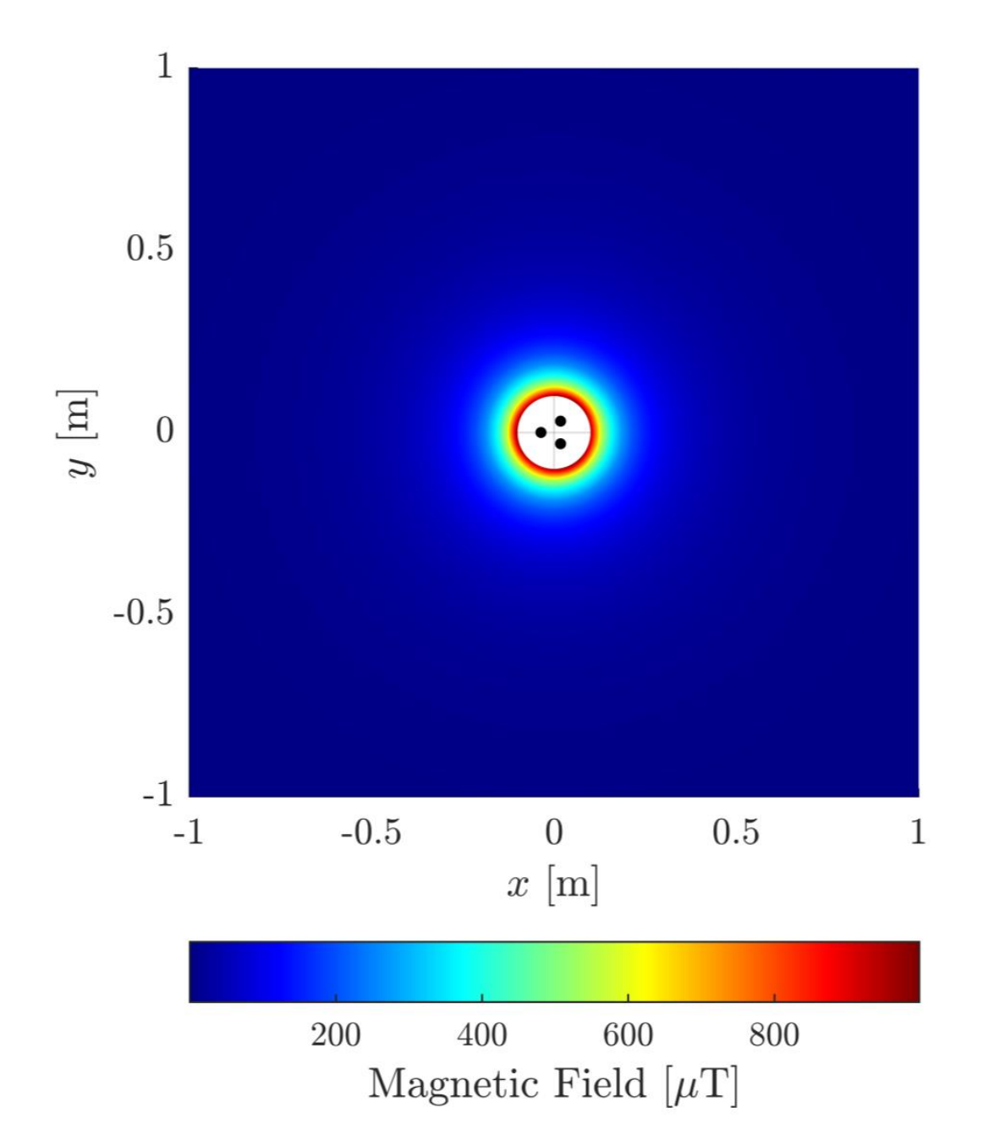


Figure 7: A surface plot of the magnetic field norm.

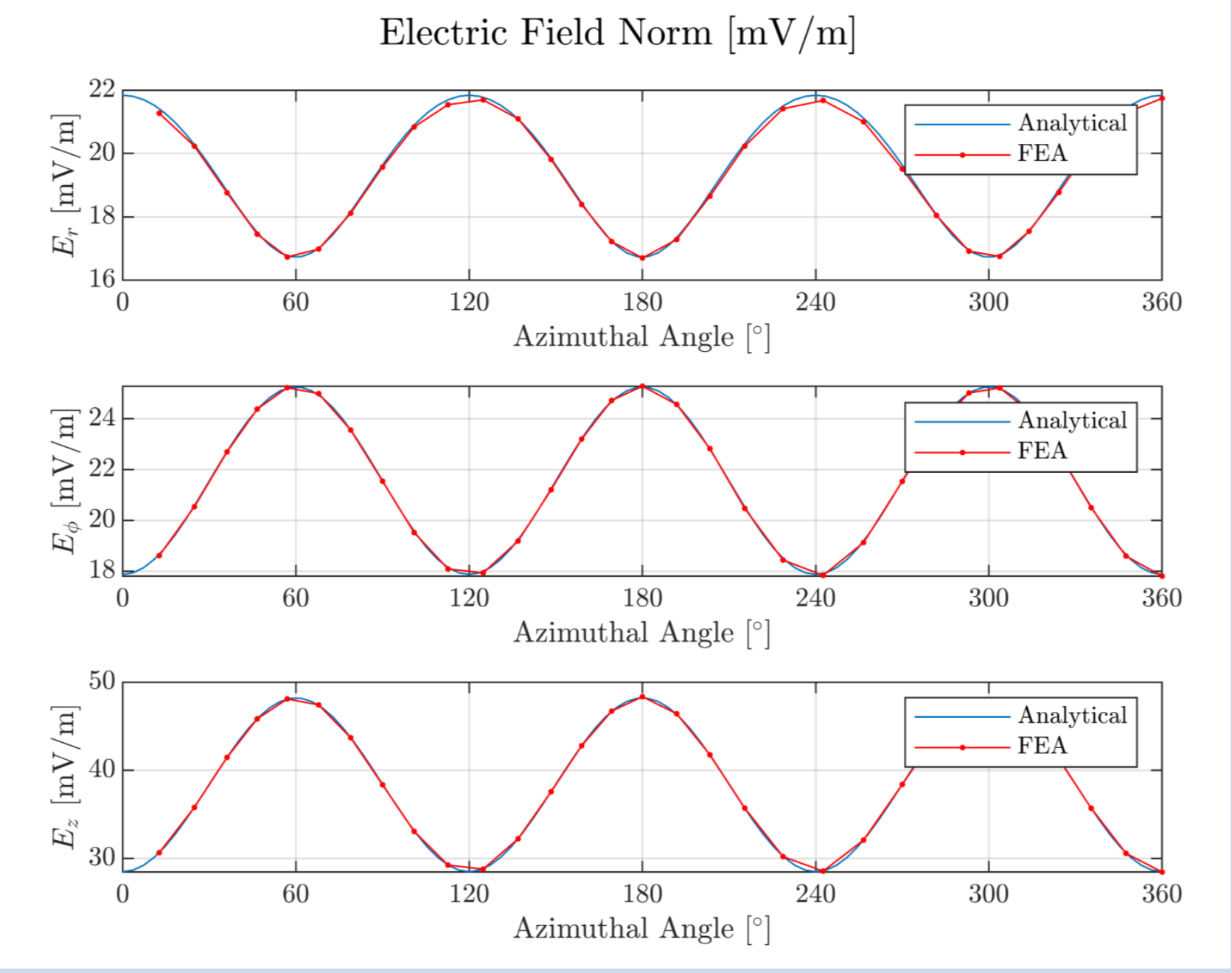


Figure 8: Agreement between the numerical and analytical solution for electric field norm due to three helically twisted line currents plotted in cylindrical coordinates.

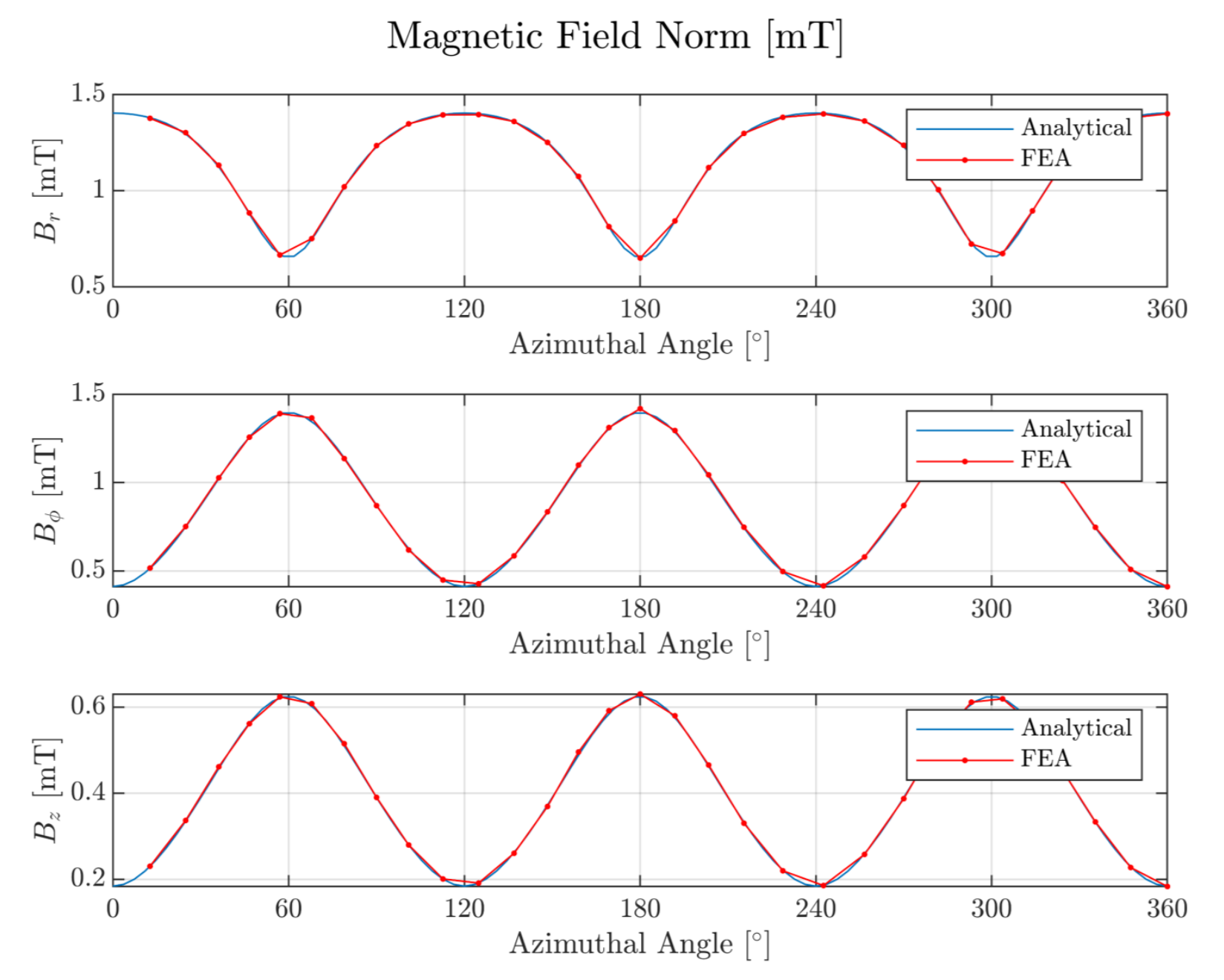


Figure 9: Agreement between the numerical and analytical solution for the electric field due to three helically twisted line currents plotted in cylindrical coordinates.

Future Work

- App development
- Inclusion of the cable sheaths and armour in the analytical solution

References

[1] "Power cable rating examples for calculation tool verification. Reference:880", CIGRE, Tech. Rep., September 2022

[2] R. Hagel, L. Gong and R. Unbehauen, "On the magnetic field of an infinitely long helical line current," in IEEE Transactions on Magnetics, vol. 30, no. 1, pp. 80-84, Jan. 1994

Contact details

Joanna Rzempołuch, *jr9g20@soton.ac.uk