

Assessment of insulation technology for overhead line equipment

Using Finite Element Analysis to Validate Experimental Setups

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ABSTRACT

The electrification of the UK rail network poses notable challenges for overhead equipment. High voltage overhead equipment requires appropriate clearance so that impressed lightning strikes or AC overvoltages cannot discharge to the train or other earthed structures. In meeting the challenge of electrification of existing rail networks, creating space to guarantee safe operation can require demolition and rebuilding of extant bridges and other structures. This incurs a increased civil engineering costs and can cause significant disruption for other transport networks and local businesses. This paper details the assessment of two insulated bridge arm technologies designed to decrease clearance between earthed overhead structures and high voltage conductors. The obtained results use finite element analysis and empirical testing to confirm minimum safe working distances that are integral to any rail electrification project and key to any implementation that involves pre-existing infrastructure.

KEYWORDS

withstand distance, impulse testing, power frequency testing, overhead insulation co-ordination, finite element analysis, numerical modelling

1 Introduction

Establishing safe withstand distances has been a key part of rail electrification since the late 1800s [1]. Currently, the UK is facing major challenges navigating around extant structures with insufficient clearance to accommodate electrification [2].

In the majority of early standards, the clearances discussed only pertain to potential disruptive discharge at supply voltage [3]. They do not consider the eventualities of lightning strike on or near

overhead lines. Modern standards, such as BS EN 60060-1:2010, now include lightning protection and a series of tests to ensure equipment will not fail should a lightning impulse hit an overhead line. However, the methods and derivations used for establishing these clearance distances are often not explicitly outlined. This characterises the evolution of the standard withstand distance is somewhat opaque. Hence the need for additional assessment as overhead line equipment changes and the use of insulating components increases to confirm and potentially update standard design values that are often taken for granted. The integration of electromagnetic modelling has also proved a unique benefit in assessing these clearances.

2. Results

Table 1 records results from wet impulse testing and confirms withstand distances of 280mm for Arm A arm and 340mm for the Arm B. The addition of the surge arrester reduces these distances to 0mm and 60mm for Arm A and Arm B arms respectively. The dry test results produced distances of 260mm and 300mm for Arm A and Arm B without a surge arrester. Connecting the surge arrester reduced these distances to 0mm and 60mm as in the wet tests.

Table 1 Impulse testing withstand results

Wet/dry test	Surge arrester used?	Withstand distance (mm)	
		Arm A	Arm B
Wet	No	280	340
	Yes	0	60
Dry	No	260	300
	Yes	0	60

Table records the wet power frequency testing results of 80mm and 100mm for a 5 minute withstand of 40kV for the Arm A and Arm B arms. In dry conditions the withstand distances are 5mm and 80mm respectively.

Table 2 Power frequency testing withstand results

Wet/dry test	Withstand distance (mm)	
	Arm A	Arm B
Wet	80	100
Dry	5	80

3. Analysis and Conclusions

Using two COMOL models of Arm A, Figure 1, and Arm B, Figure 2, to explain various electromagnetic phenomena observed during testing, the following conclusions have been drawn.

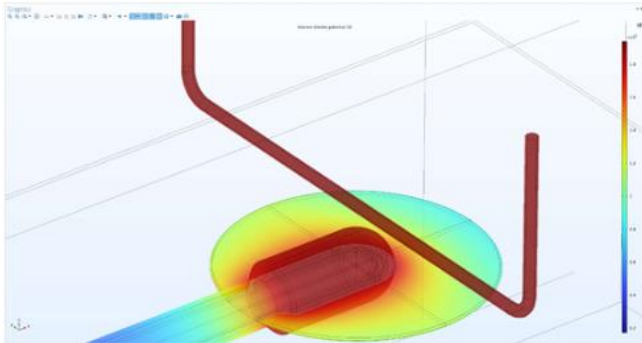


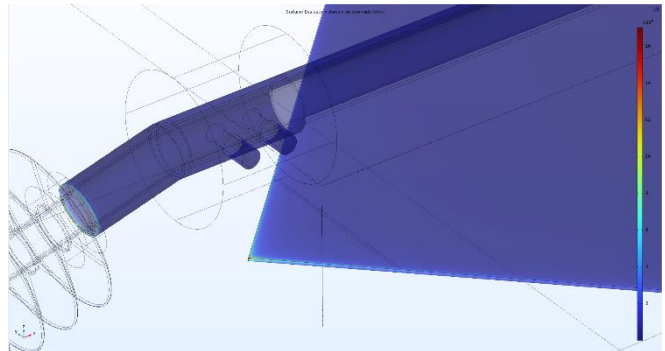
Figure 1 COMSOL plot volume electric field of Arm A.

Arm A arm is more resistant to breakdown due to the rounded design and large amount of insulating material. However, some back discharges were observed during testing indicating a build-up of surface charge on the insulation of the arm. There is also concern over potential partial discharge issues. A previous test on an older version of Arm A resulted in a puncture and permanent damage to the arm.

Using forensic work on the previous arm and measurements taken by hand the Arm A model was created. Upon deconstructing the arm it was discovered that the glass-reinforced plastic core has an aluminium fixture attached to the end which is used to connect the contact wire. The most likely reason for this puncture is the aluminium inside the insulating material being at the same volts as the contact wire. This most likely occurred after partial discharges weakened the insulation surrounding the aluminium. It is likely the encapsulated conductor and the mix of insulation systems used caused local field distortion and charge accumulation at interfaces

leading to partial discharges and accelerated degradation. This design was used to create a FEA model, Figure 1, to further illustrate the potential high fields across the bulk insulation near to the connection with the contact wire. In summary, whilst the withstand distances of the Arm A arm are smaller there is a potential risk of long-term accelerated ageing, ultimately leading to degradation and failure of the insulation.

Figure 2 COMSOL plot of surface electric field of Arm B.



Comparatively, Arm B arm requires a larger withstand distance due to its design particularly in regard to its conducting elements. Specifically, there are two large nuts mounted on protrusions on the side of the arm which can be seen in Figure 2. The domain of the Arm B FEA model where the bolts have been rendered with a finer mesh for increased accuracy. The bolts have been conservatively modelled as cylinders. The bolts on the arm are hexagonal M16 screws with undoubtedly higher fields. These bolts caused issues during testing due to the high field points of their edges. Arm B arm was initially tested with the same configuration of the 1m2 earth plate at 45° to the length of the arm. However, due to the geometry and size of the arm, high field points caused a reverse polarity effect during negative confirmation where withstand distances began to increase rather than decrease. The earth sheet in the model was also identified as a high field point creating a path between the bolt edges at 193kV and the corner of the aluminium plate. This model is validated by observation of several discharges from the bolt area as seen in Figure 2.

REFERENCES

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