WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

Superconducting Cables – Network Feasibility Study

Project Closedown Report

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Contents

Glossary

Abbreviation	Term
Cost Benefit Analysis	CBA
Distribution Network Operator	DNO
High Temperature Superconducting	HTS

Executive Summary

Investigating new ways of providing additional capacity to electricity distribution networks is of great interest to Distribution Network Operators (DNO) as many networks are reaching their capacity limits. Additionally, conventional approaches of network reinforcement like building new substations, are not always suitable in urban locations where space and land availability are limited, increasing the need for finding alternative solutions.

For this reason, a network feasibility study was performed by the University of Bath as part of this project, to investigate whether superconducting cables should be used to solve capacity issues in electricity distribution networks and make appropriate recommendations for a network trial.

It was concluded that currently, superconducting solutions are significantly more expensive than conventional solutions and for this reason a demonstration project is not recommended. However, it is estimated that if prices of superconducting materials keep dropping by 10% every year, a trial could be feasible in five to ten years.

1 Project Background

The increasing number of electricity distribution networks reaching their capacity limits means that the need for network reinforcement will continue to grow. Reinforcing our networks using conventional approaches involves among others, building new electricity substations and installing additional transformers at the sites where capacity needs to be enhanced. This can be incredibly challenging in urban environments due to limited land availability and high costs, creating the need to investigate alternative solutions.

The problem can be solved by installing new transformers or substations where it is easy to do so and then transferring their capacity to the networks that need it. Due to their high efficiency, small volume and high capacity, superconducting cables are an attractive solution for connecting new equipment to the physically remote networks that require the additional capacity.

In this project, a feasibility study was performed to determine whether such an implementation should be considered.

2 Scope & Objectives

The project has assessed the benefits and technical issues of using superconducting cables to provide additional capacity in dense urban environments. In such locations land prices or availability can be problematic in establishing new substations.

This project was a feasibility study with the aim to improve knowledge of the technology's benefits, challenges and costs to determine whether a demonstration project is appropriate.

Objective	Status
Complete detailed feasibility study on Superconducting Cables.	✓
Improve knowledge on technology's benefits.	✓
Improve knowledge on technology's challenges.	✓
Improve knowledge on technology's costs.	✓
Determine whether a demonstration project of superconducting cables in the electricity distribution network is appropriate.	✓

3 Success Criteria

The main success criteria of the project included presenting a comprehensive review of superconducting cable technology and a case study of how the technology could bring benefits to WPD's networks. Additionally, through the review of the technology, establishing a relationship with manufacturers of superconducting cables was a very important success criterion of the project. Finally, by analysing the capital and operating costs of the technology, the project was considered a success by providing a clear recommendation for a trial project.

Success Criteria	Status
A comprehensive review of superconducting cable technology is presented.	✓
A relationship with superconducting cable manufacturers has been established.	✓
A case study of how the technology can bring benefits to WPD's networks is demonstrated.	✓
A viable pathway leading to a trial project is recommended where full details of capital and operating costs is documented	✓

4 Details of Work Carried Out

This study examined the feasibility of using High Temperature Superconducting (HTS) cables in UK electricity distribution networks to address network capacity problems.

Compared with conventional copper power cables, superconducting cables can offer several unique benefits:

- Under the same power transmission voltage level, the current carrying capability of HTS cables is three to five times more than that of conventional copper cables. This means that a superconducting cable could replace several conventional cables, requiring less space and land.
- Superconducting cables can carry equivalent power capacity at a much lower voltage level which could enable the replacement of large, expensive high voltage conventional cables with lower voltage superconducting cables.
- Superconducting cables can carry AC current with much lower losses compared to conventional cables.
- Due to their very high current density, superconducting cables could be of very compact size, providing a promising solution where underground space is limited.
- As superconducting cables have no thermal and electromagnetic impact on their surroundings, it is suitable to install them in the already existing underground pipelines, thus expanding the power transmission capacity.

These unique characteristics of HTS cables make them an attractive technology, especially in urban areas where underground space and land availability is limited. In these urban areas, the networks are most often reaching their capacity limits, making the case for investigating the feasibility of using HTS cables in electricity distribution networks even stronger.

The project assessed the benefits and technical issues of using superconducting cables to provide additional capacity in dense urban environments. In such locations land prices or availability can be problematic in establishing new substations. As the first comprehensive study examining the feasibility of using superconducting cables in UK distribution networks, it provides significant learning.

The network feasibility study was structured in 3 work packages:

Work Package 1
Work Package 1 explored the history of Superconducting Cables, presented previous implementation projects and formed a comprehensive Cost Benefit Analysis (CBA) of existing Superconducting cable technologies with detailed comparisons of all their aspects to traditional solutions. This offered valuable knowledge on the

Superconducting cable technology and based on the costs indicated in which areas of the network a more detailed case study should be performed.

Work Package 2
Based on the findings from Work Package 1, in this work package a site for the possible installation of a trial superconducting cable in WPD's network was selected. A detailed study was undertaken to justify the selection of the site, explain the installation procedures and requirements and analyse the costs. The study also considered the future requirements of the installation, which includes operational procedures, maintenance, and response to faults, repair and modelling of installation in WPD's power system analysis tools. Finally, all the aspects of the proposed implementation were compared to the conventional solution to provide clear conclusions.

Work Package 3
Work Package 3 provided an overview of the learning and knowledge that was captured in the previous two stages, considered the future of the superconducting technology and made the final conclusions for a network trial.

5 Outcomes

Work Package 1 presented the history of the superconducting cable technology, previous implementation projects in electricity distribution networks and explored the existing superconducting cable technologies comparing them with the conventional cable solutions.

Furthermore, to understand the structure of superconducting cable systems and their main challenges, their key aspects were analysed, including the installation, operational and repair procedures and requirements, maintenance requirements, expected lifetime and costs. The same aspects were discussed for the conventional cables, finally forming a Cost Benefit Analysis comparing the two technologies.

Through the investigation of Work Package 1, the following conclusions have been made:

- Superconducting cables have already been demonstrated to transfer similar or more power than the conventional cables, at lower voltages with reduced losses.
- Superconducting cables have the unique advantages of zero magnetic and electric field radiations, potentially making their installation easier.
- With the technology being very young and the lack of appropriate demand, the cost of superconducting materials is high. This results in high capital costs for superconducting cables.
- A simple cost calculation model for superconducting cables has been developed, as part of a preliminary cost comparison study between superconducting and conventional cables of different voltage ratings. From the results obtained, it was concluded that due to the high capital costs of superconducting cables, the usage of superconducting cables to add capacity at a 132/11kV site (where the costs of the conventional solution are the highest) should be considered in the detailed case study of Work Package 2.

Following the recommendations made in Work Package 1, the case study of Work Package 2, considered the implementation of a superconducting solution to provide capacity to a 132/11kV substation that required reinforcement. As part of this work, detailed comparisons were performed between the superconducting and conventional solutions to investigate whether the superconducting implementation should be considered. The comprehensive descriptions of superconducting cable and XLPE cable are provided to give a full understanding each technology.

The main conclusions from Work Package 2 are:

- 11kV superconducting cables are capable of transferring power to substations requiring reinforcement in near future, by transferring the spare capacity from the nearby substations.
- Compared to conventional cables, 11 kV superconducting cable has advantages of delivering bulk power with one single cable, with reduced space or right of way, noise, losses (resulting in carbon emissions) etc.
- The present value of superconducting cable solution is £23.11m compared to £14.11m of conventional solution over the 40 years' operation. The superconducting solution

consisted of a superconducting cable providing one of the two infeed's to the substation while the second infeed was provided using the convention 132kV cable and 132/11kV transformer. The conventional solution consisted of two 132kV cables and two 132/11kV transformers providing the two infeed's to the substation.

- Superconducting cables are more suitable to be used, where conventional cables can't deliver due to space, noise or emission constraints, such as urban city and residential areas.
- Superconducting cables could be more cost effective to be used in heavily loaded areas over a short length.
- As pointed out in reference [5], superconducting cable cost can be significantly reduced in future. For the current study, if superconducting cable cost is reduced to £8/kA-m, then the present value of superconducting cable will be the same as conventional cable.
- The competitiveness of superconducting cable can be improved by reducing the cooling cost.

Overall, Work Package 2 of this network feasibility study has shown that superconducting solutions are currently significantly more expensive than traditional reinforcement solutions, therefore an implementation project cannot be considered. For this reason, Work Package 3 explored the future of superconducting cables and investigated in further detail the changes in the market and costs required to make them an attractive option for implementation in electricity distribution networks. Additionally, Work Package 3 described the unique case where Superconducting Cables could perhaps be the only reinforcement option in other DNO networks. The work completed in Work Package 3 has shown that:

- The capital cost of superconducting solutions of shorter length could be comparable to conventional solutions in 5-10 years if prices keep dropping by 10% every year.
- Superconducting solutions consume only a small proportion of the total land required by conventional solutions and could potentially be the only viable solution, where there is a shortage of land availability and no other reinforcement solutions are suitable.

6 Performance Compared to Original Aims, Objectives and Success Criteria

Objective	Status	Performance
Complete detailed feasibility study on Superconducting Cables.	✓	The feasibility study was structured in 3 Work Packages which covered all planned aspects. Reports were produced capturing the learning and documenting the work completed for each work package.
Improve knowledge on technology's benefits.	✓	Work Package 1 provided valuable knowledge through the literature review and Cost Benefits Analysis performed.
Improve knowledge on technology's challenges.	✓	The case study of Work Package 2 has shown that the main challenge of the technology is the high cost compared to conventional solution.
Improve knowledge on technology's costs.	✓	This was explored in Work Packages 1 and 2. The costs of the solutions considered were obtained from Superconducting Cable Manufacturers.
Determine whether a demonstration project of superconducting cables in the electricity distribution network is appropriate.	✓	Work Package 2 has shown that currently a demonstration project is not recommended and Work Package 3 has estimated that in 5-10 years if prices of superconducting materials keep dropping, a demonstration project could potentially be feasible.

Success Criteria	Status	Performance
A comprehensive review of superconducting cable technology is presented.	✓	Work Package 1 presented the history of the superconducting cable technology and previous implementation projects. The key aspects of superconducting cable systems were analysed, including the installation, operational and repair procedures and requirements, maintenance requirements, expected lifetime and costs.
A relationship with superconducting cable manufacturers has been established.	✓	This was achieved in both Work Packages 1 and 2. In Work Package 1, manufacturers provided general information about the costs of superconducting cables and in Work Package 2 they provided specific costs for the case study.
A case study of how the technology can bring benefits to WPD's networks is demonstrated.	✓	Work Package 2 presented the Case Study that explored the usage of superconducting cables to solve capacity issues at a 132/11kV substation.
A viable pathway leading to a trial project is recommended where full details of capital and operating costs is documented	✓	The project concluded that a demonstration project is not recommended as the detailed costs analysis has shown that superconducting solutions are significantly more expensive than conventional solutions.

7 Required Modifications to the planned approach during the course of the project

The planned approach was followed during the project and no significant modifications were made.

8 Significant Variance to Cost and Benefits

Activity	Budget	Actual
WPD Project Management	£25000	£18876
Bath University Contract	£64809	£64809

The reduced Project Management costs are due to spending less time on the project than planned.

9 Lessons Learnt

The network feasibility study has offered valuable learning on the superconducting cable technology, its unique benefits, previous implementations and costs compared to conventional solutions.

From the interaction with the superconducting cable manufacturers as part of Work Packages 1 and 2, it was found that costs of superconducting cables vary from manufacturer to manufacturer due to the processes they follow and the materials they use. This cost variability was taken into account in the cost estimations of Work Package 1. Additionally learning was obtained about the relationship between superconducting cable manufacturers and suppliers of superconducting materials, as they work very closely together to provide solutions for potential projects.

The site selection for the Case Study in Work Package 2 has shown that projects that involve building a new 132/11kV or 132/33kV substation do not take place very often. In most cases the capacity problem is solved by replacing the existing transformers or reconfiguring the load that the constrained substation is feeding. Additionally, it was found that reinforcement projects usually solve a number of problems including load and asset condition related issues. This makes the comparison of different reinforcement solutions challenging when performing a Cost Benefit Analysis.

Through Work Packages 1 and 2 it was found that the installation procedures for superconducting cables are similar to those of conventional cables, however the installation of a superconducting system is still something that is recommended to be done by the manufacturer of the technology as DNOs do not have previous direct experience.

It was found that the benefits of the superconducting cable technology including the high power density and low losses, could be very important in resolving network capacity issues in electricity distribution networks. However, it was demonstrated that due to the significantly higher costs of the superconducting solution compared to the conventional approaches, a demonstration project is not recommended.

10 Planned Implementation

The project has shown that an implementation project is not recommended due to the high costs of the technology. However, if the costs of the superconducting technology keep falling by 10% every year, it is recommended to re-examine the feasibility of a demonstration project in 5-10 years.

11 Facilitate Replications

There is no requirement to replicate the project. However, a replication of the feasibility study would be recommended after 2022 as the changes in the costs of the superconducting technology could make the implementation feasible in the future.

12 Contact

Further details on replicating the project can be made available from the following points of contact:

Future Networks Team
Western Power Distribution,
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