WESTERN POWER DISTRIBUTION

INNOVATION

NEXT GENERATION NETWORKS

SUPERCONDUCTING CABLES – NETWORK FEASIBILITY STUDY

WORK PACKAGE 3

Report Title	:	SUPERCONDUCTING CABLES – NETWORK FEASIBILITY STUDY WORK PACKAGE 3
Report Status	:	FINAL
Project Ref	:	WPD_NIA_015
Date	:	26/05/2017

Document Control

	Name	Date
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Revision History

30/05/2017	V3.0	Final
26/05/2017	V2.0	Final Review
28/04/2017	V1.0	Draft for Review

Glossary

Abbreviation	Term
DNO	Distribution Network Operator
HTS	High Temperature Superconducting
SC	Superconducting Cable
XLPE	Cross-Linked Polyethylene
PV	Present Value
FV	Future Value
CBA	Cost Benefit Analysis
GSP	Grid Supply Point

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Chapter 1

Introduction

1.1 The Motivation behind this Feasibility Study

The increasing number of electricity distribution networks reaching their capacity limits means that the need for network reinforcement will continue to grow. Reinforcing the networks using conventional approaches includes building new electricity substations and installing additional transformers. This is incredibly challenging in urban environments due to limited land availability and high costs, hence creating the need to investigate alternative solutions.

This study examines the feasibility of using High Temperature Superconducting (HTS) cables in UK electricity distribution networks to address the problem.

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 its 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 its surroundings, it is suitable to install them in the already existing underground pipelines, thus expanding the power transmission capacity.

These unique characteristics of High Temperature Superconducting 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.

1.2 The Objective

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

The project will assess 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 will provide significant learning and could possibly lead to the UK's first trial.

1.3 The Three Work Packages

This feasibility study consists of the following 3 work packages:

Work Package 1

Work Package 1 forms a comprehensive Cost Benefit Analysis (CBA) of existing Superconducting cable technologies and detailed comparisons of all their aspects to traditional solutions.

Work Package 2

In this work package, a site for the possible installation of a trial superconducting cable in WPD's network will be selected and a detailed study will be undertaken to justify the selection of the site, explaining the installation procedures and requirements and analysing the costs. The study will also consider 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 will be compared to the conventional solution to provide clear conclusions.

Work Package 3

Work Package 3 will provide an overview of the learning and knowledge that was captured in the previous two stages and will make appropriate recommendations for a network trial.

This WP3 report has been structured into the following chapters: Introduction, Summary & Conclusions from previous Work Package's, Idealized Superconducting solution costs, HTS systems Futuristic cost predictions, varied length case investigations and Conclusions. Chapter 1, Introduction, aims to provide the reader with all the background information on the motivation behind this feasibility study. Then, Chapter 2, Summary & Conclusions from previous Work Packages, gives an overview of the findings from the work completed in this study up to now and explains how this shapes the scope of Work Package 3. Chapter 3 starts by demonstrating the superconducting solution costs required to make them at least as expensive as conventional solutions. Then Chapter 4, performs a projection of the costs in the following 10 years based on past trends, showing how much further in the future superconducting solutions could be financially attractive if prices continue to fall at the existing rate. Chapter 5 continues to examine the relationship between infeed length and total solution costs, while Chapter 6 investigates the land requirements that could make the superconducting solutions the only option on in, certain cases. Finally, Chapter 7 summarises the conclusions and learning of all Work Packages.

Chapter 2

Summary & Conclusions from previous Work Packages

2.1 Summary of Work Package 1 report

Work Package 1 is aimed to explore the existing superconducting cable technologies and compare them with the conventional cable solutions. It presented the history of the superconducting cable technology and previous implementation projects in electricity distribution networks. 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:

- Using Superconducting cables, the resistance of the distribution cables can be reduced to nearly 1/300 times the resistance of the conventional cable, thus reducing the resistive losses.
- 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, thus 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.

2.2 Summary of Work Package 2 report

Since Work Package 1 indicated that a previous reinforcement project at a 132kV/11kV or 132kV/33kV substation should be considered in the case study, the work commenced with the selection of such a project.

A 132/11kV substation in WPD network, which required reinforcement was chosen for this study. Based on the currently available infrastructure and applicability, two solutions have been considered for this reinforcement. The first is the conventional solution, which consisted of the implementation of a new 132/11kV substation. The second is the novel superconducting solution, which consisted of one conventional 132kV infeed feeding a new 132/11kV transformer and an additional infeed provided using an 11kV superconducting cable system. Considering both solutions, a feasibility study has been carried out and the key points are summarized as follows:

- Industrially acceptable solutions have been proposed using both the superconducting and conventional technologies ensuring they meet the standards imposed by P2/6[1].
- The costs of the superconducting solution have been obtained from manufacturers to ensure that the study is based on the current superconducting technology market.
- Simulated models for the superconducting and conventional solutions have been produced which examined the impact of each solution in the power flows, losses and fault levels in the network. The results showed a unique advantage of reduced fault current magnitudes and losses using the superconducting solution.
- From the power system simulations, the operational costs of each solution were calculated and superconducting solution is observed to be slightly less than conventional.
- Superconducting solutions are very compact and does require very less space compared to conventional, saving a significant capital cost on land purchase.
- To examine the financial case of each solution, NPV calculations were performed, which considered both the capital and operation costs of each.
- It was observed that the superconducting solutions' initial capital cost is nearly 70-75 % more than the conventional cables, thus highlighting the fact that superconducting solutions are currently significantly more expensive than traditional reinforcement solutions.
- From the above, WP2 recommended that Work Package 3 should explore the future of superconducting cables and investigate in further detail the changes in the market and costs required to make them an attractive option for implementation in electricity distribution networks.

[1] Energy Networks Association, Engineering Recommendation P2/6 – Security

2.3 Scope of Work Package 3 report

Since Work Package 2 concluded that superconducting solutions are currently more expensive than conventional solutions, Work Package 3 examined the changes in costs required to make them more attractive for usage in electricity distribution networks in the future. Additionally, the relationship between infeed length and cost was investigated to see whether different implementations could be more financially attractive than others. Finally, the land requirements of superconducting and conventional solutions were also compared to indicate for what cases superconducting solutions could potentially be the only option.

Based on the work completed in Work Package 2, Chapter 3 starts by demonstrating the superconducting solution costs required to make them at least as expensive as conventional solutions. Then Chapter 4, performs a projection of the costs in the following 10 years based on past trends, showing how much further in the future superconducting solutions could be financially attractive if prices continue to fall at the existing rate. Chapter 5 continues to examine the relationship between infeed length and total solution costs, while Chapter 6 investigates the land requirements that could make the superconducting solutions the only option in, certain cases. Finally, Chapter 7 summarises the conclusions and learning of all Work Packages.

Chapter 3

Idealised Superconducting Solution Costs

3.1 Introduction

Based on the findings from WP2, for the specific case analysed, superconducting cables are observed to be more expensive in terms of initial capital cost. This chapter aims to explore the economic challenges of superconducting cables, by calculating how much cheaper they should become to compete with conventional solutions, in terms of initial capital investment.

The methodology employed for this analysis is as follows:

1. Identifying the cost of conventional solution
2. Calculating the percentage share of different components in both solutions.
3. Calculating the cost of the superconducting infeed that would make the cost of the superconducting solution approach the cost of the conventional solution.

3.1.1 Identifying the cost of conventional solution

In the previous Work Package the conventional solution considered had an approximate cost of £13.5 million. This will form the basis of the cost calculations of the superconducting solutions required for a range of conventional solution costs of £8 – 16 million. The aim is to calculate how much the superconducting solutions should cost, to compete with each conventional solution.

3.1.2 Calculating the percentage share of different components in both solutions.

The most important part of this work is to quantify the cost contribution of individual components to the total solution. To achieve this, the layout diagrams for the individual solutions have been developed as shown in figure 3.1, which would give a much better indication of all the components required.

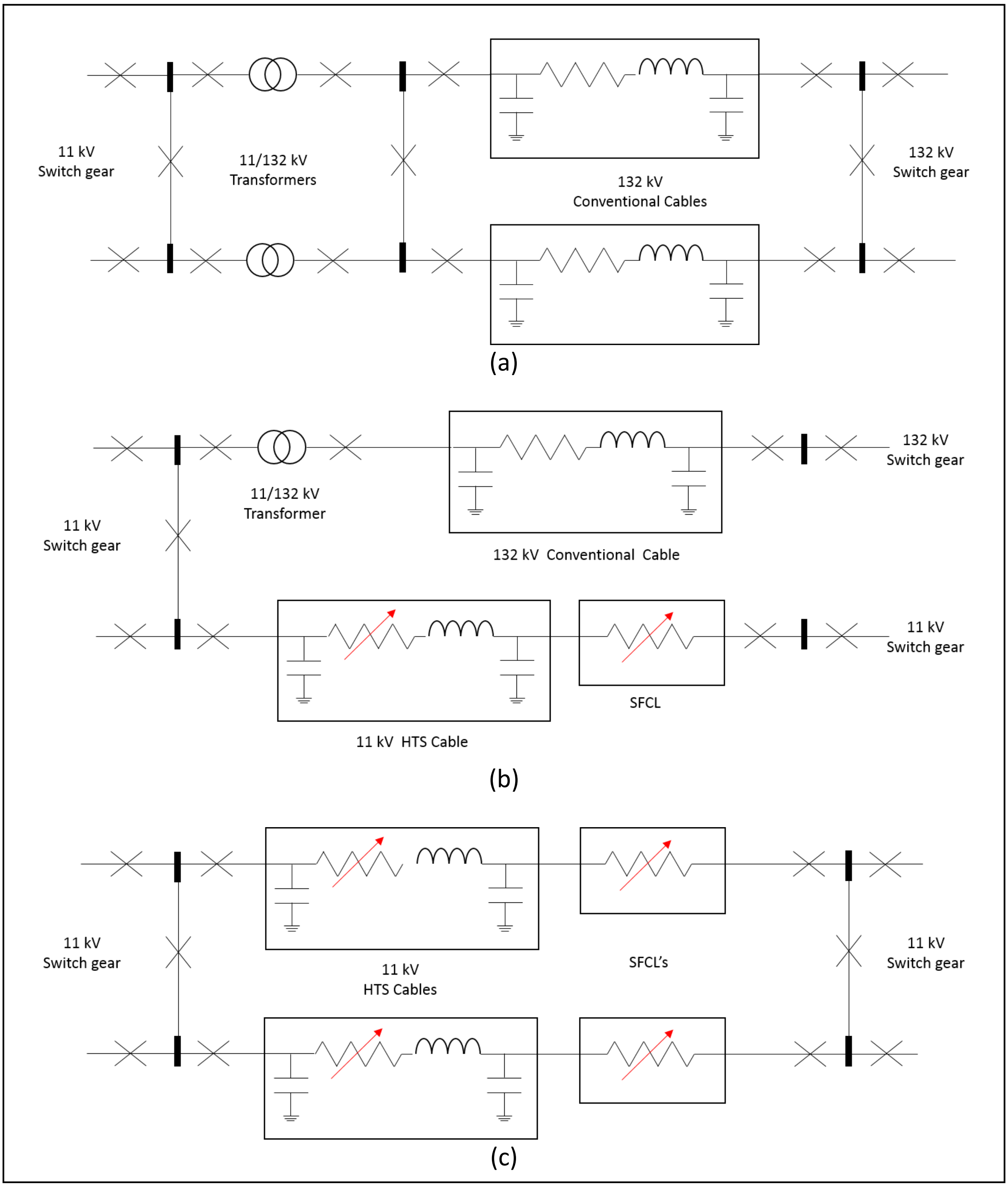

Figure 3.1: Layout diagrams for: (a) Conventional (b) Superconducting + Conventional and (c) Fully superconducting solutions.

The cost contributions have been estimated and quantified, as shown in the Tables 3.1, 3.2 and 3.3. From WP1 and WP2 it was found that the land required for the superconducting solutions if far less than the conventional solutions. Additionally, the cost of high voltage switchgear will be very high for the conventional solution compared to the low voltage switchgear needed in the superconducting solutions, as the superconducting solutions are being operated at low voltages. This explains the lower percentage of the switchgear cost contribution in the HTS solution compared to conventional solution as detailed in Tables 3.2 and 3.3.

Table 3.1: Cost contributions of individual components towards the conventional solution

		Percentage
Land cost		4 %
132 kV Cables cost		24 %
Transformers & 132 kV switchgear cost		28 %
Civil cost	132 kV Substation	12 %
	132 kV Cables laying	30%
11 kV switch gear		2%
Total		100%

Table 3.2: Cost contributions of individual components towards HTS + conventional solution

		Percentage
Land cost		2 %
132 kV Cables cost		12 %
11 kV HTS cable		49 %
SFCL		
Cooling System		
Installation		
Transformers cost		14 %
Civil cost	132 kV Substation	6 %
	132 kV Cables laying	15 %
11 kV switch gear		2 %
Total		100%

Table 3.3: Cost contributions of individual components towards complete HTS solution

	Percentage
Land cost	<1 %
11 kV HTS cable	98 %
Cooling System	
SFCL	
Installation	
11 kV switch gear	1 %
Total	100%

3.1.3 Cost of superconducting cable infeeds, referring to the cost of conventional solutions.

As shown in Tables 3.2 and 3.3, it is observed that a single superconducting infeed should cost around 49% of the total solution cost to make the price of the superconducting solution equal to the price of the conventional solution. This value is the same in the fully superconducting solution as well, as this requires two superconducting infeed's, so each accounting to 49%. So, using this value and the price of conventional solution as a reference, the supposed cost of superconducting infeed is calculated as shown in below equation:

$$Superconducting\ infeed\ cost = Conventional\ solution\ cost \times \frac{49}{100}$$

An example for this calculation is shown below, to make it clear.

Example 1:

Calculate the cost of each superconducting infeed referring to the cost of conventional solution of £14 million.

Cost of Conventional Solution = £14 million

Cost of Superconducting infeed = £14 million x 0.49 = £6.86 million

The cost calculated is for the superconducting infeed, which will comprise of Superconducting cable, cooling system, SFCL and installation charges. As the superconducting technology is still very young and most DNOs are lacking expertise in assembling the components of the superconducting solution, it is up to the superconducting cable manufacturers to take up the responsibility. Hence, the total cost of the superconducting system, also includes installation works. Thus, the pricing information quoted in the figure 3.2 is considering the total cost of the HTS system. The cost of superconducting infeed shown is same for both the partial and complete HTS solutions, for the solutions of 5 km in length.

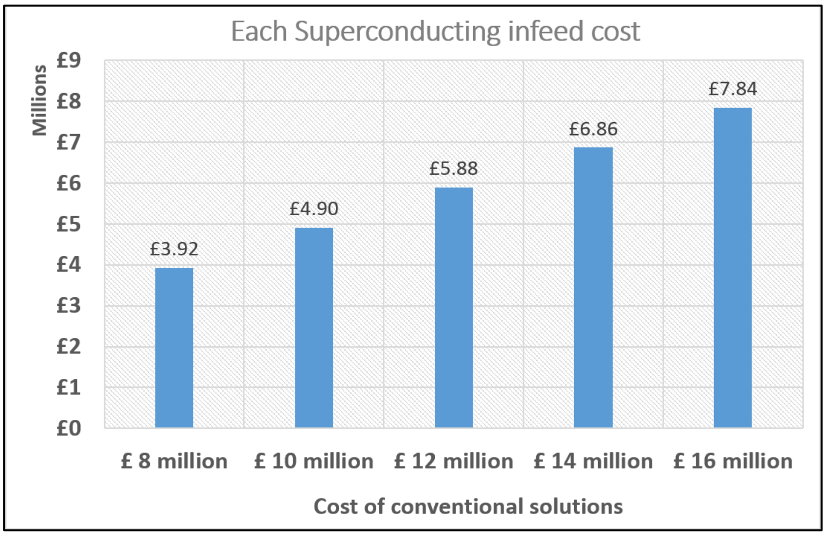

Figure 3.2: Cost of superconducting infeed leading to superconducting solutions being as expensive as conventional solutions.

3.2 Conclusions

Following the work completed in Work Packages 1 and 2, this Chapter demonstrates that for the Superconducting solution to be of the same cost as the conventional solution, the superconducting infeed cost should be 49% of the conventional solution cost. If that is the case, then the implementation of the superconducting solution could be considered. This idealised cost is significantly lower than the cost considered in the Case Study of Work Package 3.

Work Package 2 has shown that the total superconducting solution cost for the case examined was more than 60% more expensive than the conventional solution cost. Therefore, it is of interest to investigate the expected trends of the superconducting solution costs to see in how many years this cost difference could reduce to zero.

Chapter 4

HTS systems future cost projection

4.1 Introduction

This Chapter aims to perform an estimation of the costs of the superconducting solutions in the future based on the HTS material price trends over the last years.

4.2 HTS Materials and Costs Trends

HTS materials are fragile and a significant amount of degradation in its properties will be observed upon applying more than the specified mechanical, electrical and thermal limits. These materials are discovered just 3 decades back and the widely used REBCO (2G) HTS materials are discovered only in the last decade only. This lays out a significant challenge upon understanding its properties and engineering the ways to utilise them wisely. Depositing these HTS materials upon the varied substrates involves a lengthy and time consuming process, to form the HTS tapes [1]. The process involved is nearly equivalent to the fabrication of the semiconductors, thus making it very expensive. But as the technology evolved and the properties of HTS materials studied widely, the process involved is currently being simplified, thus cutting down the unnecessary cost. A lot of investment is being put into this area by various governments funding agencies, to make them much robust and efficient, thus bringing these materials much closer to varied industrial applications. [2]

Right now, HTS tapes are fabricated as custom made, depending on the kind of end application [1]. This is a much common way of finding its most promising application. But over a period, it is expected to see these HTS tapes being sold in readymade condition. For this to happen, a lot of increase in demand should occur, which indeed will cut down the costs much more. Demand and cost are mutually dependent, which would take certain time to stabilize. From figure 4.1, it is observed that the cost of HTS materials has already been decreased by nearly 100 times within the last decade [3]. The current price of HTS tapes is widely considered to be financially feasible for a variety of applications, mostly involved in using high field magnets. With the recent sharp increase in demand resulting from varied industrial applications, the number of superconducting manufacturers slowly started to increase. This is a good indication, which will bring down the cost to a huge extent in the next few years.

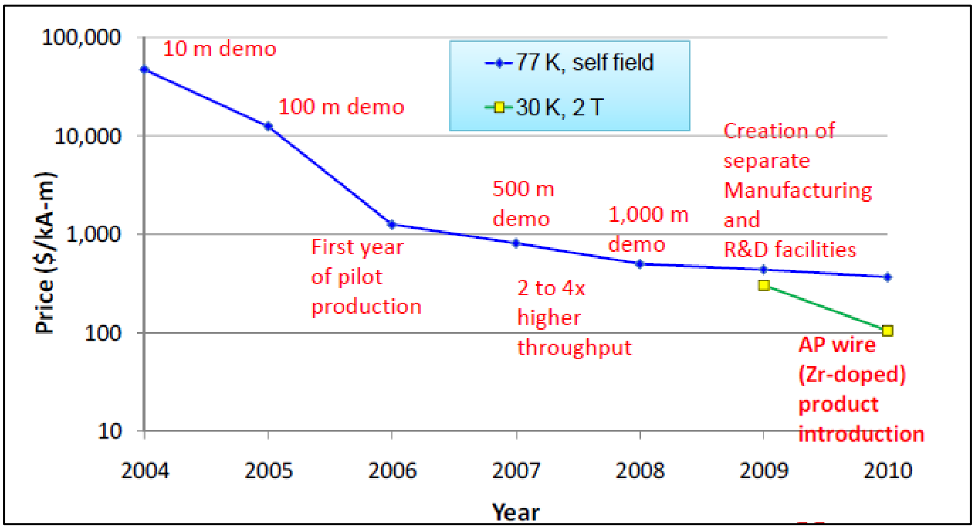

Figure 4.1: Reduction in the price of superconducting tapes with years [3]

HTS cables are one such application, which can be made financially feasible only to a certain limited number of applications, w.r.t. its current market price. It is forecasted that the price of superconducting material will keep decreasing by 10 % every year, for the coming up years, until the market gets stabilized [3]. Based on this criterion, the price of HTS materials will be calculated as shown in the below equation:

$$HTS\ material\ cost = Current\ HTS\ Material\ cost \times \left(1 - \frac{10}{100}\right)^n$$

where, n denotes the number of years. Considering the current market price of superconducting material to be £350/kA-m, the future cost of these materials has been calculated. It is observed that the superconducting materials cost will account for nearly about 45% of HTS systems price, by comparing the quotations obtained from industries to the current market price of superconducting material. Thus, based on this, the cost of HTS cable and solution will be extrapolated proportionately as shown in the equation below.

$$HTS\ cable\ cost = HTS\ Material\ cost \times \frac{100}{45}$$

Figure 4.2 shows the forecasted price of complete superconducting, superconducting + conventional solutions w.r.t. its tallied conventional solution cost. The costs shown are calculated, considering the solutions as presented in the figure 3.1, for a 5-km long cable. Over a duration of 10 years, it is observed that, both the complete superconducting and HTS + Conventional solutions are becoming comparable to the conventional solutions. This gives a good indication for the superconducting applications in the power grid, making them much more competitive in the future. To demonstrate how the calculations have been done, an example is also shown below.

Example 2:

Project the cost HTS material for 5 years from now, given present cost of £350/kA-m

Current HTS Material cost = £350/kA-m

HTS Material cost after 5 years = 350 x $(1-0.1)^5$ = 350 x 0.59 = £206.67/kA-m

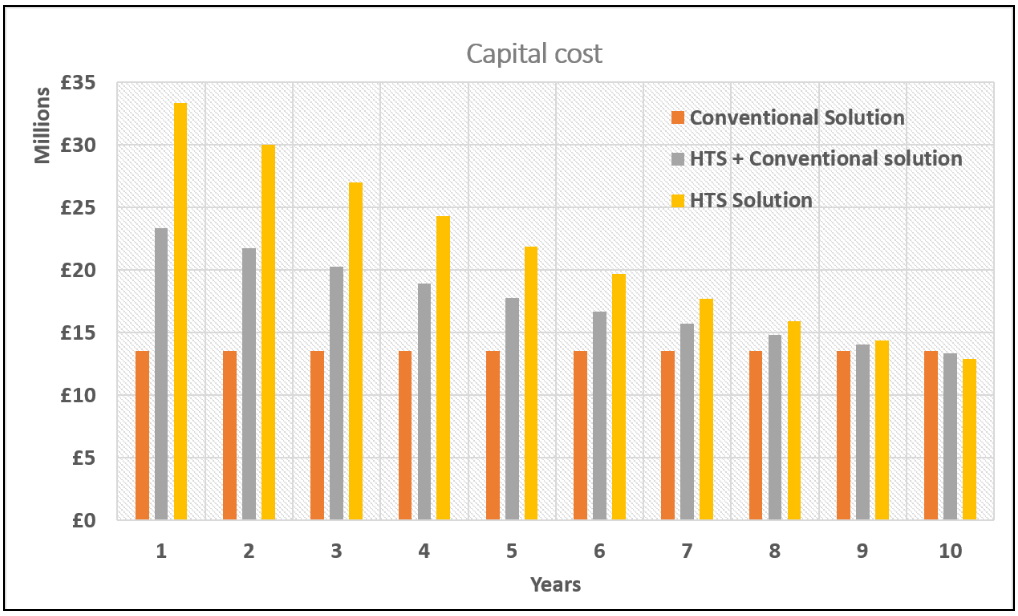

Figure 4.2: Forecasted price of superconducting solutions and its comparison to the conventional solutions

4.3 Conclusions

Based the past trend of HTS materials cost, the cost of HTS solutions (of 5 km case) has been predicted for the next decade.

From the results obtained, it is shown that a decline in the difference of costs between the HTS and conventional solutions would be expected if the prices of the superconducting materials kept falling. At the end of 10 years, HTS solutions are observed to compete the conventional solutions, which gives a good indication regarding the future prospects of HTS technology.

Chapter 5

Costs-infeed length relationship

5.1 Introduction

In the previous chapter, it is observed that the 5-km HTS solutions are capable enough to compete with the conventional solutions in terms of cost only after 10 years from now considering a price drop of 10% every year. This chapter examines the relationship between the required infeed length and the cost of the superconducting solution to investigate whether the cost difference between conventional and superconducting solution changes with different infeed lengths. The projected costs for the following 10 years are then calculated.

5.2 Infeed Length and Costs Analysis

It is evident that the 5-km superconducting cable solution is expensive when compared to the conventional cable solution. Even though Chapter 4 showed that the 5-km superconducting solution will have comparable costs to the conventional solution after 10 years from now, there is no indication of their feasibility in near future. From the breakdown cost details of conventional solution specified in Table 3.1, the auxiliary equipment and substation equipment are observed to contribute a good share towards the total solution cost. In the case of the superconducting solution, unlike conventional solution, majority of the cost contribution comes from the superconducting material, which is distributed linearly, along the length of the solution. Hence, it is of interest to see how the costs of either solutions will vary based on length of the solutions.

Unfortunately, the breakdown details of the superconducting solution are not available. This limits the quantification of the superconducting solution cost based on varied lengths. So, to simplify, the cost of superconducting solution is varied linearly, as reducing cable length also reduces the amount of superconducting material and cooling capacity required. Thus, considering the already known 5 km superconducting solution cost as a reference, the cost of the solutions of varied length will be calculated appropriated using the cable length factor. But, for the conventional solution, as the detailed cost values are available, the costs are categorized appropriately into constant and variable costs. Thus, by maintaining the constant costs same for all the lengths and varying the Variable cost using the cable length factor, the conventional solutions are quantified for varied lengths. The cost evaluation procedure has been demonstrated in the example 3, to make it easier to understand. Furthermore, as the HTS + conventional solution is a hybrid one, with half solutions from either side, its cost is also evaluated similarly.

Based on this methodology, the cost calculations for conventional, Conventional + HTS and complete HTS solutions has been carried out as shown in Figure 5.1. The cost of the solutions has been calculated as shown in the Example 3.

Example 3:

Calculate the cost of Conventional and Superconducting solution for a 3-km case

$$\begin{aligned} &Cost\ of\ conventional\ solution\ for\ 3\ km \\ &\quad = Constant\ cost\ (ref\ to\ 5\ km\ case) + Variable\ cost \end{aligned}$$

$$\begin{aligned} &Constant\ cost \\ &\quad = Land\ cost + Transformers\ \&\ 132\ kV\ switchgear\ cost \\ &\quad + 132\ kV\ Substation\ civil\ cost + 11\ kV\ switch\ gear\ cost \\ &\quad = £548{,}024 + £3{,}691{,}142.00 + £1{,}814{,}395.00 + £288{,}510 \\ &\quad = £6{,}342{,}071.00 \end{aligned}$$

$$\begin{aligned} &Variable\ cost \\ &\quad = 132\ kV\ Cables\ cost \times Cable\ length\ factor \\ &\quad + 132\ kV\ Cables\ laying \times Cable\ length\ factor \\ &\quad = £3{,}227{,}596.00 \times \frac{3}{5} + £3{,}993{,}082.00 \times \frac{3}{5} = £4{,}332{,}406.00 \end{aligned}$$

$$Cost\ of\ Superconducting\ solution\ for\ 5\ km = £33{,}689{,}973.00$$

$$\begin{aligned} &Cost\ of\ Superconducting\ solution\ for\ 3\ km \\ &\quad = Total\ solution\ cost \times Cable\ length\ factor \\ &\quad = £33{,}689{,}973.00 \times \frac{3}{5} = £20{,}213{,}983.00 \end{aligned}$$

Figure 5.1 shows the calculated costs of varied length solutions, as demonstrated in the example 3. The costs difference among the solutions is observed to be decreasing with the decrease in length, which gives a positive indication for the short length superconducting solutions to be possible soon. Saying this, it is quite interesting to study when the superconducting solutions of varied lengths can become feasible, when compared to conventional solutions. Thus, the next section will calculate the costs of superconducting solutions for the next 10 years, considering the cost details of the last cade.

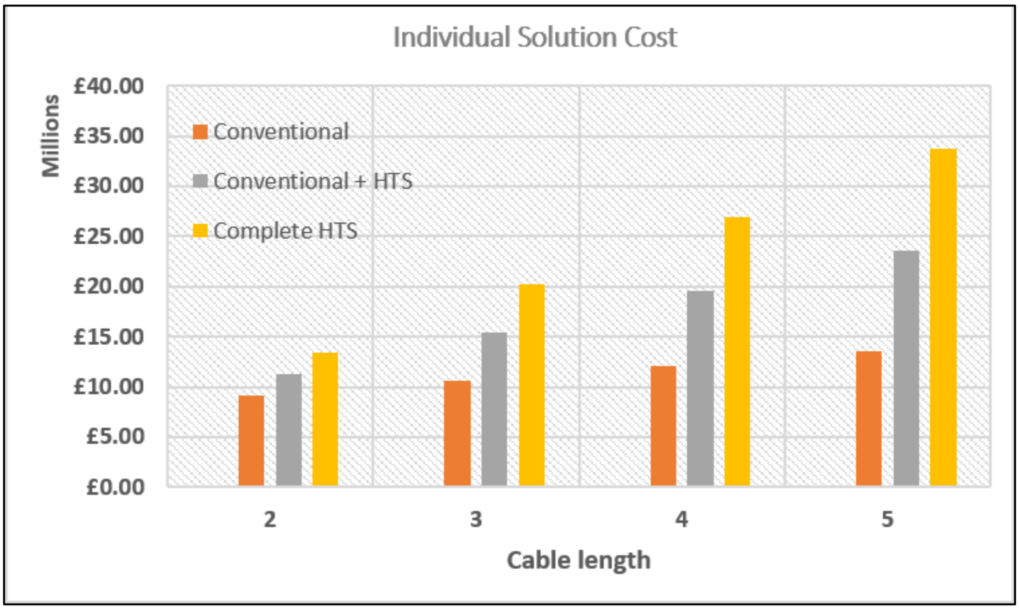

Figure 5.1: Cost of individual solutions for varied cable lengths.

5.3 Future prediction of superconducting solution costs for varied lengths

It has been observed previously, that the cost difference of the complete HTS and Hybrid (HTS + Conventional) is reducing gradually while reducing the solution length. But, still all of them of varied lengths are observed to be still expensive when compared to their appropriate conventional solutions. The cost difference is ranging from few £millions to as high as £20 million. The highest the cost difference, the more years are required for the superconducting solutions to become feasible assuming the 10% price drop. Hence, considering the solutions with lower cost difference, it makes sense to project their cost for the next few years. This gives a detailed picture of the range of superconducting solutions that could be feasible in the year wise manner.

The cost predictions of the superconducting solutions of varied lengths have been forecasted in a similar fashion as in Figure 4.2. Figures 5.2, 5.3 and 5.4 show the forecasted future price trends of superconducting solutions of 2, 3 and 4 km respectively. The results show that the superconducting solutions of short length are very promising, for future applications in the next coming few years, than waiting until the next decade for 5-km superconducting solutions to materialize. The methodology and assumptions involved in performing these calculations is similar to the calculations shown in Example 2.

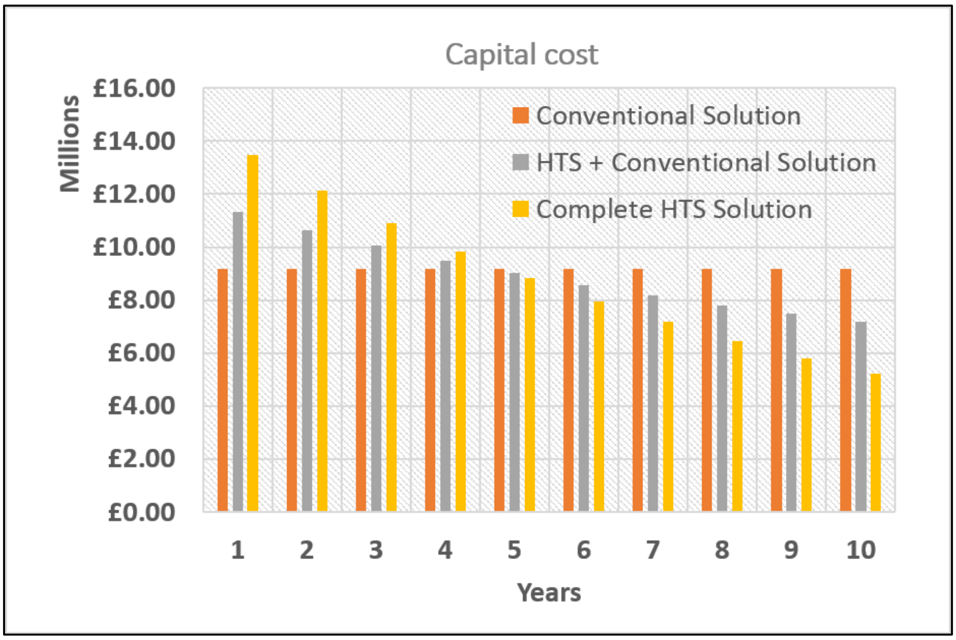

Figure 5.2: Forecasted price of 2 km superconducting solutions and its comparison to the equivalent conventional solutions

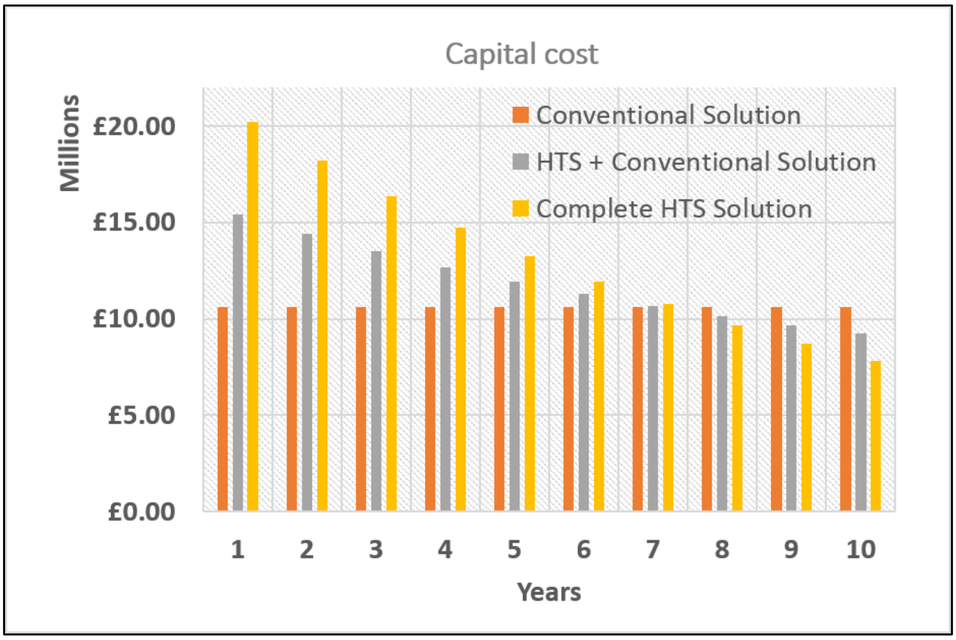

Figure 5.3: Forecasted price of 3 km superconducting solutions and its comparison to the equivalent conventional solutions

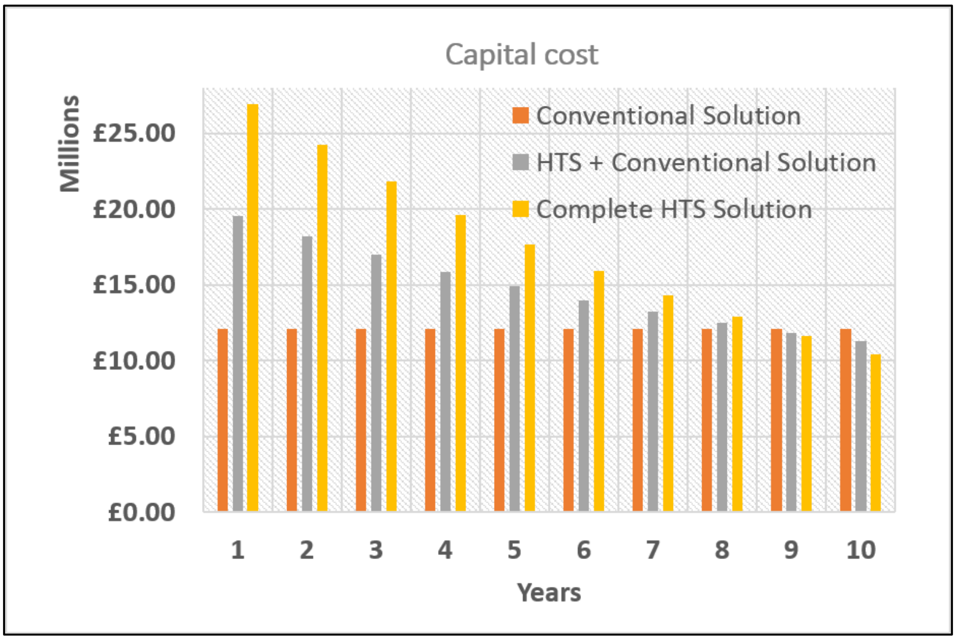

Figure 5.4: Forecasted price of 4 km superconducting solutions and its comparison to the equivalent conventional solutions

5.4 Conclusions

As stated in the beginning of the chapter, considering the 5-km length case as reference, the cost of superconducting and conventional solutions for varied lengths (2, 3 and 4 km) have been evaluated. Based on these calculated values, the cost of HTS solutions for the next decade have been estimated, following the similar strategy used in previous chapter.

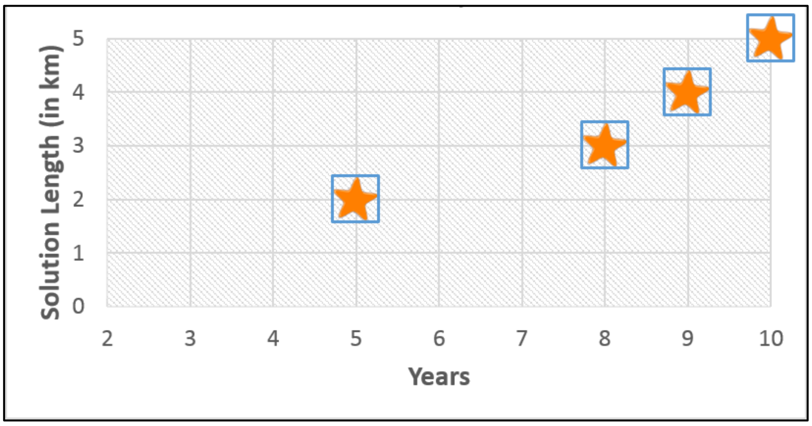

Figure 5.5: Plausibility of superconducting solutions (both partial and complete HTS) while compared to their equivalent conventional solutions.

The results show that HTS solutions of shorter length are observed to be feasible in a shorter time span for the similar conventional solutions. For example, a 2-km superconducting solution will be able compete conventional in only next 5 years, as from figure 5.5.

Chapter 6

Land Area Requirements

6.1 Introduction

Irrespective of the capital costs, superconducting solutions are well known for their high-power densities and realising the maximum power transfer at lowered voltages, thus avoiding the need of large power transformers and large sub stations. This chapter aims to give the overview of the land requirements for both superconducting and conventional solutions of comparable power ratings.

6.2 Land Requirements Investigation

The cost of land has been increased exponentially in recent times, while its availability has been reducing. This means that establishing new electricity substations in urban locations is becoming increasingly challenging. Superconducting solutions can be a good alternative in such cases, as they could in some cases require just a small proportion of the land required by conventional solutions as shown in Table 6.1, removing the need to obtain additional land.

Table 6.1: Quantification of the Land required for individual solutions

Solution Type	Land area required (Sq.mts)
Conventional	3500 - 4500
Conventional + HTS	2000 - 2500
Complete HTS	150 - 250

6.3 Conclusions

It has been observed that superconducting solutions could consume only a small proportion of the total land required by conventional solutions. This makes it clear that superconducting solutions could be the only viable solution, where there is a shortage of land availability.

Chapter 7

Learning and Conclusions

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

As this Chapter aims to provide a clear summary of the key learning gained from the study, the main conclusions from the 3 Work Packages of the study are demonstrated in Figure 7.1.

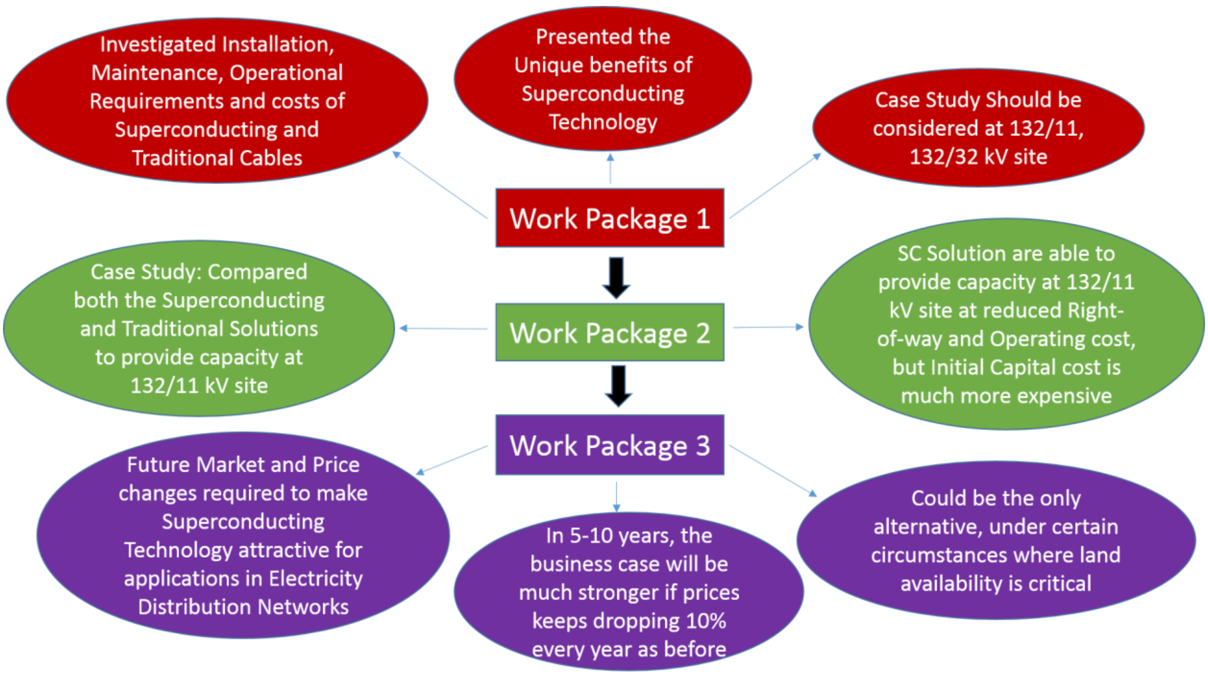

Figure 7.1: Summary chart of the entire study.

Therefore, this study has shown that:

- Superconducting cables are currently made industrially available and are identified to have the unique benefits of high power density, small right of way requirement, fault current limiting function and low losses costs.
- It is observed that the superconducting solutions' initial capital cost is nearly 70-75 % more than the conventional solution, thus highlighting the financial hurdles that the superconducting cables should surpass soon.

- Based on the calculated results, it is observed 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. Please note that this is based only on the expensive conventional solution considered in the Case Study of Work Package 2. The cost of the conventional solution could vary significantly for different reinforcement projects, so in other projects it could take longer than 5-10 years for the price of the superconducting solution to be comparable to the conventional solution.
- It has been observed that superconducting solutions consume only a small proportion of the total land required by conventional solutions. This makes it clear that superconducting solutions could be the only viable solution, where there is a shortage of land availability.

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