Lincolnshire Low Carbon Hub

Communications Review

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1. Introduction

1.1. An Introduction to Western Power Distribution

Western Power Distribution (WPD) is the electricity distribution network operator for the Midlands, South Wales and the South West. We deliver electricity to over 7.6 million homes and businesses over a 55,300 sq km service area. Our network consists of 216,000 km of overhead lines and underground cables, and 184,000 substations.

At WPD we are committed to facilitating the uptake of low carbon technologies, as we seek to deliver value for our connected customers. Through the Low Carbon Network Fund (LCNF) we are undertaking a wide range of projects to develop innovative ways of operating our network to support the Low Carbon Transition Plan.

1.2. Project Background

The Low Carbon Hub for East Lincolnshire has been designed to test a variety of new and innovative techniques for integrating significant additional capacity of low carbon generation on to electricity networks, in an effort to avoid the costs that would normally be associated with more conventional methods. The project has received £3m of funding from Ofgem's Low Carbon Network Fund.

In this project, Western Power Distribution is seeking to explore how the existing electricity network can be better utilised and thus deliver low carbon electricity to customers at a significantly reduced cost in comparison to conventional reinforcement.

Lincolnshire, being on the East Coast, regularly experiences windy conditions, making it particularly attractive for businesses seeking to build onshore and offshore wind farms. Western Power Distribution receives a high volume of enquiries from developers which makes the location ideal for this project. We have also had enquiries about other forms of generation, such as solar photovoltaic.

1.3. Communications Infrastructure

The ability to carry out active network management (as proposed with the Low Carbon Hub) resides around a communication system that has the capability to send information to a variety of intelligent devices in real time. This will be made possible through the installation of a number of new optical fibre and microwave links between existing substation and radio sites as shown.

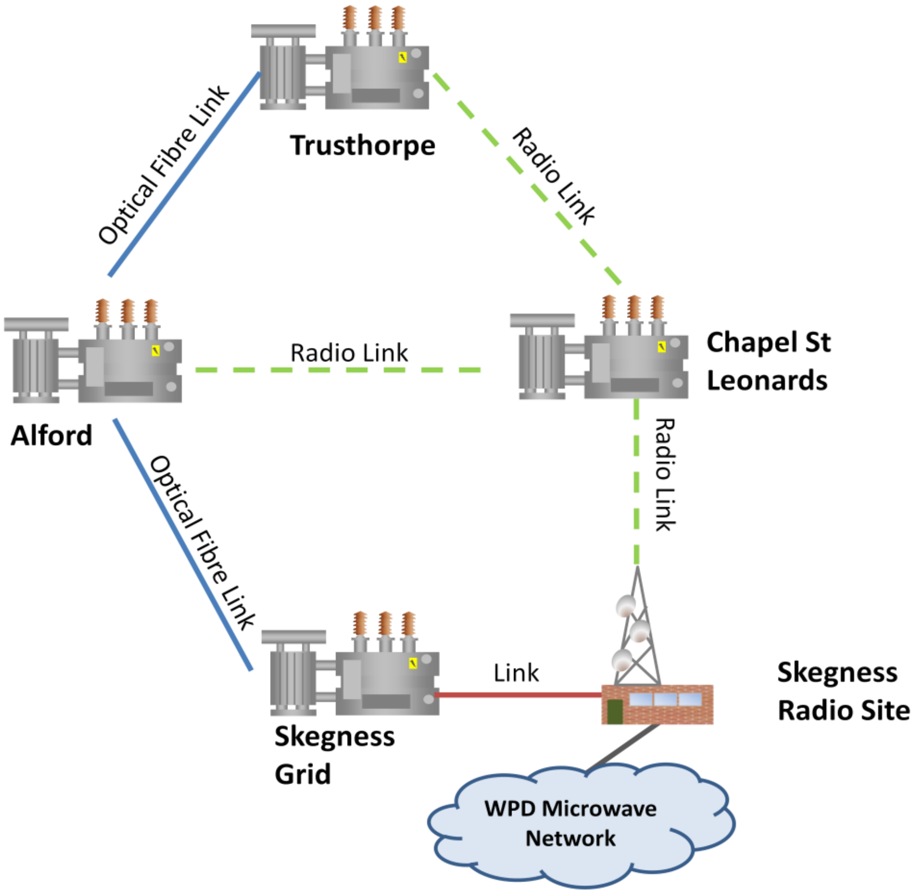

Figure 1. Low Carbon Hub Communications Infrastructure Layout

Our existing control system, GE's PowerOnFusion will also be updated to facilitate real time visibility of the East Lincolnshire network within our network control room and act as a host to any additional control software needed to carry out active network management.

1.4. Document Purpose

As part of the design phase for the Low Carbon Hub, a review has been undertaken to assess the differing techniques available for adding optical fibre to 33kV overhead lines. This has considered work been undertaken by the Energy Networks Association (ENA) in developing industry standards as well as consultation with optical fibre providers such as AFL. Existing installations have also been taken into account. This desktop exercise is forming the basis of the design activity for both new build overhead lines, and sections of network where the communications are to be retro-fitted.

A further exercise has been undertaken to assess differing radio communications techniques that could be employed such as Microwave or MiMo UHF Radio.

2. Optical Fibre

Optical Fibre has been selected as one of the techniques to utilise with the Lincolnshire Low Carbon Hub due to the potentially low installation cost and the high performance available with overhead line systems. The Low Carbon Hub includes both new build overhead lines with fibre and existing lines where the fibre will be retro fitted.

Installing optical fibre on 33kV wood pole overhead lines presents a number of challenges due to the line configuration. In higher voltage overhead lines, additional earth wire conductors provide an additional non-phase conductor on which optical fibre can be attached. As shown below, 33kV wood pole lines carry three live conductors and no additional earth wire. Consideration must be taken as to how the fibre will be installed, maintained and repaired in the event of a fault or cable damage. Many of the conclusions drawn regarding optical fibre could also be applied to other overhead lines with similar configurations such as 11,000 volts.

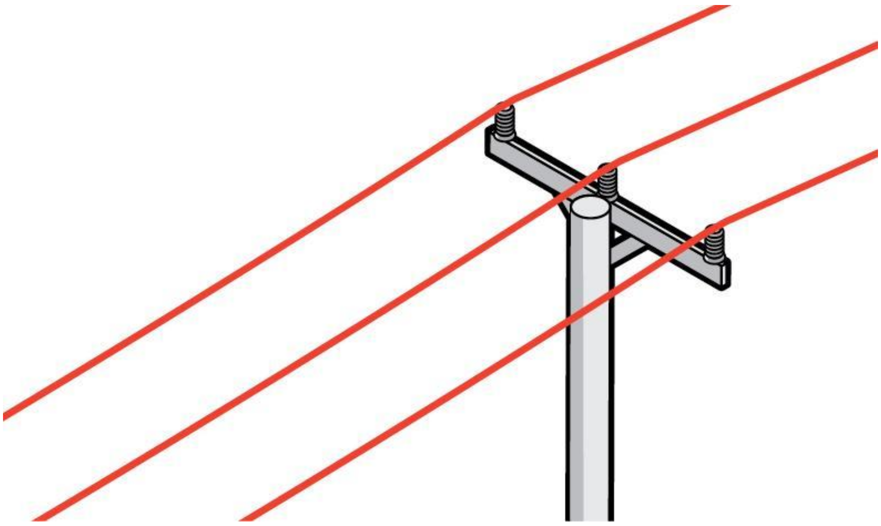

Figure 2. 33,000 Volt Overhead Line Configuration

This section of the document will outline some of the overhead optical fibre technologies available and assess their suitability to both 33kV new build and retro –fit scenarios.

The three techniques considered in this document are;

- Optical Phase Conductor (OPPC)
- All-Dielectric Self-Supporting cable (ADSS)
- Optical cable wrapped onto phase conductor (Phase Wrap)

With all the above technologies consideration has been given to the impact on overhead line construction standards such as ENATS 43-20 and ENATS 43-40. Where possible technologies have been sought that minimise the impact on overhead lines designs and key parameters such as pole height and span lengths.

2.1. Optical Phase Conductor (OPPC)

OPPC is an entirely metallic cable containing embedded optical fibres. It is designed as an analogue of an overhead line conductor (for example ACSR or AAAC) and is installed as a replacement for one of the phase conductors along the route. The optical fibres are contained in a stainless steel tube which replaces one of the wires used to assemble the conductor.

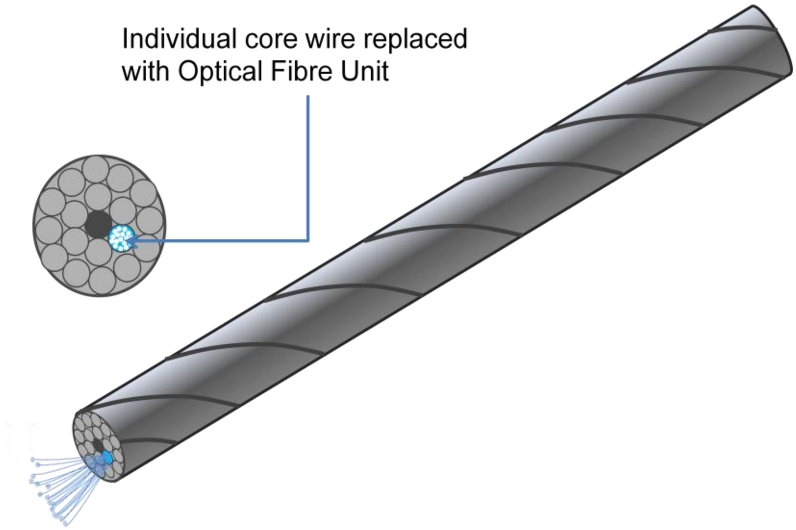

Figure 3 – OPPC Conductor

The mechanical, electrical and thermal characteristics of the OPPC will be designed to match the original conductor as closely as possible, but the OPPC will inevitably be slightly larger and heavier or slightly weaker and less conductive than the conductor it replaces because of the need to create space in the pattern of wire stranding into which the optical fibres can be placed. This is more noticeable in the case of smaller conductors and for designs with high fibre counts when more than one wire is replaced with tubes containing optical fibres.

2.2. All-Dielectric Self-Supporting cable (ADSS)

ADSS is an entirely non-metallic cable which is very like a conventional fibre optic cable in appearance and behaviour. It is installed by fixing to the support structures (poles or towers) of an overhead line rather than burying it underground. Aerial installation is quicker and less expensive than underground installation, but the aerial environment is more dynamic and technically more challenging than the very stable underground environment, and more attention to the design characteristics of ADSS cables is required to ensure a secure and reliable service life. ADSS cables are typically supplied in drum lengths of between 3 and 6km, often in precise lengths that are designated to known locations within the overall installation programme.

ADSS cables contain optical fibres inside one or more plastic buffer tubes. The tubes are stranded around a central FRP strength member which provides rigidity to the cable design. The bundle of tubes and CSM is called the optical core, and this is protected from the external environment by one or more layers of sheath material and high strength yarns of glass and/or aramid filaments. The design of the cable must take into account the parameters of the aerial environment, such as sunlight, pollution, wind loading, ice loading, temperature cycling, vibration, unsupported span length and the strength of the electric field surrounding the power conductors on the overhead line. Typically these parameters will vary widely between different geographical regions and different types of overhead lines and so most suppliers will offer a range of ADSS cables.

2.3. Optical cable wrapped onto phase conductor (Phase Wrap)

Phase Wrap consists of an optical fibre cable installed in-situ around an existing electrical conductor. This technique uses the mechanical strength of the electrical overhead line conductor to support the fibre as it is wound around the wire. Depending on voltages and clearance distances, phase wrap can be installed on live overhead lines using a specialist installation machine that travels along the electrical conductor.

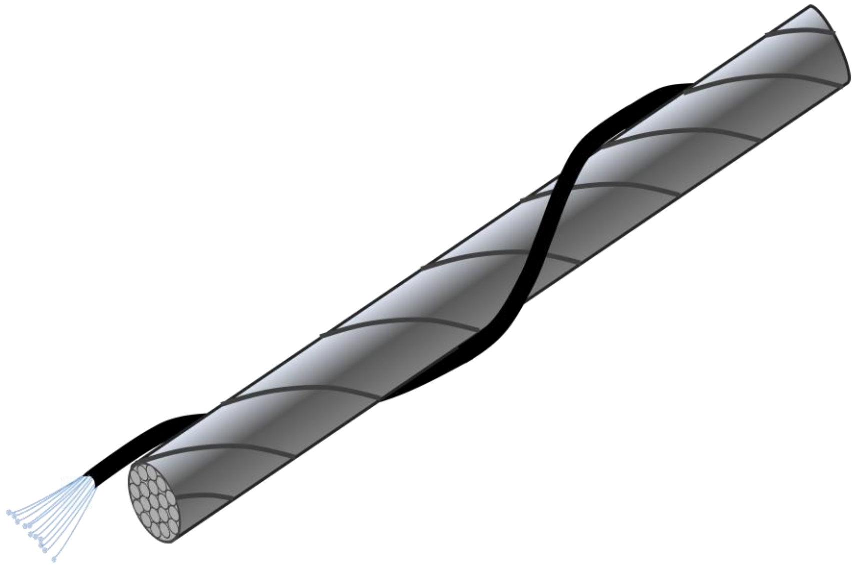

Figure 4 – Optical fibre wrapped around a phase conductor

Phase Wrap cables are non-metallic and the design will be capable of including up to 72 optical fibres contained in 4 buffer tubes which are stranded together with strength members to form an optical core. A sheath surrounds this core to provide environmental protection.

3. Installation process

The installation process for each technology differs considerably and somewhat dictates the appropriateness of to either new or retro-fit applications.

OPPC is installed in the same way as a standard ACSR electrical conductor using the same stringing and sagging techniques and equipment. Lengths of OPPC cannot be joined using compression or swaged fittings and so there is an extra step in the installation process to provide an optical splice at each joint. Termination of the optical component of OPPC at the ends of the line and at any intermediate node through an optical insulator is also a required additional step. The installation process is carried out under power outage conditions and all optical joints must be completed before the line is energised.

Figure 5 - OPPC in-line joint mounted on 33kV wood pole

Photograph Copyright AFL

Figure 5 shows the jointing of OPPC fibre tails utilising a pole mounted housing. The joint box is energised at 33kV and mounted on a post insulator.

ADSS installation uses standard stringing and sagging techniques and equipment, although the loads involved are smaller than conventional conductors and the equipment may need to be lighter duty with precise tension control at low loads. Installation may be possible on MV lines without a power outage and in any case once the cable is installed the line can be re-energised before the optical jointing is completed.

Phase Wrap cable is installed using specialist equipment and on wood pole overhead lines the installation process is greatly assisted by the use of a mobile work platform to lift the equipment around each pole. Wood pole circuits must be de-energised during the installation process, but this can be intermittent with the outage removed when installation work is not actively taking place (overnight for example). Optical joints that are installed in conductor-mounted enclosures or on pole cross-arms must be completed under outage conditions. Joints at low level on poles can be completed under energised conditions once phase to ground (PTG) insulators are in place.

Figure 6 – Phase Wrap installation on 10kV single phase line.

Photograph Copyright AFL

4. Considerations for retrofit on existing 33kV overhead line

The best technologies to use in retro-fitting fibre optic cables to existing 33kV lines are ADSS and Phase Wrap. ADSS may be preferred when the geometry of the overhead line allows for its installation. Wrap cables may be preferred when there is inadequate clearance or strength in the design of the line to allow ADSS to be used. OPPC can be utilised but this requires the complete replacement of one phase conductor, which can prove relatively costly and does little to extend the life of the overhead line for the investment.

4.1. ADSS

The design of the cable must take into account the parameters of the aerial environment, such as sunlight, pollution, wind loading, ice loading, temperature cycling, vibration, unsupported span length and the strength of the electric field surrounding the power conductors on the overhead line. Typically these parameters will vary widely between different geographical regions and different types of overhead lines requiring, requiring a specific design of ADSS cable.

In medium and low voltage overhead line applications, the effects of the surrounding electric fields on the lifetime of the ADSS cable are trivial and the mechanical loads imposed by relatively short unsupported span lengths are not demanding. ADSS cable designs for these applications are straight-forward and not expensive.

ADSS cables can often be installed without power outages on tower structures, provided weather conditions are favourable and safety clearances are maintained, and this is a major advantage of ADSS technology compared to OPPC or wrapped cables. For single circuits on wood poles, power outages may be required.

Generally ADSS cables are installed with less sag than the surrounding conductors, but ADSS sags more than conductors under ice and/or wind loading conditions. They move further and more quickly under wind and ice loads and care must be taken in designing ADSS installations to provide sufficient separation between the power conductors and ADSS cable to prevent clashing in adverse weather.

4.1.1. Advantages

The main advantage of ADSS is the separation it provides between the fibre optic communications and power supply functions of the overhead line; this allows for easy and independent access to both functions and satisfies many organisational and operation requirements of power utilities.

4.1.2. Disadvantages

The key disadvantages of ADSS reflect this separation: the extra cable imposes additional loads on the support structures and there may not be enough space within the geometry of the overhead line to install ADSS in a position that does not compromise ground clearance and flashover clearance. In addition, overhead MV lines with pole-mounted furniture such as switches, transformers, etc can lack suitable attachment locations for additional cables. Of the three type of cable technology discussed, ADSS cables are the most vulnerable to third party damage such as theft, vandalism, shotgun damage, crop fires and impact/ entanglement with vehicles.

4.2. Phase Wrap

The installation of phase wrap cable on the 33kV wood pole overhead lines requires a power outage. The presence of installed optical fibre cable on its host conductor adds both weight and cross-sectional area to that conductor. The host conductor will therefore sag more than surrounding un-wrapped conductors in still air and will move more under the effect of wind load. For most conductors this effect is slight and it can be modelled for analysis. Phase Wrap does not induce galloping or aeolian vibration in conductors, and the helical wrap configuration can act to suppress these effects. Previous trials with Phase Wrap systems have shown that routine maintenance tasks on MV lines such as insulator replacement, cross-arm replacement, transformer replacement and work on pole-mounted switches can all be carried out without compromising the wrapped cable.

4.2.1. Advantages

The main advantages of Phase Wrap lie in the speed of installation, the lack of disruption to the local environment caused by the installation process, and the low impact on the characteristics of the overhead line caused by the presence of Phase Wrap. Phase Wrap does not require poles to be strengthened or conductors to be renewed and does not affect the ground clearance or geometry of the line.

4.2.2. Disadvantages

The main disadvantage of Phase Wrap is that it does not provide physical separation between communications and electricity supply functions and so any future maintenance or repair activities must be carried out under outage conditions.

5. Considerations for installation on new build 33kV overhead line

The best technologies to use on a new build overhead 33kV line are OPPC or ADSS, mainly as both construction types can be undertaken as part of the overhead line build process. The design of the line may be changed prior to construction to increase the height and strength of the poles to allow ADSS to be installed more easily, or to position pole-mounted furniture such as switches, transformers, etc in a way that allows space for the optical insulators used in OPPC insulations to be satisfactorily incorporated. Applying Phase Wrap technology is less desirable as it adds additional constriction activities to the overhead lines build process that can be completed more efficiently with ADSS or OPPC. Further details are provided in the following discussion.

5.1. OPPC

When access to the optical fibres is required at network nodes, the fibres must be separated from the electricity supply function of the OPPC and brought to earth potential. This is achieved by means of an optical insulator assembly which combines the functions of an electrical isolator and a joint closure that connects the fibres in the OPPC to a conventional optical fibre cable. The key requirements are to bring the optical fibres physically down to ground level and to use an insulator that is rated for the operating voltage of the line.

5.1.1. Advantages

The key advantages of OPPC are that the optical fibres are embedded into the design of the overhead line: they are unobtrusive and secure, and no additional cable is required to be installed along the line. This means that there is no incremental load on the poles and the line characteristics and appearance are not changed from a ‘normal’ overhead line.

5.1.2. Disadvantages

The key disadvantages of OPPC are that the fibres are very difficult to access for maintenance or testing purposes and the conductor cannot be cut and mechanically re-jointed during overhead line maintenance activities without disrupting optical continuity.

5.2. ADSS

The key characteristics of this construction type are as laid out in section 4 of this document. For new build overhead lines, additional pole height can be taken into consideration at the design phase to ensure suitable clearances between phase conductors and the ADSS cable. This also allows for suitable clearance between the ground and the under slung ADSS cable reducing the positional for disruption by third parties.

6. Operational Considerations for Optical Fibre

In normal conditions, once installed, the presence of OPPC, ADSS or Phase Wrap on an MV line each has negligible effect on the operation of the line. Electrical and thermal ratings of the line remain unchanged for all 3 technologies and the only concern is the extra load on the poles imposed by the addition of ADSS. This is not a problem for OPPC or Phase Wrap.

The situation changes under maintenance operations or during fault condition. For all three technologies, maintenance and repair crews must be aware that the lines carry optical fibre communications links and that cutting the optical cable under any circumstances will disrupt traffic carried over the optical network. Further work will be required to develop operational procedures as part of the Lincolnshire Low Carbon Hub project. There are then specific operational considerations to address for each of the technologies:

6.1. OPPC

OPPC can be treated as a normal phase conductor for most maintenance activities. Live line working is carried out in the normal way and temporary earths can be attached when de-energised working is being carried out. OPPC is compatible with most standard overhead line hardware including post-, polymer- and string-type insulators, and armour rods can be used to repair broken strands. Since the OPPC cannot be cut without disrupting optical communications, sections of OPPC can only be electrically isolated where the optical fibres pass through optical insulators. Electrical continuity at these locations is provided by jumpers which can be physically disconnected from the OPPC. At other locations where optical insulators have not been used, the electrical and optical continuity is provided together through the OPPC itself and this cannot be temporarily cut or disconnected.

6.2. ADSS

ADSS is separate from the electricity supply although it is attached to the same poles. All normal working practices and operations can be carried out in the presence of ADSS although it may physically interfere with some processes. Temporary earths can be attached to ADSS when needed, although special attachment hardware is required to prevent damage to the sheath and optical core of the cable (due to relatively low crush strength of ADSS compared to conductors). ADSS can be disconnected from the poles and temporarily laid on the ground if necessary to improve access for replacing conductors, transformers or poles, etc. and this will not prevent optical network traffic from being carried over the ADSS.

6.3. Phase Wrap

Phase Wrap is intimately attached to the host conductor and must be carefully handled when working on the overhead line. Insulators and cross-arms can be replaced, conductors re-tensioned and poles moved without disturbing the Phase Wrap cable or disruption optical network traffic provided line crews are sufficiently aware of the precautions needed. Temporary earths can be fitted to phase-to-phase (PTP) and phase-to-ground (PTG) transitions and to wrapped conductors in order to comply with safety practices during de-energised working. Wrapped conductors can be lowered to the ground if necessary. Electrical isolation can only be provided at locations where PTP or PTG transitions are installed: jumpers between adjacent sections of conductor can be disconnected at these locations without disrupting the optical network traffic. At other locations, the pole bypass hardware does not provide sufficient insulation to guarantee adequate electrical isolation.

7. Radio Communications

Radio communications are being used on the Low Carbon Hub as an alternative to installing fibre optic cable. This section seeks to explore the challenges associated with installing such a system at primary substation sites. There are four communication channels that are to be deployed in areas where no overhead line is being replaced and hence no fibre optic cable will exist. These new radio links will provide communication channels for:-

- Teleprotection
- SCADA
- Remote Management

Three types of radio solution were considered, these were:-

- Traditional Microwave Radio
- MiMo UHF Radio
- IP Based Microwave Radio

All radio systems can be impacted by climatic conditions, and all need a tower or mast at each end of the link, this can lead to planning issues. In addition licensed radio systems require an annual licence fee to be paid to OFCOM.

7.1. Traditional Microwave Radio

Traditional Microwave radio systems consist of a minimum of 3 parts, these are the Indoor Unit (IDU), the Outdoor Unit (ODU) and the Dish.

The Dish acts as a collector of radio waves and focuses them to a single point at its centre. The ODU is usually attached to the back of the Dish and receives and transmits radio waves. The ODU can optionally be mounted remote from the Dish and a wave guide can be installed between the Dish and the ODU. In addition two ODU's can be connected to the back of the dish to provide resilience if one ODU fails. Each ODU will have a corresponding IDU. The IDU is usually installed in an indoor rack and is connected to the ODU via a coaxial cable..

Traditional Microwave radio usually has a high bandwidth, typically Megabytes. Various physical interfaces are available on many IDU's such as E1, STM etc. and the radio link can be configured to support multiple virtual links over the air. In some instances a Multiplexor (MUX) will be required to allow other services to be carried over the link.

7.1.1. Advantages of Microwave Radio

The main advantage of a modern microwave radio is its ability to carry high volumes of traffic with very low latency. The high bandwidth gives it the ability to simultaneously carry many data channels at the same time. The cost of modern Microwave systems has reduced over the last few years making it similar in cost to other lower bandwidth solutions. And modern Adaptive microwave systems can provide robust communications even in poor climatic conditions.

7.1.2. Disadvantages of Microwave Radio

As microwave radio uses high frequency radio waves it can be more susceptible to climatic conditions than lower frequency radio solutions, however adaptive microwave has overcome many of the issues to do with link fade. Licence fees can be higher than other solutions.

7.2. MiMo UHF Radio

UHF MiMo Radio is an Ultra Low Latency radio system for use in the UHF radio spectrum. The Radio has 2 transceivers to provide Multiple In and Multiple Out (MiMo) radio paths. This means the unit has 2 aerials, one polarised horizontally and one polarised vertically. Unlike Microwave there is no ODU and the system consists of a radio and an aerial with two coaxial feeder cables to between the radio and the aerial.

7.2.1. Advantages of MiMo UHF Radio

The advantages of UHF MiMo Radio are that it should be less affected by climatic changes as it uses a lower radio frequency approx 450MHz and the licensing costs should be lower.

7.2.2. Disadvantages of MiMo UHF Radio

One of the main disadvantages of MiMo UHF Radio is the fact that it supports significantly less bandwidth than Microwave radio. In addition the units can only support one tele-protection channel at a time. To support multiple channels, multiple radios have to be installed. In addition the units require twice as much cable as there are 2 aerials.

7.3. IP Based Microwave Radio

IP based microwave radio has been around for many years. In fact WiFi is in essence an IP based Microwave radio. They are small, low cost, use light or unlicensed radio spectrum, and easy to install. They can support point to multi point modes but can only carry IP based traffic so are not suitable for tele-protection. However they can provide a very low cost solution for SCADA and management backup links. When installed most work as layer 2 devices, i.e. acting as a pseudo wire and have no layer 3 routing ability.

The radios can support considerable amounts of bandwidth, typically 300Mega bits or more. They use many of the techniques utilised in UHF MiMO radio, however they have variable latency and rely on speed and retransmission of the underlying TCP/IP technology to provide robustness.

7.3.1. Advantages of IP Based Microwave Radio

The main advantage of IP Based radio is it's low cost to purchase and low cost to install. They have very high bandwidths available, and can support point to multi point and low power requirements. Often they can be powered directly from the Ethernet switch port.

7.3.2. Disadvantages of IP Based Microwave Radio

The main disadvantage is their variable latency making then unsuitable for tele-protection.

8. Recommendations for the Low Carbon Hub

Based on this desktop study, the Low Carbon Hub will be taking a number of these technologies to the construction phase. This includes the following techniques and applications:

- New build 33kV overhead lines – OPPC
- Retro-fit fibre to existing overhead lines - Phase Wrap
- Wireless communication links – Adaptive Microwave

OPPC has been selected for new build activity as it closely replicates existing installation processes and provides a good degree of mechanical protection for the optical fibres. Phase wrap will be used on existing overhead lines due to the relatively low cost and fast installation process.

It is recommended that traditional adaptive microwave is used for all wireless communications links except the one between Chapel St Leonard and Alford. This link is for backup for remote management and will not carry any tele-protection traffic so it is recommended that a simple Microwave Ethernet bridge is used.

All Antennas will be mounted on short masts, attached to the existing buildings. If this provides insufficient height to establish a viable link, then a lattice tower will be used (subject to planning). The tower will be in the 15m to 20m height range.

9. Next Steps

This document is primarily a desktop review of available techniques providing information to support the design process for the Lincolnshire Low Carbon Hub. Further work is required to provide the detailed system design for both the 33kV overhead lines and communications infrastructure. This activity will be undertaken during 2011 ready for construction commencing in 2012.Detailed design work will lead on to developing a procurement and installation plan.

Operating overhead lines with optical fibres presents a number of additional challenges, especially in fault conditions. Further work will be completed by WPD to review operational procedures and produce support documentation for field staff. This will include maintenance plans, fault restoration strategies and inspection instruction.

A summary report will be produced on completion of the Low Carbon Hub project in 2014. This will include detailed learning relating to the application of communications infrastructure on 33kV assets, including the level of success of optical fibre and wireless communications.

9.1. Further information

For further information relating to the Lincolnshire Low Carbon Hub or this document please contact CNUKEnergyProjects@Central-Networks.co.uk.

We would like to thank our project partners and suppliers for their assistance in producing this document, in particular AFL.