APPLICABILITY OF ALL-DIELECTRIC SELF SUPPORTING CABLE SYSTEMS TO VERY HIGH VOLTAGE OVERHEAD POWER LINES

Chris N. Carter, Jimmy Deas, Neil R. Haigh*, Simon M. Rowland*

The National Grid Company plc, Leatherhead, UK.
*BICC Cables Ltd, Helsby, UK.

ABSTRACT

It is well known that dry-band arcing provides a significant obstruction to the installation of All-Dielectric Self-Supporting (ADSS) cables in high voltage overhead power line environments. This paper reviews the aspects of high voltage overhead power line installations which need to be borne in mind when consideration is given to the deployment of ADSS cables. Progress is reported upon an ongoing (15 month long) field trial to investigate the phenomenon of dry-band arcing within HV ADSS installations, and in particular, the extent to which catastrophic failure of the ADSS cable can be prevented by utilising a length of semiconductive rod, installed alongside the ADSS cable span, as an arc control mechanism. In addition to presenting the results from the trial, which has included extensive environmental data monitoring, an example is shown of catastrophic dry-band arcing damage which has occurred to an installed ADSS cable on the trial site.

INTRODUCTION

Optical Cables for Overhead Lines

The de-regulation of the telecommunications and electricity distribution industries now taking place world-wide, has led to a dramatic increase in the demand for optical cable systems which can be installed on high voltage power networks. The competition and increased commercial pressures within these industries, has resulted in a number of means by which the optical cable may be deployed, depending upon various issues such as bandwidth, number of discrete fibres cost, speed of installation and long term system reliability. Currently, there are three dominant types of optical cable which are deployed: the optical ground wire (OPGW), the spiral wrap cable and the all-dielectric self supporting optical cable (ADSS). The OPGW cable is a popular choice if the overhead line system requires a new earthwire for refurbishment purposes or if a new overhead line circuit is being built. The spiral wrap cable which can be wrapped around an existing earthwire is attractive for transmission lines with existing earthwires which have a significant remaining lifetime, or if low installation costs and rapid deployment are important. The ADSS cable offers particular advantages in that it can be installed without the need to de-energise the power circuits, and, being separate from the power system, it offers unique benefits in terms of system maintenance and asset management in general. It is also of use as a short term repair cable where there is an urgent need to maintain an optical communications link, whilst repairs or refurbishments are made to the overhead power line carrying the existing communications channel. In such an instance, an interruption of several weeks (or possibly only a few days) to the communications link whilst the circuitry is repaired, might be completely unacceptable to the telecommunications service provider. In the UK, Energis, the telecoms carrier owned by the National Grid Company, use ADSS product for such rapid repairs.

The main drawback with ADSS cable, is that under certain circumstances, it can be catastrophically damaged by a phenomenon known as dry-band arcing. In the UK for example, concern with regard to dry band arcing damage has resulted in a situation where ADSS
cable will not be deployed on overhead lines at 275 kV and 400 kV unless as a short term repair section, whereas, it has been installed and performed reliably on 132 kV lines for around a decade.

**Dry-Band Arcing**

On a typical UK lattice tower, the ADSS cables are usually suspended at the level of the bottom or middle cross arm on a tower (Figure 1) and for a standard twin circuit tower, this will usually be at a point midway between the bottom four conductors. As a consequence, the ADSS cable, which will be at, or close to, ground potential where it is attached to the tower, is situated in an electromagnetic field which can give rise to a significant voltage gradient occurring along the length of the cable. Whilst the cable remains dry, this voltage gradient, which can be of the order of tens of kilovolts dropped over several metres, will not in itself present a problem. However, if the surface of the cable becomes conductive, due to the presence of moisture and/or pollution, the gradient can induce milliamp sized currents along the cable. By the nature of the system this current will be greatest at the point where the cable is joined to the tower, and, for reasons of symmetry, zero at the midspar position. Figure 2 schematically shows the voltage gradient and associated leakage current for a typical ADSS cable, from which it can be noted that the majority of electrical activity is confined to a region of the span referred to as the ‘active length.’ Dry-band arcing takes place as the cable surface dries out, either naturally, or as a result of electrical Joule heating. The occurrence of such a dry band around the cable will lead to a break in the previously continuously conductive cable surface, and thereby, a large voltage may be dropped across the short section of cable which constitutes the dry-band gap. If electrical breakdown occurs across the gap, then the corresponding arcing activity can lead to erosion of the cable surface, and ultimately, a deep furrow being cut into the cable sheath. In extreme cases, the strength member within the cable may become exposed and weakened, leading to catastrophic failure of the cable altogether. However, for commercial reasons, such failures have not been widely reported or discussed in the literature. Therefore, in the following section, we describe those parameters which we believe to be critical for the safe deployment of ADSS cables in high voltage environments. We also report on the progress to date on the development of a device which will prevent dry-band arcs in situations where they would otherwise have occurred.

**DEPLOYMENT OF ADSS CABLE**

**System Voltage and Space Potential Contours**

As described above, the threat of dry-band arcing has resulted in the situation where, in general, ADSS cables have been used routinely on overhead line systems at 150 kV or below, but not for example at, 220, 275 and 400 kV. This is a consequence, not only of the reliable performance to date of such cables in the field in 132 and 150 kV installations, but as a result of assessments made upon the magnitude of the space potential within which the ADSS cable is to be strung. Such an assessment is useful because it can be used to estimate the likelihood of the occurrence of dry-band arcing, and in this regard, formulae and indeed, commercial software now exists, which can use the configuration and geometry of the phase conductors to estimate the space potential around the ADSS cable when strung in the overhead line system. The output of the software is usually displayed in the form of a plot of the electrical space potential contours in planes perpendicular to the cable span, although it is capable of much more. The desired outcome of such a calculation is the identification of regions of low, preferably zero, space potential, within which the ADSS cable may be strung. Experience in the field to date has led to a general heuristic which associates a ‘safe’ ADSS installation location as lying within space potential contours of 12 kV or less, and potentially hazardous locations as being above this threshold value. Because the construction, geometry, and location of the overhead line towers is likely to vary considerably along the overhead line route, the above field calculations may not necessarily be undertaken in simplistic terms for the route in its entirety, and accordingly there may be a need to take into account the specific tower geometries. More importantly, but less obviously, the effect of a line outage of one of the circuits if it is a twin circuit system, and the impact of extreme environmental conditions such...
as wind induced ‘blow out’, need to be considered. Even in conditions where the cable is typically in a low space potential, such changes in conditions can increase this to a level where the threat is high. It must not be forgotten that the ageing mechanism is not a gradual one but occurs suddenly and quickly depending upon the environmental conditions’.

**Leakage Currents and Arc Properties**

A further refinement of the assessment of the in-service environment around an ADSS cable is the evaluation of the magnitude of the leakage currents which may be drawn along the cable by the capacitively coupled voltage gradient. In particular, considerable effort has been made to investigate how the nature of the damage occasioned to the cable sheath is related to the magnitude of such currents and the properties of their associated electric arcs. It has been established that the greatest damage to the cable occurs when the earth leakage currents are in the range of 1-5 milliamps and accordingly, a nominal threshold of 1 mA can be chosen below which arcing activity is considered to be acceptable, and highly unlikely to lead to damage to the cable sheath. Support for such a threshold level can be drawn from the observations of laboratory tests utilising high voltage, low current arcs on wetted cables as well as from field experience on the performance of ADSS in 400 kV installations, such as the recent UK field trial at Hunterston.

**Geographical and Environmental Considerations**

It is clear from the above analysis that the combination of the overhead line space potential and resulting current induced on the ADSS cable are of primary importance in assessing the potential for dry-band arcing damage to occur. The situation is however further complicated by the difficulty in predicting (and indeed verifying) the electrical resistance of the ADSS cables when in service, as this directly affects the magnitude of the leakage currents which may be driven by the induced space potential. For example, when dry, the resistance of the cable is estimated to be in the region of 10's of Megohms per metre, such that when in a 400 kV overhead line installation and a corresponding worst case space potential position of 35 kV the available current on the cable will be much less than 0.5 mA and, consequently, damaging arcing is unlikely to take place.

However, the presence and combination of rain, dew, salt-spray and pollution upon the cable can alter the situation, such that the leakage currents are high enough that damaging arcing is initiated. The resistance per unit length of any real cable will vary, from very high when dry, down to a variable lower limit, determined by the prevailing conditions, when polluted and wet. Humid, marine locations will often result in values of the order of $10^5$ ohms/m, whereas inland rural areas well away from industry may rarely see less than $10^2$ ohms/m. However, although these more conducting conditions may be rare they can be damaging. Even in the cleanest areas it would be prudent to assume that $10^5$ ohms/m will be attained infrequently. Thus it is not simple to use the geographical location of the route (e.g. coastal/inland/rural/industrial) as a guide to the suitability of ADSS cable to an application. In marginal cases there may be a need for the severity of pollution that may be precipitated onto the cable to be assessed, in order that the worst case electrical resistance of the cable can be estimated and the magnitude of the earth leakage current derived. An indication of such an estimation technique is illustrated in Table 1, which shows how the space potential threshold level at which damaging arcing may occur varies with the resistance per unit length of the cable. Furthermore, the table also shows how the resistance per unit length may vary with the level of pollution (classified arbitrarily as light, medium and heavy). Further work is required in order for meaningful pollution levels to be associated with specific geographic locations. For example, marine pollution, which can be classified in this case as heavy, may be fairly frequent close to the sea, but cannot always be ruled out 50 km or more from the coast; rural areas which might be thought of as pollution free (i.e. light) may on occasion, have agricultural pesticides and fertilisers applied in aerosol form from the air, which may become deposited as pollution upon the cable. Industrial pollution itself is emitted from a large number of sources, is often poorly documented, and can be redistributed almost anywhere by the prevailing meteorological conditions.
HIGH VOLTAGE ADSS SYSTEMS

A number of solutions have been proposed to enable ADSS cables to be installed in very high voltage overhead line systems, and these can be broadly divided into two areas:

i) Use of arc resistant (Anti-Tracking) sheaths;

ii) Development of arc control methods.

Arc Resistant Cable Sheaths

With the advent of ADSS cable failures in the field, it was generally recognised that polyethylene (PE) cable sheaths were unlikely to provide reliable, long term protection against arcing damage, even within 132 kV installations. Consequently, attention has been focused within the last 5 years or so, upon the development of sheath materials that offer resistance to and the growth of arc tracks or erosion. Certainly, ADSS cables with such arc resistant sheaths have led to an improvement in the performance of the cables. However, such resistance will not always protect the cable over its required service lifetime. Such protection has certainly not been proven, and it is difficult to see how this could be achieved until many more years of experience has passed. The evidence of laboratory testing is not strong since this has been with unrepresentative high current tests which are less onerous than low current service conditions.

Arc Control Mechanisms

Several means have been described in the literature by which electrical activity within the vicinity of the ADSS cable may be modified or controlled to the extent that damaging arcing does not take place. For example, the cable sheath itself can be made to be semiconductive. However this has drawbacks, not only in terms of cable processing, but in finding the balance in cable conductivity per unit length such that dry band arcing is prevented, whilst electrical Joule over-heating does not, in itself lead to failure of the cable. In this paper we report upon the progress made to date for an arc-control system which comprises of a semiconductive rod which is attached to the ADSS cable, and pushed out from the tower over the first 50 metres of the span. Details of this technique were first described at IWCS '95 and at IWCS '96 last year. Briefly, the retrofit rod system comprises of a rod with a resistance per unit length in the range 300 to 1300 kilohms per metre, attached to the ADSS cable by a series of semiconductive clips spaced typically at around 30 cm apart. The rods are pushed out by hand from the tower to a distance of 50 metres, covering the so called ‘active length’ of the ADSS cable, where the leakage currents might exceed the damaging arcing threshold. Details of the field trial used to assess the performance of the retrofit rod system are described below.

An issue associated, but different from the threat of dry-band arcing, is corona discharge. This can occur at the ends of the metallic clamps, which act as stress raisers, and can lead to slow, gradual, erosion. This is different from the type of dry-band arcing described here, which can be an all-or-nothing event, with damage occurring over a very short space of time, possibly days. It is our experience that in some locations, dry-band arcing is very rare, but when and where it does occur, maybe after many arcing-free years, damage can be very rapid indeed.

FIELD TRIAL OF RETROFIT ROD ARC CONTROL SYSTEM

Trial Configuration

As first reported at IWCS '96 last year, a field trial of now 15 months duration, is underway, to evaluate the performance of the retrofit rod system in a very high voltage 400 kV installation. The overhead line system is located in a coastal region of Southern England, in conditions which are particularly aggressive because of the local environment. Furthermore, prior to the installation, the ADSS cable sheath was ‘pre-aged’ by hand, using a mild abrasive process, estimated to provide a preliminary weathering of the cable sheath surface equivalent to around 2-3 years of exposure in the field. This was necessary, as the strongly hydrophobic nature of standard cable sheaths can be quite efficient in preventing dry banding (and hence arcing) from taking place during the first few years following installation of a cable. To further provide acceleration of the conditions liable to promote dry band arcing, the ADSS cable was not strung in the optimum space potential location on the
tower, but was instead, offset by around 1 metre from the tower centre axis, such that the space potential at the cable midspan was of the order of 20 kV during the continuous in-service condition of the cable. In addition, it was also estimated that for such an offset position, an outage of one of the transmission circuits would, in the worst case, raise the space potential to around 35 kV thereby representing an extremely aggressive environment for the cable.

The trial configuration comprises two ADSS cable spans as illustrated schematically in figure 3, one of the spans (section A to B) has been used as an experimental control, and it therefore was not fitted with the retrofit rod device. The other span (section C to D) has been used to evaluate a range of retrofit rods, and associated component hardware, such that the optimum rod system could be identified, for use in the most aggressive of environments. An intelligent, solar powered data logging workstation was installed upon the central tower on the span, to provide continuous data for a range of environmental and electrical parameters, deemed to be of interest to the analysis (see below). The installation has been visited every few months, at which time the cable spans are lowered, and the cable sheaths inspected for damage. Figure 4 shows the cable line engineer at work, installing the retrofit rod system live-line on the 400 kV installation.

**Parameters Analysis**

The following performance parameters have been explored to date during the trial:

**Rod System Hardware.** Critical to the optimisation of the retrofit rod system has been the assessment of the performance of a range of rods of differing resistivities per unit length, and a variety of components for terminating the rod at both its tower and span ends.

**Installation.** The rod system is designed to be installed without switching circuits out, and as a consequence resolution of health and safety critical factors such as the techniques for earthing the rod system before, during, and after installation of the rod has been paramount.

** Leakage Current Monitoring.** At the central tower position, the earth leakage current has been measured from both the control span and the span fitted with the retrofit rod system. The mean, minimum and maximum currents are measured every 10 seconds for an interval of 10 minutes and automatically recorded. In addition, a 50 Hz notch filter has been used to allow high frequency currents associated with electrical arcing activity to be resolved separately from the continuous earth leakage current.

**Environment.** Air temperature, relative humidity, the amount of rainfall, the wind speed and wind direction have all been monitored continuously during the trial.

**Pollution precipitation.** To measure how the precipitation of pollution could affect the surface resistance of an ADSS cable, two orthogonal 30 cm length glass rods were installed on the tower and their end-to-end resistances measured continuously.

**Field Trial Result Analysis**

The primary outcome of the year long trial to date has been the confirmation of the highly aggressive nature of the field trial site and installation, which has resulted in the occurrence of electrical damaging activity as described below. The leakage current monitoring system was also found to be successful in recording the electrical activity upon the cables, where it should also be noted that the measured currents, of the order of a few milli-amps agreed well and were typical of those expected within such a very high voltage environment. For example, figure 5 shows the changing leakage currents detected during outages of the overhead line system. Similarly, it was also found that the leakage current from the semiconductive rod system correlated as expected when rods of differing resistance per unit length were installed onto the span. All the measurements have verified the two software packages used to model the rod and cables' performance.

**ADSS Control Span**

For the ADSS control span (sections A to B in figure 3), severe tracking damage due to dry band arcing was found to occur within 6 months at span location B, and 9 months at span location A, after which time, due to the severity
of the damage, it was decided to remove the cable from the trial. Figure 6 shows the severity of the damage which occurred at span location A, wherein it can be seen that a severe furrow was cut into the cable sheath for a distance of around 20 cm from the cable suspension armour rods. Damage of a similar nature was noted upon the monitored end of the ADSS cable (Span section B) after only 6 months, and, in this case, the associated electrical activity upon the cable was detected by the leakage current monitoring system for several weeks prior to the site inspection (see figure 5). The physical nature of this damage was consistent with dry-band arc compression, rather than the gradual damage associated with continuous arcing.

**ADSS Cable Fitted with Retrofit Rod System**

For the cable span fitted with the retrofit rod component hardware, a range of performance data has been obtained allowing the system to be optimised. Retrofit rods which had a resistance per unit length of the order of a few hundred kilohms per metre were found to be too conductive, giving rise to a very low level of damage at the end of the rod on the span. The physical nature of this damage being that associated with continuous arcing damage rather than that of arc compression. No damage was observed under the retrofit rod itself. The upper limit of the rod resistance is currently being probed using rods of resistances of the order of 1 to 10 Megohm per metre, for which no damage has been observed to date. The aggressive environment of the location has also served to focus attention upon the mechanical and environmental performance of the rod attachment hardware; this has been modified and developed accordingly, to ensure its long term performance.

**Environmental Data**

With regard to the environmental data monitoring, there has been only limited success in reliably correlating any single environmental factor with the occurrence of electrical activity upon the cables. For example, figure 8 shows the filtered leakage current on the ADSS control cable simultaneously with a measured rainfall event, suggesting perhaps that the rainfall served to initiate the arcing activity. However, such conclusions cannot always be drawn from the data. For example, it is the case that for highly polluted cables, heavy rainfall is beneficial in terms of washing the pollution based contaminants off the cable surface, light rainfall is detrimental if the moisture serves only to convert the pollutants into an active electrolyte. Figure 9 also shows electrical activity upon the control cable, correlated in this case with the measured relative humidity over the period. Incidentally, for the period of time shown in this figure, the control cable was fitted with a device, attached to the cable suspension armour rod which was designed to reduce and control corona activity. The electrical activity data shown in the figure suggests that elimination or reduction of corona is not in itself sufficient to prevent electrical activity from occurring upon the cable, and in this case dry-band arcing can still be seen to occur.

**CONCLUSIONS**

The design parameters of high voltage ADSS cable installations have been reviewed in relation to the likelihood of occurrence of dry-band arcing activity and related damage to ADSS cables. It is proposed that ADSS cables only be strung in locations on the tower where the space potential is at or below a nominal threshold level of 12 kV. However, this threshold level may vary for particular ADSS installations, depending upon how environmental conditions, such as the deposition of pollution upon the cable, can alter the cable resistance per unit length.

The progress of a field trial to investigate dry-band arcing upon an ADSS cable in a 400 kV high voltage overhead line system has been described. In particular, an arc control method has been developed in the form of a retrofittable rod, which can be installed alongside the ADSS cable to reduce arcing activity to an acceptable level. In addition the trials have led to a better understanding of the ageing of traditional ADSS cables with so called dry-band arc resistant sheaths, both with and without corona protection. This has reinforced the belief that these have a very limited application on high-voltage power lines above 150 kV.
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REFERENCES


Table 1: Relationship Between 'Safe' Space Potential Threshold Level and Cable Resistance per Unit Length

<table>
<thead>
<tr>
<th>Safe Potential Threshold Level [kV]</th>
<th>Cable Resistance per Unit Length [Ω]</th>
<th>Associated Pollution Level (Arbitrary)</th>
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<tr>
<td>10</td>
<td>10^5</td>
<td>Heavy</td>
</tr>
<tr>
<td>18</td>
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<td>Medium</td>
</tr>
<tr>
<td>30</td>
<td>10</td>
<td>Light</td>
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</table>
Figure 1: Schematic of a Typical Twin Circuit Tower (UK) & associated Space potential contours

Figure 2: Schematic showing the relationship between the Induced Voltage and Current on ADSS Cable strung in an overhead power line.

Figure 3: Schematic of Configuration of HV ADSS Field Trial

Figure 4: Live-Line Installation of Semiconductive Retrofit Rod System
(a) Continuous current on rod. Showing effect of a circuit outage.

(b) High frequency current on control span.

(c) Continuous current on control span.

Figure 5: Detection of Dry-Band Arcing Activity on ADSS Cable during Field Trial

Figure 6: Damage to ADSS Cable due to Dry-Band Arcing

(a) Continuous current on control span

(b) High frequency current on control span.

(c) Rainfall events

Figure 8: Dry-Band Arcing Activity Correlated against Rainfall
Chris Carter graduated in 1963 from the University of London. He has since worked on magnetohydrodynamic power generation, superconducting magnet design, AC loss measurements in superconductors, failure mechanisms in the joints of power cables and since 1979, the development of optical communications on power lines.

Simon Rowland was born in London, England. He obtained a BSc from the University of East Anglia and a PhD from the University of London. He joined BICC Cables from STC Technology Ltd in 1989 where he worked on power cable insulation materials. He is Programme Manager for Telecoms Research and Development at the Helsby Technology Centre.

Jimmy Deas was born in Walton-on-Thames, Surrey, England. He has an HNC in Electronic Engineering and an HND in Software engineering, and has worked at the National Grid Company on a number of overhead lines projects since 1989. He has been responsible for establishing the field based data monitoring system for the H+ ADSS project.

Neil Haigh was born in Cheshire, England. He graduated with a BSc and PhD from the University of London, specialising in the field of Applied Optics. He joined BICC in 1988 and is actively involved in the area of optical fibres for HV ADSS development.