

A TRIAL INSTALLATION OF HIGH VOLTAGE COMPOSITE CROSS-ARMS

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Abstract: Four high voltage composite cross-arms have been installed as part of a non-energised trial taking place in the Scottish Highlands. The non-cylindrical geometry of their two main structural members offers improved mechanical strength-to-weight ratio compared to cylindrically-shaped insulators of similar cross-sectional area. The instrumentation system aims to monitor mechanical performance through the use of embedded strain gauges and a combination of a load cell, accelerometer and inclinometer at the cross-arm nose. An industrial data capture and control platform is used to capture sensor outputs and store them until retrieval. Networked cameras with local storage capabilities are used to capture video recordings of the cross-arms. The trial has helped establish handling, transportation and installation procedures. The first results from the instrumentation system indicate the resilience of the cross-arms to winds reaching up to 151 mph (243 km/h) while no irregularities regarding snow and ice accretion have been observed.

1 INTRODUCTION

Continuously increasing demand for electrical energy combined with rising environmental concerns and land prices which create difficulties in obtaining permissions for new overhead lines, have forced the industry to seek solutions for improving the power transfer capabilities of existing infrastructure. Several methods are available for uprating overhead lines including conductor re-tensioning or replacement, increasing the line voltage or re-purposing suspension towers as tension towers in order to increase the ampacity [1, 2]. One of the most attractive propositions however, is the replacement of the steel lattice tower cross-arms with ones made out of insulating materials.

In recent years, advances in composite technology, the reduction in manufacturing costs and the challenges faced by the energy sector have resulted in composite cross-arms emerging as a financially viable alternative for uprating existing power lines. Contrary to competing solutions, the deployment of composite cross-arms requires minimal modifications to the existing towers while eliminating the need for a separate insulator string. In addition to the increased power rating, other benefits of the technology include a narrower right-of-way requirement, the reduction of electromagnetic radiation at ground level and reduction of the visual impact of lines due to the compaction of tower dimensions [2].

Over the past few decades insulating cross-arms have seen some commercial application on low and medium voltage lines because of their minimal structural requirements [3]. This paper describes a trial installation of composite cross-arms for high

voltage lines (275 kV and above) together with the instrumentation system used to monitor various aspects of their performance.

2 THE COMPOSITE CROSS-ARM

The cross-arm referred to in this paper consists of four insulating members, end fittings, grading rings and a nose connection for the attachment of the conductor (Figure 1). When the cross-arm is installed, the insulating members are placed in a pyramid configuration with the two larger members positioned horizontally in respect to the ground and perpendicular to the tower body while the two lighter members are inclined.

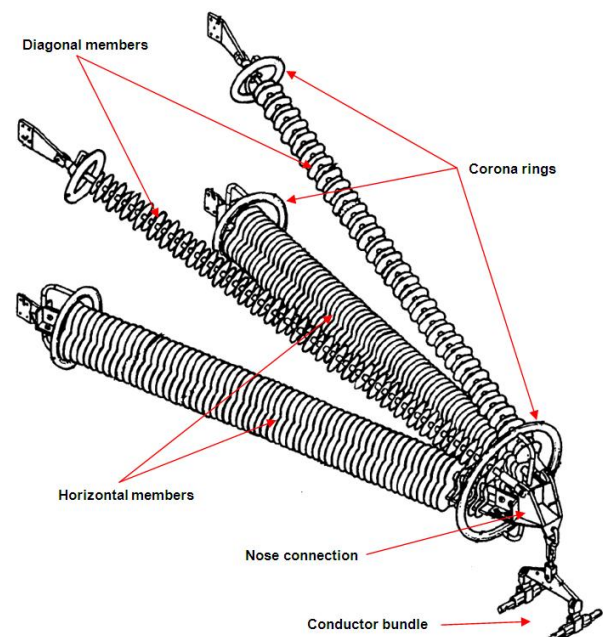


Figure 1: Composite cross-arm diagram [4]

The horizontal members are the main structural elements of the cross-arm and are designed to be under compression when installed. The unique shape of their core enables them to exhibit improved resistance to bending and buckling. This is because the second moment of area of a profile with such a cross-section is at least two times that of a profile with a circular cross-section of comparable area [4]. These members therefore can be manufactured to be cheaper and lighter than cylindrical shaped members since half the material is required to achieve the same structural requirements. The diagonal members resemble long-rod insulators and are installed to be under tension offering additional support to the structure.

The sheds of the horizontal members are designed to follow the shape of the core to avoid wastage of material without compromising the creepage distance.

3 INSTALLATION

Composite cross-arms can be used with new overhead lines or retrofitted to existing ones. For this trial installation the latter option was chosen to demonstrate among other features the relative ease with which this can be achieved.

3.1 The site

The high altitude site of the trial is located in the Cairngorms national park in the Scottish Highlands (Figure 2). This location was specifically chosen due to the adverse weather it experiences especially during the winter months. At 637 meters above sea level, with temperatures reaching -20°C and winds exceeding 100 mph (161 km/h) it represents one of the worst case scenarios that the cross-arms will face in service in the UK.

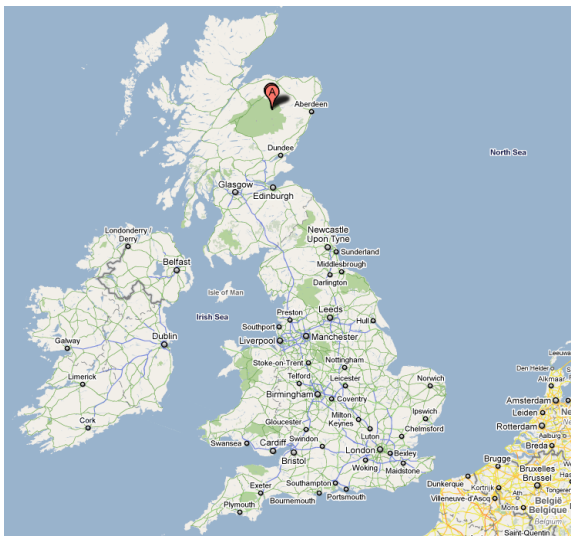


Figure 2: Location of the installation site in the UK (A)

Four composite cross-arms were installed in November 2010, two of which are instrumented, on a 132 kV line that has been decommissioned since 1995 (Figure 3). Regardless of the close proximity of the towers to each other, it has been observed that the peculiarities of the local environment allow for substantial difference between the two adjacent instrumented cross-arms. Points of interest include the effects of the prevailing wind as well as ice and snow accretion.



Figure 3: Decommissioned line on high altitude trial site

3.2 Handling and transportation

The horizontal members of each composite cross-arm are substantially heavier than the tension members as a result of the increased mechanical requirements. Because of that, bespoke lifting handles were fabricated that attach to the end fittings which allow for safe lifting and handling of the horizontal members by four persons.

To safely transport the cross-arms to the installation site, a special rack – mounting frame was fabricated that enables the packaging of both the horizontal and diagonal members of four complete cross-arms into a van (Figure 4).



Figure 4: Four disassembled cross-arms en route to the installation site

3.3 Installation procedure

After the individual members have been transported to site the insulators that comprise the cross-arm are transported to the base of the tower where the composite cross-arm is assembled complete with end fitting and field grading devices (Figure 5).



Figure 5: Assembling the composite cross-arm

Following the removal of the conductor, the metallic cross-arm is then removed from the tower and lowered to the ground (Figure 6). In this case the conductor was pinned directly to the tower body while the cross-arms were swapped.



Figure 6: Removing the metallic cross-arm

With the help of a specially designed lifting frame, the composite cross-arm is then raised into place. The two horizontal members are bolted first and the two diagonal members follow shortly after on the same mounting points as the previous metallic cross-arm (Figure 7).



Figure 7: Raising the composite cross-arm

The installation is completed with the re-attachment of the conductor to the nose cone using the same accessories (clamps, hanger brackets) as the ones used previously on the glass insulator (Figure 8). The experience gained from this first trial indicates that the whole installation procedure can be completed within half a day.



Figure 8: Completed retrofit installation of composite cross-arm

4 INSTRUMENTATION SYSTEM

Due to the unique non – cylindrical geometry of the composite core of the horizontal members there was no precedent of the profile's mechanical performance. Despite the cross-arm being designed to withstand loads 50% more than the specification (Table 1) and tested successfully in a controlled environment (Figure 9), service conditions are not always predictable.

Table 1: Cross-arm load cases

Load Case	Max. Vertical (kN)	Max. Transverse (kN)	Max. Longitudinal (kN)
High Ice	19.52	0.1	0.22
Wind and Ice	9.74	15.03	0.15
Failure Containment	2.1	0.02	17.6



Figure 9: Failure containment: broken conductor test

Therefore, it was deemed prudent to develop a system to monitor the forces and weather conditions that the cross-arms are subjected to during their first trial. Analysis of the data obtained will provide even better insight on the behaviour of the cross-arm and eventually give more confidence of its actual capabilities.

4.1 Mechanical performance monitoring

4.1.1 Strain Gauges Strain gauges were embedded half way along the core of the horizontal members to measure the strain experienced by each member on three planes: vertical, horizontal and axial. This is possible because the conductors are not being energised.

A full Wheatstone bridge configuration was employed for the strain gauges measuring the strain on each plane (Figure 10). This arrangement, as well as the placement of the gauges, ensures that each bridge produces a signal related only to the stress applied in one plane.

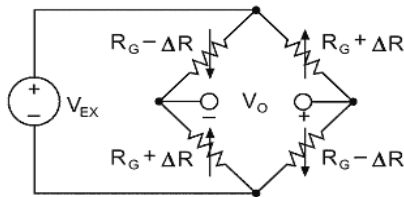


Figure 10: Strain gauges in full Wheatstone bridge configuration

The purpose of the strain gauges is to observe how the forces seen by each member change with the varying wind loading and especially assess how the profiles bend, if at all. Also the gauges can help to identify whether or not the load is distributed evenly among the two horizontal members, which are the main structural supports, after installation.

4.1.2 Load Cell Ice accretion on the conductor during the winter months can significantly increase its weight and therefore the weight that the cross-arm needs to withstand. Furthermore conductor galloping due to high winds can put additional stress on the cross-arm. To monitor these effects, a five tonne load cell was installed between the nose attachment point and the conductor clamp (Figure 11). The load cell can provide useful information regarding the forces applied by the conductor to the cross-arm.

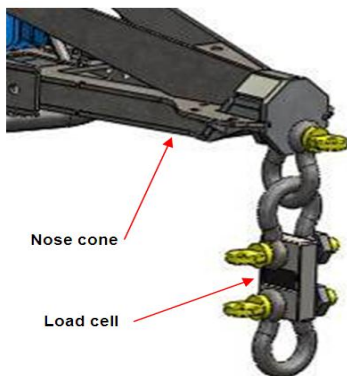


Figure 11: In-line load cell attached to cross-arm nose cone

4.1.3 Accelerometers Two accelerometers (Figure 12) per cross-arm were installed, one attached to the nose cone and the other to the hanger bracket adjacent to the conductor. The former aims to log any vibrations experienced through the nose connection and monitor any up-lift experienced by the cross arm. The latter aims to measure any relative movement of the conductor in respect to the cross arm.

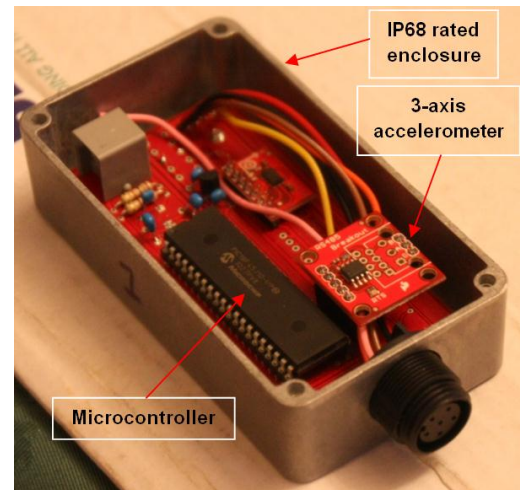


Figure 12: Accelerometer unit

The units can measure acceleration on three axes in the range of $\pm 8g$ (where g represents 9.8 ms^{-2}) with a resolution of 16 bit. Readings are taken at a rate of 100 Hz while an 8 MHz microcontroller is used to control the sensor and transmit the data to the data acquisition system over a twisted-pair cable.

That data can be used in conjunction with those obtained from the load cell to better estimate the forces seen by the cross-arm under different weather conditions. Eventually, interpretation of the data will result in optimisation of the design.

4.1.4 Weather station In order to get the most accurate weather data possible a weather station was installed on the top cross-arm of each instrumented tower. The weather station is able to record temperature, humidity, pressure, dew point, wind speed and direction. The data is to be used to match the mechanical loads on the cross-arm to specific weather phenomena.

4.2 Pollution and ice accretion monitoring

Although this trial does not test the electrical performance of the composite cross-arms, it is important to identify how the environmental conditions might hinder their capability in future applications and attempt to optimise the profile design beforehand. This is particularly important for the horizontal, non-cylindrical members since they have not been used in service previously.

For this purpose three cameras were installed on each of the instrumented towers. Two of them monitor the composite cross-arm from different angles (Figure 13) while the third monitors the glass insulator attached to the metallic cross-arm opposite the composite one. The cameras are set to record one minute of video every hour during daytime and they are powered off during the night to conserve energy.



Figure 13: Camera stills from tower cameras, nose view (left) and top view (right)

The installation site experiences heavy snowfall during the winter months. The cameras can provide useful information on how ice accretes on the surface of the cross-arm and how effective is the current profile design in that respect. Moreover, the videos recorded will help identify which areas of the non-cylindrical horizontal members are more prone to accumulating pollution in the long term.

4.3 Power sourcing and data acquisition

Despite the excellent scientific value of the site, the remoteness of the location posed a great challenge in respect to the monitoring system. Since the line was not live, the only viable option for powering the electronics was to generate the power locally using small scale wind turbines and storing it in batteries on the towers. The turbines are mounted on specially fabricated brackets on the towers.

While the cameras have the capability of storing their recordings on board, the rest of the equipment does not. An industrial data acquisition and control platform is used to capture sensor outputs and store the data. It also controls the power cycling of the cameras through a relay module. This however is located near the base of the tower together with the power system. Because of that, the voltage signals from the strain gauges and load cells are converted to current signals and amplified in order to ensure their fidelity during transmission. Communication of the data logging system with the accelerometers and weather station is achieved via RS485 and RS422 serial links respectively which are effective for transmitting data over the approximately 25 m long twisted pair cables.

The data acquisition system and the cameras are connected to wireless access points on each tower. With the help of high gain antennas, the data collected from each tower are relayed

periodically to the nearby ski centre awaiting retrieval. A block diagram of the system is shown in Figure 14.

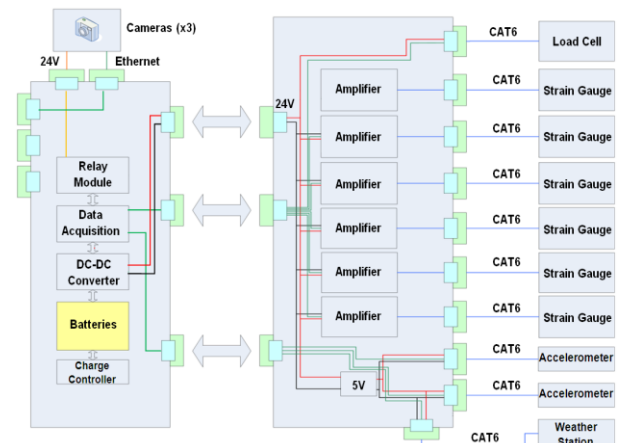


Figure 14: Block diagram of monitoring system

5 RESULTS

At the time of writing the majority of the mechanical data from strain gauges and load cells are still under review. However, the success of the location chosen is apparent from the weather data obtained and images recorded from the cameras.

The highest wind speed that the cross-arms were subjected to during the December 2010 – April 2011 period was 67.43 m/s (or 150.84 mph) recorded on the 10th of March 2011. Furthermore the cross-arms experienced periods of heavy snowfall during December of 2010 (Figure 15) and February 2011 (Figure 16).



Figure 15: Composite cross-arm top view recorded on 01 December 2010

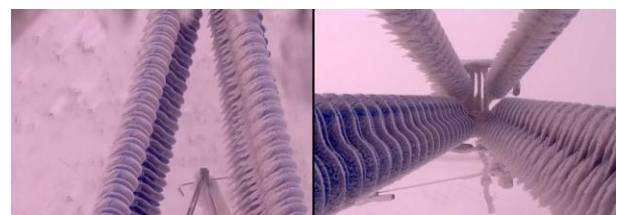


Figure 16: Composite cross-arm nose view (right) and top view (left) recorded on 21 February 2011

While Figures 15 and 16 show significant ice accretion on the cross-arm they also indicate that this phenomenon is of a similar magnitude on both the horizontal and the more conventionally shaped diagonal members. Furthermore, the glass cap-and-pin tension insulators from nearby towers exhibit comparable levels of ice and snow accretion (Figure 17).



Figure 17: Ice accretion on glass insulators on adjacent towers

In effect, the above observations lead to the tentative conclusion that the non-cylindrical geometry of the horizontal members is unlikely to affect the performance of the cross-arm in such conditions. Additionally ice and snow are distributed uniformly along the length of the cross-arm. Initial concerns for greater concentrations on the nose, at the area where all four members meet, appear to have been ill-founded.

6 CONCLUSION

This trial installation of high voltage composite cross-arms is aimed primarily to test mechanical performance. Through the process however, handling, transportation and installation procedures have also been established and tried successfully.

The data collected from this first trial together with those of a live trial planned for later in 2011 will be used to further optimize the cross-arm design both mechanically and electrically. At the same time, further work is being done to ensure the compliance of the cross-arm design with existing standards and industry approved testing procedures and practices in order to prepare the ground for deployment in the near future.

7 ACKNOWLEDGMENTS

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