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Introduction of high temperature low sag conductors to the Irish transmission grid

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SUMMARY

This paper describes how gap-type High Temperature Low Sag (HTLS) conductor was introduced onto the Irish national grid from inception stage through to its first installation on 80km of 220kV overhead line commencing July 2010. ESB International (ESBI)[A], ESB[B] and EirGrid[C] plc together investigated the use of HTLS conductors as it was considered the best solution to meet the desired requirement to achieve an uprating capacity of 50% on over 1000km of existing 110kV and 220kV transmission circuits. The aim of meeting at least 40% of Irish energy requirements from renewable sources could in part be met by maximising the capacity of existing transmission infrastructure. In 2008 ESBI carried out a suite of detailed design studies which recommended that gap-type conductors be introduced as they best satisfied the key technical, economic and acceptable risk criteria for use on the Irish network. Detailed specifications were developed to cover all elements of conductor behaviour, fittings, accessories and type testing. However from the outset it was clear that the introduction of gap-type conductor could not be assessed from simply a design perspective. A thorough examination of the inter-relationship between conductor mechanical/electrical properties and the installation procedure is required. Specifically the low pull-out tension and its impact on electrical undercrossings, the restriction on section lengths requiring the use of semi-strain arrangements and the impact of clamp-in temperature on both structure loads and therefore electrical rating performance. The impact of the conductor and the installation procedure on the structural stability of existing structures was assessed against existing ESB design criteria and required the use of PLS-CADD®, PLS POLE® and PLS TOWER® applications. These assessments resulted in a full suite of installation and safety procedures, which assisted in the development of specialised contractor training for all those appointed to work on HTLS uprate projects.

Post energisation verifications of sag, conductor vibration and noise levels have confirmed that the overhead lines installed using HTLS are operating within the design standards, proving that by adherence to detailed design, installation, type testing, quality and safety standards HTLS conductors can be an important cost effective solution to uprating existing transmission lines.

KEYWORDS

High Temperature, Low Sag, Gap-type Conductors, Uprating, Testing, Installation

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1. BACKGROUND AND CONDUCTOR SELECTION

In line with international experience obtaining planning permits for new overhead transmission lines (OTLs) is a task that is becoming increasingly difficult in Ireland. The awareness amongst both the planning profession and the general public of environmental issues and impacts of new OTLs has lead to an ever increasing difficulty in gaining permits. In addition, the ongoing development of EU and National planning law is placing increased burdens on the applicant in terms of quality and volume of assessment which is required to obtain positive decisions; hence it can take many years to gain permits [1]. Whilst there will always be a requirement to build additional OTL infrastructure, utilities can also look to maximise the use of the existing grid network and increase its capacity through the use of innovative technology such as HTLS conductors. The development of the transmission grid by ESB in Ireland began in 1927 however the bulk of the 220kV and 400kV system was constructed between 1960 and 1985. Since that time, the network has remained largely unchanged while demand has increased by over 150%. The Irish transmission system operator, EirGrid, has forecast that network capacity will need to double by 2025 to cater for increased power flow requirements due to high levels of additional renewable and conventional generation with the aim of meeting at least 40% of Irish energy requirements from renewable sources [2]. In line with developments in other European countries, the dual problem of public resistance to the construction of new transmission lines combined with political pressure to connect an ever increasing percentage of small scale dispersed renewable generation to the Irish grid has resulted in capacity problems.

1.1. Review process

The terms of reference for the review group tasked with investigating the options for uprating transmission lines included the avoidance of planning permission requirements i.e. no significant physical change to existing structures as well as the minimisation of outage duration and disruption to landowners. The review [3] considered five types of HTLS conductor as follows:-

- ACSS – Aluminium Conductor, Steel Supported
- G(Z)TACSR – Gap-type (Super) Thermal resistant Aluminium alloy Conductor Steel Reinforced
- (Z)TACIR – (Super) Thermal resistant Aluminium alloy conductor Invar Reinforced
- ACCC – Aluminium Conductor Composite Core
- ACCR – Aluminium Conductor Composite Reinforced

The five candidate conductors were evaluated under the following criteria:-

- Requirement for conductors – line design criteria and existing conductor sizes
- Review of available conductors – conductor types and considerations
- Technical comparison – sag-tension, ratings, losses, EMF, corona, aeolian vibration
- Fibre optic considerations – unshielded network with no option to use wrap or OPPC with HTLS
- Evaluation of options based on three key criteria – technical, economic and risk mitigation

1.2. Key evaluation criteria

The key evaluation criteria for selection of suitable HTLS conductor types were:-

- Primary and secondary technical merits – Technical criteria were separated into primary (essential) technical merits and secondary (advantageous) technical merits. Primary criteria were deemed as those that must be met by a conductor type and secondary as those that may be considered beneficial but not critical (e.g. simple installation). The primary technical criteria considered included rated tensile strength (RTS), sag-tension behaviour, structure loads, design availability and manufacturing considerations. The secondary technical merits considered handling and damage considerations, simple installation, availability of standard hardware, tools and equipment, contractor experience and standardisation over a range of conductor sizes.

- Economic advantages - The economic advantages were considered on a total life cycle basis and compared with other HTLS candidates as well as benchmarked against the uprating costs if undertaken using conventional ACSR or AAAC conductors in cases where this was considered a viable alternative. Considerations included costs of conductor/fittings, installation, losses under normal loading conditions and maintenance including repair times.

- Risk mitigation - HTLS conductors were seen as a new product in terms of transmission use and experience in Ireland. Key criteria included the amount of HTLS conductor types installed worldwide and track record, the quantity manufactured by HTLS supplier(s), the service history of HTLS from manufacturers, the availability of bespoke HTLS designs optimised to ESB requirements, the risk of supply interruption due to manufacturer size and demand quantity as well as product supply lead time.

1.3. Review outcome

The goal of the joint review was to evaluate and recommend the most appropriate HTLS conductor type(s) for use on the Irish transmission network for 110kV and 220kV uprates. The key evaluation criteria were used to rank each of the five considered conductor types and based on this ranking it was recommended that gap-type G(Z)TACSR conductors would best meet the requirements in all cases.

2. SPECIFICATION/TENDER PROCESS – EVALUATION OF SUPPLIERS

2.1. HTLS specification

A five year term-contract for G(Z)TACSR conductors was drawn up for the period 2010 to 2014 which included quantities for sizes equivalent to each existing ACSR conductor on the ESB transmission network.

To ensure that all aspects of design, supply, test and installation of the new conductor would be fully addressed in the tendering process a detailed specification was produced, drawing on IEEE Std 1283 [4] and Cigre TB 426 [5] recommendations. IEC 62420 [6] for gap-type conductors, IEC 62219 [7] for conductors with formed wires and IEC 62004 [8] for thermal resistant aluminium alloy wire were also included in the specification. Full design requirements were covered in the specification including:

- Required thermal rating, including specific weather parameters based on Cigre TB 299 [9] recommendations and use of Cigre TB 207 [10] as a basis for rating calculations.
- ESB transmission line design criteria, outlining required design limits such as conductor permanent stretch, maximum weather load, and ruling spans limits.
- Conductor design requirements such as PLS-CADD® (Power Line Systems Inc.) models, initial emissivity of 0.6, grease drop point of 260°C and expected design life.
- Other requirements of the specification included fittings for each respective candidate conductor design, type and sample testing, installation procedures (including equipment, stringing manual, training, and installation support).

2.2. Evaluation and Qualification of Suppliers

The evaluation and qualification of each tendered supplier and designs offered took a similar approach to that performed for the HTLS evaluation, i.e. technical, economical, and risk mitigation.

To evaluate the sag-tension behaviour of each design offered, the PLS-CADD® cable model files were examined through PLS-CADD® design software and their thermal ratings generated through the RateKit® thermal ratings application. Where a design could achieve the required ratings and meet the line design criteria outlined in the specification, it was deemed technically compliant and a candidate for further assessment.

The economic evaluation comprised the tendered prices for G(Z)TACSR, fittings, testing, installation equipment, installation training and support also added to projected losses to produce the total life costs over a twenty five year period. The projected capitalised losses were based on a specified set price per kW and calculated for each conductor size over an estimated total circuit length under everyday load conditions.

The mitigating risk which was the final evaluation criteria assessed the track record of each supplier based on the criteria outlined in the specification and ensured that a robust and full tendering process would be carried out.

Candidates who complied with all aspects of the technical specification were subjected to detailed technical and quality audits coupled with sub-supplier evaluation prior to award of contracts. These quality audits were undertaken to ensure compliance with ISO9001 [11] as a minimum standard. Assessment involved reviewing quality assurance procedures, production flow charts, product traceability, non-compliance reporting, work practices & instructions, and also manufacturing and test facilities.

3. TECHNICAL/DESIGN CONSIDERATIONS

3.1. Design approach

ESBI have used lidar surveys since 2005 for the survey, design and construction of nearly 1000km of 110kV transmission lines including more than thirty separate uprating/rebuild projects at 110kV as well as some 250km on five HTLS projects at both 110kV and 220kV. ESBI has developed a lidar specification which calls for production/delivery of a digital terrain model (DTM), above ground feature-coded points (e.g. vegetation, buildings, structures, wires etc.), vertical imagery as well as a numbered library of high quality oblique images of each structure on the lines. Large scale national mapping together with the existing transmission and distribution network records and other services are also utilised. PLS-CADD® transmission line design software is used to build a model of the line from the lidar data. In conjunction with line condition assessment reports and existing technical records, the lidar model enables ESBI to provide reliable designs and highly accurate as-built records on completion of transmission line projects in accordance with safety legislation requirements.

In line with many other utility companies, ESB's line design philosophy has developed and matured over the decades. Most transmission lines built prior to 1990 were designed using deterministic loadings which had been periodically revised over time to account for various incidents and or climatic events. Since then ESB has moved to modern reliability based design codes, namely IEC60826 [12] and EN50341-1 [13] for all new transmission lines. However when approaching the uprating of old lines, one has to consider if the uprated line will be re-commissioned to modern design standards or whether the tower design is left unchanged as its service history has been exemplary. ESBI's approach was to adjust the initial erection tension of the new HTLS conductor such that the ultimate loads, derived using the original design approach, were less than or equal to that of the original conductor. If the lidar data together with thermal rating studies showed that the uprating could be achieved, no strengthening of the tower was deemed necessary. Conversely when the loading of the HTLS conductor, as calculated based on the standards used to derive the original loads, indicated that those original loads were exceeded,

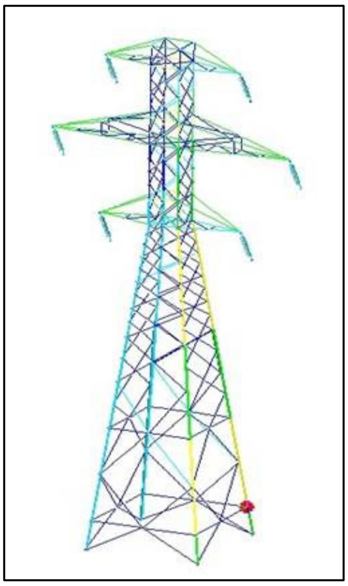

Figure 1. Tower loading model

the towers were then analysed for loading based on EN50341-1 [13] and EN 50341-3-11 (Irish National Normative Aspects) [14]. Once new loading calculations were completed, PLS Tower® (Power Line Systems Inc.) was used to model and analyse the old towers and define the appropriate level of tower/foundation reinforcement.

ESBI utilises detailed line condition assessments completed by experienced in-house inspection teams to determine the necessity for preventative or remedial actions on existing structures or hardware. The importance and need for condition assessments is clearly outlined in Cigre TB 141 [15] and forms the basis for re-design and undertaking strengthening/retrofitting procedures on existing structures and foundations to satisfy both safety and design standards. Although gap-type conductor does not significantly increase the loading on existing structures, ESBI recognises the need to perform indirect non-destructive tests such as concrete coring (for compressive and tensile strength) and detailed visual inspections on steel and other associated hardware.

Another consideration was the use, both existing and future, of optical fibre. On the ESB transmission network there are over 900km of non-earthwire transmission overhead lines with optical fibre wrapped on one phase conductor. An optical fibre station to station connection has been achieved by installing wrapped optical attached cable (OPAC) onto one of the phases. Use of HTLS conductors meant that continuing the use of this design was not possible due to the effects of the high operating temperatures on the optical fibres. To date no solution exists. ESBI are currently studying alternative methods of providing an optical fibre station to station connection. Some alternative solutions being investigated are high temperature wrapped OPAC, wrapped OPAC on MV/38kV lines, use of All dielectric self-supporting (ADSS) / Metal attached self-supporting (MASS) cables, stand-alone optical fibre link, under grounding, and lashed OPAC cable.

3.2. Gap-type conductor behaviour

The feasibility and limitations of operating traditional ACSR conductor at high temperature are widely reported in overhead line conductor literature [16]. HTLS conductors present capabilities of significantly higher operating temperatures due to the materials and/or construction methods they utilise. The construction of gap-type conductor is unique (see Figure 2) and thus requires the overhead line designer to be cognisant and understand the differences in sag-tension performance of this type of conductor against conventional ACSR conductors. Gap-type conductor consists of aluminium layers and a steel core separated by a highly stable heat resistant compound filled gap [17]. An extra high tensile strength steel core is generally adopted together with aluminium-zirconium for the aluminium layers [18]. This conductor design, along with its specialised installation technique, results in extremely favourable conductor sag-tension behaviour.

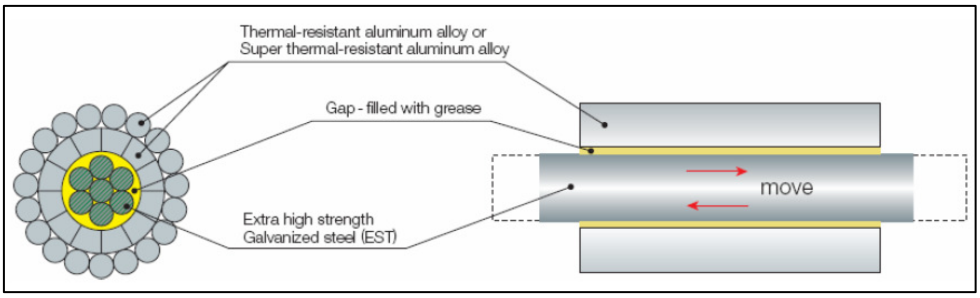

Figure 2. Gap-type conductor, G(Z)TACSR [19]

The operation and low-sag performance of gap-type HTLS conductors are based on controlling and lowering the transition point below which both the steel core and aluminium layers are under tension. With traditional composite conductors e.g. ACSR, this transition point, often referred to as the “knee-point”, is usually beyond the normal operating range of the conductor and hence no low-sag advantages may be realised. As conductor temperatures increase, the tension decreases to the point where the aluminium layers are no longer under tension and subsequently the change in conductor tension with temperature is controlled solely by the steel core.

Gap-type conductor is installed with the steel core under tension such that the conductor can benefit from operation under steel core tension over most of its operating temperature range, although making for a more complex installation process including the use of semi-strain arrangements [20]. In addition to this, since temperatures during installation may vary somewhat, consideration also needs to be given to the impact of varying the transition point over this temperature range. With traditional conductor, the transition point may occur at some high temperature beyond normal operating temperature and have no practical effect on sag-tension calculations. However, with gap-type conductor, varying the transition point means that the sag-tension calculation is only valid for a given installation temperature.

3.3. Production of stringing/sag tables

With conventional conductors, sag charts/tables are provided for a range of temperatures (0-30°C) such that the maximum operating temperature sag is constant. However with gap-type conductors, since the transition point does vary over a range of installation temperatures, the maximum operating temperature sag must remain the same regardless of the transition point variation, thereby ensuring consistent final sags for ground clearance purposes. Consistent high temperature sags will be achieved, however ambient temperature tensions will vary significantly with tower loading and aeolian vibration implications.

Figure 3 shows the typical gap installation tension scenario, at 0°C (installation temperature) the everyday tension will be close to 3.1kN; however, where the installation temperature is 30°C, the resulting everyday tension at 0°C may be close to 3.4kN, about 10% higher. Individual stringing charts/tables must be computed having regard to the effect of transition point variation on a section-specific basis. Stringing tables were derived and cross checked using PLS-CADD® overhead line design software.

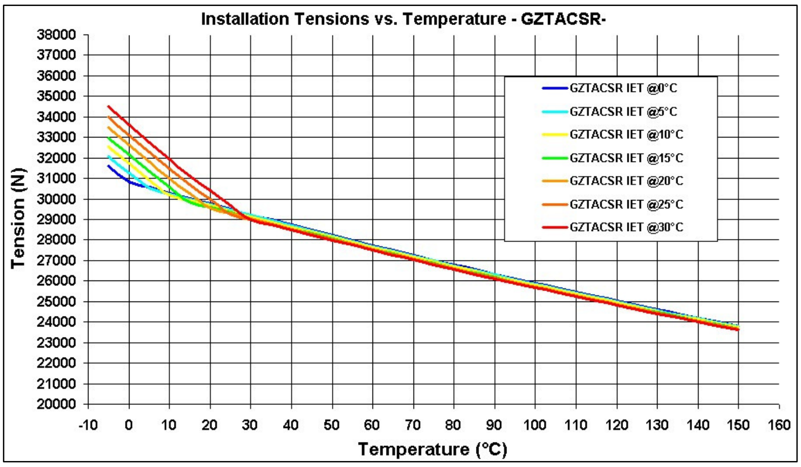

Figure 3. Gap-type conductor tension variation with installation temperature

4. TYPE TESTING – CONDUCTOR AND ACCESSORIES

In accordance with the recommendations of Cigre TB 426 [5] an extensive type testing program drawing on international standards and ESB specifications was undertaken on all conductors, associated hardware/fittings and tooling. Testing at various supplier and independent test laboratories was undertaken prior to the acceptance for use of all conductors. In addition, onsite installation testing was performed to cater for tests that could not be adequately replicated in laboratory conditions.

Installation can lead to some of the highest stress concentrations on a conductor. A combination of bending, torsion and tension are applied to the conductor during stringing, therefore it is vital that these specific characteristics are tested during the type testing phase of the project. This will ensure that potential hazards and performance issues are not encountered during the installation phase of any project. All type tests were carried out successfully on each gap-type conductor. The range of tests carried out covered the three basic type test procedures, basic characteristics tests for line design, installation conditions and in service tests (mechanical, electrical performance and environmental).

4.1. Type test programme

The test programme for gap-type conductors and fittings was based on ESB's existing tests for conventional ACSR conductors, modified to cater for the requirements of HTLS conductors. This included qualification tests on each conductor outlined in Table 1, followed by a suite of type tests on the conductor as detailed in Table 2 :-

Table 1. Qualification tests on gap-type conductor

Element	Test	To Specification
Full Conductor	Cross-sectional area, diameter, round/formed wires, linear mass, surface condition, lay ratio/direction, wire canting, mass of grease	IEC62420
	DC resistance of conductor	IEC61089
Aluminium Strands (Z)TAL	Diameter, tensile stress, elongation, resistivity test, thermal-resistant property	IEC62004
Steel Strands (ACS or EHS)	Diameter, stress at 1%, tensile test, ductility (elongation, torsion, wrapping), galvanising/al. clad.	EN50540 (ACS) IEC60888 (EHS)

Table 2. Type tests on gap-type conductor

Element	Test	To Specification
Full Conductor	Annular gap, stress-strain & UTS	IEC62420
	Aeolian vibration proof, sheave	IEC60794/ESB
Aluminium Strands (Z)TAL	Aluminium thermal-resistant property	IEC62420
Steel Core	Stress-strain & UTS, creep	IEC62420

Type testing of vibration dampers and insulator fittings were carried out as outlined in Table 3 below :-

Table 3. Type tests on vibration damper fittings/conductor fittings

Element	Test	To Specification
Vibration Dampers	Characteristic, visual/dimensions, galvanising on weights /wire, slip test on conductor, clamp bolt tightening test, Pull test on weights, fatigue test	ESB
	Corona/RIV	IEC61284
Fittings	Visual, dimensional, material verification, galvanising, non-destructive testing, mechanical (damage & failure load, slip test, clamp bolt tightening, tensile), heat cycle test, corona/RIV	IEC61284 / ESB
	Galvanising24 Hour Tensile Load	ESB

4.2. Conductor creep and Stress/Strain curves

Four creep tests were carried out on steel core samples for each conductor type using the tensions associated with the full conductor. This was on the basis that significant aluminium creep would not be applicable to conductor behaviour since at elevated operating temperatures the full conductor load would be carried on the steel core only. It was also expected that core-only creep measurements should have a higher degree of accuracy than bi-metallic conductor creep measurements.

Three room temperature tests were specified at 15%, 25% and 40% of full conductor RTS respectively. This was typically 30-80% of steel core RTS in each case. A single high temperature test at 100°C was also specified at 20% of full conductor RTS. Results from the creep tests demonstrated significantly increased steel core creep at high load and/or high temperatures, ranging from 0.02% to 0.1% as compared with normal tension core creep values of 0.01% or less.

Stress-Strain tests were carried out on core and full conductor in the same manner as for ACSR conductors. The stress-strain and creep data from the type tests were used to provide updated PLS-CADD® conductor models for each of the conductors supplied by the manufacturers to ensure reliable sags-tension behaviour.

4.3. Conductor aeolian vibration

The aeolian vibration tests were carried out to IEC60794-1-2 [21] for ten million cycles with a target of achieving ±100µs at the suspension clamp in the active test span, as per ESB requirements. 200µs peak to peak is in line with international practice for bending strain endurance levels [22]. However, the inherent self-damping of the gap-type conductors meant that maintaining this strain level over ten million cycles was difficult and required the shaker to be positioned two to three metres from the suspension clamp as shown in Figure 4. Gap conductors generally have superior self-damping capabilities than traditional ACSR conductors. This relates to the differences in construction of the conductors and how energy is dissipated between the core and outer layers due to the effect of the gap itself and the properties of the high temperature grease. As the conductor begins to vibrate, the steel core and the aluminium strands have different vibration characteristics and therefore the different layers directly impact on each other. This effect makes it more difficult to get a standing wave (which is the worst case for a conductor) and therefore results in improved self damping performance.

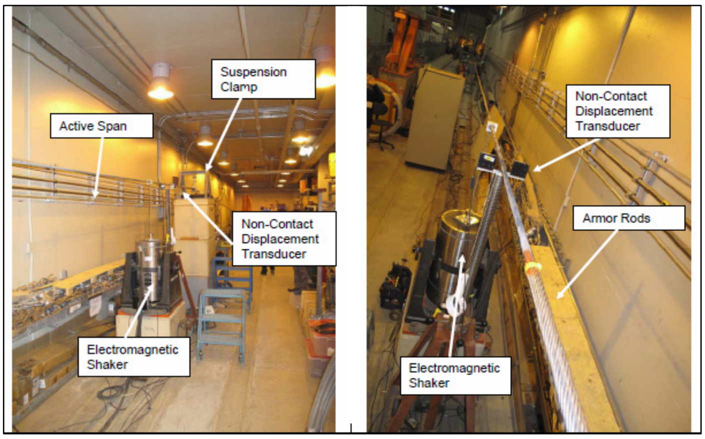

Figure 4. Conductor aeolian vibration test arrangement

Independent laboratory tests have shown that gap-type conductors have high self-damping characteristics [23]. These test results show that the energy balance amplitude will typically be less than 1mm and significantly less than the 5-10mm amplitude resulting from testing at ±100µs. Hence, it is questionable whether the specified target bending strain is appropriate for gap-type conductor aeolian vibration testing.

4.4. Accessories testing

All type tests were carried out successfully on the conductor accessories, however some minor issues arose during the testing which merit further discussion.

As part of ESB's specification a 24hr duration tensile test was required on the full conductor with deadend fittings and mid span joint in-situ. The aim of this test is to stress the conductor/clamp system over an extended period of time, such as to represent a sustained environmental load. This test highlighted an issue due to the differing mechanical characteristics of the outer aluminium layers and steel core. In this test the steel and aluminium deadends and mid span joints were compressed under zero tension. The test sample was then placed in the tensile test bed; step loaded according to the specification and applied for the required timeframe of 24hr. The conductor failed in the aluminium layers at various different time interval, 2hr, 5hr, and 14hr during the 24hr tests. Three different conductor sizes failed during the tests at varying time intervals indicating that this was not unique to one conductor size.

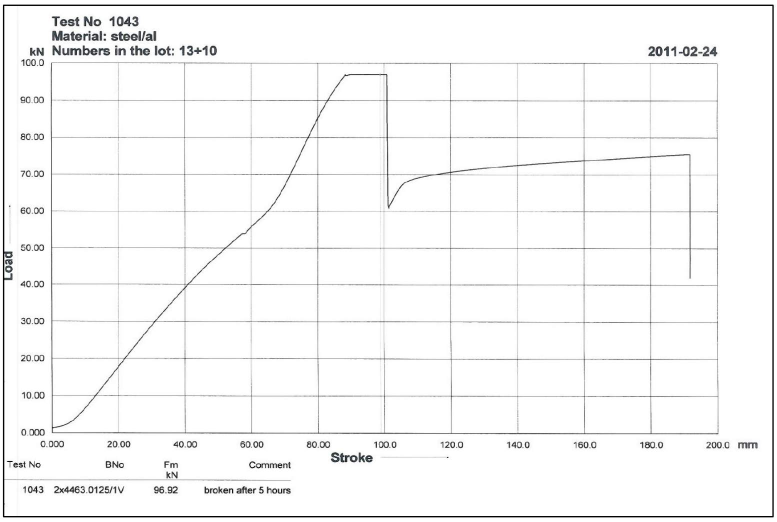

Figure 5. Failure of aluminium layer following elongation of the steel core

The failure mode of the 24hr test was attributed to transferral of a large amount of load to the aluminium outer layers. It was also noted that the extra high tensile steel used for the core had a relatively high percentage elongation as measured in the conductor type tests. The transferral of load to the aluminium outer layers caused rapid elongation leading to failure – indicating that the aluminium layers are not designed to support excess mechanical load. A separate test was carried out on the conductor only using epoxy resin as the clamp mechanism, which proved successful and demonstrated that the problem was linked to the combined conductor and fittings arrangement.

The approach agreed by all parties was to pre-tension the steel core to approximately 23% of its RTS (full conductor) for one hour, thereby allowing the steel to elongate sufficiently. Subsequently the aluminium layers were compressed and the full test sequence applied. Following this revised testing procedure, all of the 24hr tests were satisfactorily completed. This pre-tensioning approach is supported by the fact that it is reflective of the actual installation techniques for gap-type conductor. It should be noted that the suite of standard tensile tests on fittings as outlined in IEC 61284 [24] passed without the requirement of pre loading the steel core.

Slip limit windows to ESB specifications were also required to be achieved for the suspension clamp assemblies. This condition was new to the supplier and took minor re-designs on the clamp to achieve the required limits. These tests were specified as having a slip window between 20% and 30% of the breaking load of the conductor. This dual criteria meant that the clamp had to hold up to 20% RTS but a slip of 2mm had to be seen before the upper limit of 30% RTS was reached.

The implications for overhead line insulator strings (both ceramic and composite) in operating phase conductors at elevated temperatures are highlighted in a number of publications [[4], [16], [25]]. The insulator arrangement considered as being the most susceptible to heat transfer from the conductor is that of the I-suspension insulator string type. This was overcome by ensuring that the suspension clamp and armour rod system were designed to efficiently dissipate heat from the conductor so that acceptable temperatures at the insulator fittings was achieved. Armour rods were not deemed necessary for the strain assemblies and during the IEC 61284 [24] heat cycle test (whose objective is to assess the long-term electrical performance of joints) the temperature of the terminal fittings were monitored. Fitting temperatures during the test cycles were found to be at acceptable levels.

5. INSTALLATION – CONSTRUCTION SITE CHALLENGES

5.1. Stringing gap-type conductors at pre-sagging tensions

A restrictive characteristic of HTLS conductor installation is that there is a limit to the amount of tension placed on the outer aluminium layers at the time of pulling out and holding the conductor. This is to prevent exceeding the tension limits of the outer layer. This limiting factor, typically two thirds of final sag tension should not be exceeded on the conductor during the stringing process. Thorough pre construction planning is required to avoid inherent costs associated with dealing with conflicts such as lower voltage lines and other crossings. A number of options are available to mitigate against this issue through the use of temporary structures, raised stringing wheels etc.

5.2. Addressing long tension sections

Maintaining the performance of gap-type conductor is dependant on adhering to a number of requirements. A design limit of five to six consecutive spans in any one tension section, sagging of the conductor on the steel core only and a relaxation period of 12hr to allow tension release from the aluminium layers are some of the principle criteria. These requirements lead to modifications in existing design and construction practices. Traditional ASCR conductor can generally be jointed at arbitrary locations without significant impact on the installation of the conductor. Given this, drums of ACSR conductor can typically be manufactured in standard lengths such as 2km. However bespoke drum lengths are required for gap projects which represent each section of conductor between joints over the five to six spans. When there are two or more drums in one section the excess conductor, allowing for stringing set up, needs to be carefully monitored and removed from the middle drum as the conductor is pulled out. This ensures that compression joints in the straight will land at their allocated positions.

In any single stringing operation it is preferable that there is no more than one semi strain position, as landing more than one joint at an allocated structure can prove difficult. To cater for this difficulty and to allow for long straights to be pulled out, a temporary stringing structure (see Figure 6) was utilised to enable all phases to be pulled out at a mid span location in one direction, held, and then the conductor strung back in the opposite direction. This methodology allows for stringing to be completed using up to six consecutive drums i.e. three consecutive drums in either direction from the temporary structure. This in turn increases the efficiency of the stringing procedure as the machinery only requires one minor location change.

Figure 6. Temporary stringing structure

5.3. Experience with steel guy grips used for tensioning

A further observation was the unravelling of steel guy grips used for core tensioning. While swivels were used during the stringing operation none were specified for the core tensioning process. During installation training, it was found that the guy grips opened due to the torsional effect of the tensioning process. This resulted in a reduction of gripping force causing steel core slippage within the guy grip. This phenomenon was alleviated by adding a conductor swivel with appropriate mechanical rating between the guy grip and the pulley block in order to allow the guy grip to rotate in the direction of the steel core, alleviating the torsional effect.

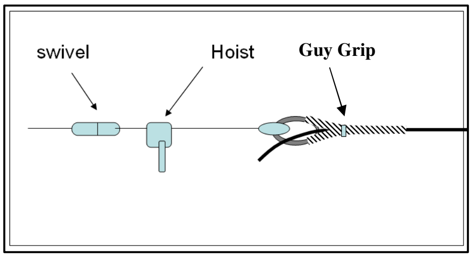

Figure 7. Tensioning steel core using guy grips

6. INSTALLATION QUALITY MANAGEMENT

6.1. Pre-energisation investigations

Suitable methods were employed to investigate the existing foundations that had been in service for up to 40 years. Cigre TB 141 [15] was used as the basis of a study to investigate existing foundations. Following a review of the original design a percentage of angle and suspension towers had their foundations fully exposed to verify as-built foundation dimensions. Concrete core samples were taken and crushed to assess the condition of the concrete. Locations were chosen by soil classification, ease of access to site and also proximity to known waterways.

As outlined in Section 3.2 above, the sagging of HTLS conductor is crucial to its operating performance. Once commissioned, a full sag survey was carried out on identified spans (critical crossings / largest spans). This survey consisted of measuring the height above ground of the phase conductor at a known conductor temperature and wind speed. These values together with sagging details for the time of deadend compression were used to verify the sag of the conductor using PLS-CADD® design software. It is crucial that the "knee point" temperature and ambient temperature on the day of survey are recorded accurately as a change in the "knee point" temperature has an affect on the operating tension of the conductor. To this end it was important that linesmen completed a sag register containing all of the relevant information from the time of termination for input into PLS-CADD® models.

6.2. Post-energisation verifications

Vibration recorders were initially installed on one of the 220kV lines with the aim of building greater understanding of the self damping characteristics of the gap-type conductors and also the performance of the Stockbridge damping systems supplied by the manufacturers. Analysis of the data downloaded from these recorders on a bi-monthly basis has shown that the conductor is operating within its vibration damping limits.

Audible noise measurements of the lines were conducted by measuring directly underneath towers located in quiet ambient noise level areas. Measurements were conducted at a series of towers in both wet and dry weather conditions for both the original energised conductor and the newly energised gap-type conductor scenarios in accordance with IEEE Std 656 [26]. No significant difference in audible noise was recorded.

Following completion of the line and re-energisation the sags were checked. Real-time loading conditions from the transmission operator and meteorological data were used to evaluate the conductor temperature at the time of survey. To date all readings have been found to be within the design standards and the conductor sag/tension performance is as per design and specification.

Sample lengths of conductor were also mounted to the body of a number of masts in varying geographical environments with the aim of assessing the relative change in conductor emissivity over time. These results will be used to confirm the expected long term operational ratings of the line.

CONCLUSION

The introduction of HTLS onto the Irish transmission grid has provided EirGrid and ESB Networks with new uprate options in terms of maximising the utilisation of existing transmission infrastructure. Over the past three years, from the initial investigation to the construction of the first HTLS lines, ESBI and ESB Networks have gained a wealth of experience in the design and installation of gap-type conductors on approximately 250km of 110kV/220kV OTLs. As highlighted through out this paper, HTLS conductor and specifically gap-type conductor presents utilities with design and installation challenges that differ to conventional conductors. Our experience shows that the qualification process plays a vital role in verifying the conductor model predictions with measured test data and how these can be integrated to validate conductor performance.

ESBI are confident that the high level of engineering and technical development, testing and technical design will ensure that all future uprates are completed successfully. It is evident that HTLS conductors will play an important and cost effective role in the uprating of existing transmission lines.

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END NOTES

[A] ESB International (ESBI) is one of Europe's leading engineering and consultancy organisations. ESBI is part of ESB's non-regulated businesses and operate across a wide area of the energy industry.

[B] ESB Networks Ltd. is responsible for building, operating, maintaining and developing the electricity network and serving all electricity customers in the Republic of Ireland. ESB Networks are the owner of the transmission assets.

[C] EirGrid is responsible to operate, ensure the maintenance of and develop the electricity transmission system in Ireland since 1 July 2006. EirGrid is the independent electricity Transmission System Operator (TSO) and Market Operator (MO) in both Ireland, and Northern Ireland.