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**CONSIDERATIONS RELATING
TO THE USE OF HIGH
TEMPERATURE CONDUCTORS**

Working Groups

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CONSIDERATIONS RELATING TO THE USE OF HIGH TEMPERATURE CONDUCTORS.

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Cigre WG03; WG12-1; WG11-3

1 INTRODUCTION

In many countries, new power lines have not been built for many years and the ability of obtaining right of ways is becoming more and more difficult. Nevertheless, over the same time period, many such countries have also experienced a small but steady increase in the power consumption. It is thus becoming necessary to uprate the thermal power transfer capacity. One of the ways in which this can be achieved is by reconditioning. This can be performed by either using conductors larger than at present or conductors with the same diameter.

Increasing the thermal rating of an existing line by use of a replacement conductor **larger** than the original (having lower resistance), will increase both transverse ice and wind loads and tension loads on existing structures. A larger conventional conductor imposing greater loads on the existing structures may reduce the reliability of the existing line unless the structures are reinforced.

Increasing the thermal rating of an existing line by use of a replacement conductor having nearly the **same diameter** as the original conductor but capable of operation at higher temperature (within existing sag clearance and loss-of-strength constraints) may avoid the need for extensive reinforcement of suspension structures. There are several different types of high temperature, low sag conductors that can be used to increase the thermal rating of existing lines with a minimum of structural reinforcement.

The most attractive choice of replacement conductor depends on the design conditions of the existing line. All are potentially a solution when the line thermal rating is to be increased by more than 50%.

This report describes the types of commercially available, tried and tested high temperature conductor that are (at the time of writing) in wide use, in one Region or another, around the world. In addition it describes the effect of these conductors on insulators and fittings. It also describes the types of fittings that are used on these conductors world wide.

This report is a result of extensive work undertaken in Cigre working groups WG 12 (electrical aspects), WG03 (insulators), and WG11 (mechanical aspect of conductors including fittings).

2 TYPES OF HIGH TEMPERATURE CONDUCTORS REF [1]

“High Temperature Conductor” is defined as a conductor that is designed for applications where continuous operation is above 100°C or the conductor is designed to operate in emergency conditions above 150°C. The types of conductor that are at present commercially available are briefly described in TABLE I

ACSS	Aluminium Conductor, Steel Supported ⁽¹⁾⁽²⁾
ACSS/TW	Trapezoidal shaped strands, Aluminium Conductor, Steel Supported ⁽¹⁾⁽²⁾
G(Z)TACSR	Gap Type Super Thermal Resistant Aluminium Alloy, Steel Reinforced
KTACSR	High Strength Thermal Resistant Aluminium Alloy Conductor, Steel Reinforced ⁽¹⁾
TACSR	Thermal Resistant Aluminium Alloy Conductor, Steel Reinforced ⁽¹⁾
ZTACSR	Super Thermal Resistant Aluminium Alloy Conductor, Steel Reinforced ⁽¹⁾
ZTACIR(3)	Super Thermal Resistant Aluminium Alloy Conductor, Invar Reinforced

TABLE I. DIFFERENT TYPES OF HIGH TEMPERATURE CONDUCTORS

- (1) Additional suffices are allowed to describe the type of core (e.g. ACSS/GA)
(2) Originally known as SSAC
(3) Could also be known as STACIR

2.1 CONDUCTOR MATERIALS.

These conductors, designed for high temperature operation, consist of various combinations of the aluminium and steel wire materials listed in TABLE II (aluminium) and TABLE III (core).

2.1.1 Aluminium materials

Type of Aluminium		Conductivity (%IACS)	Min. Tensile Strength (MPa)	Allowable Operating Temperature(°C)	
				Continuous	Emergency *
Hard Drawn	1350-H19 (HAL)	61.2	159 - 200	90	120
High Strength Thermal resistant Aluminium Alloy	KTAL	55	225-252	150	180
Thermal Resistant	TAL	60	159 - 176	150	180
Super Thermal Resistant	ZTAL	60	159 - 176	210	240
Fully Annealed	1350-0	63	59 – 97	200 – 250**	250**

TABLE II. CHARACTERISTICS OF ALUMINIUM AND HIGH TEMPERATURE ALUMINIUM ALLOY WIRES.

*Emergency operating temperature is not well defined but it is generally agreed that the emergency temperature should not apply for more than 400 hours for the total life of the conductor. This relates to 10 hours per year for a 40 year life span..

**Fully annealed aluminium strands can operate at temperatures in excess of 250°C but are normally limited to lower temperatures because of concerns about connectors and steel core wire coatings.

TAL and ZTAL aluminium wires have essentially the same conductivity and tensile strength as ordinary electrical conductor grade aluminium wire but can operate continuously at temperatures up to 150°C and 210°C, respectively, without any loss of tensile strength over time. Fully annealed aluminium wires are chemically identical to ordinary hard drawn aluminium, have much reduced tensile strength, and can operate indefinitely at temperatures even higher than 250°C without any change in mechanical or electrical properties.

2.1.2 Core materials

Zinc-5% Aluminium Mischmetal coated steel wire is capable of operation at higher temperatures than normal galvanised steel wire (i.e. 250°C instead of 200°C). Invar steel wire has a notably lower rate of thermal expansion when compared to ordinary galvanised steel core wire but has somewhat lower tensile strength and modulus.

	Min. Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Coef. of Thermal Linear Expansion (x10-6 /°C)
Galv. Steel HS Galv. Steel EHS	1230-1320 1765	206	11.5
Alum. Clad (AC) 20.3% I.A.C.S.	1103-1344	162	13.0
Zinc-5% Al. Mischmetal Standard HS	1380-1450 1520-1620	206(Initial) 186(Final)	11.5
Aluminium Clad. Invar Alloy	1080	152	3.7

TABLE III. CHARACTERISTICS OF STEEL CORE WIRES FOR USE IN OVERHEAD CONDUCTOR.

2.1.3 Aluminium and Core metal combinations

The different types of Aluminium and core materials used in high temperature conductors are shown in TABLE IV.

Core Material				
Aluminium Alloy	Galvanised steel	Aluminium clad steel	Galvanised invar steel	Aluminium clad invar steel
TAL(60TAL)	TACSR	TACSR/AC		
KTAL	KTACSR	KTACSR/AC		
ZTAL(UTAL)	ZTACSR G(Z)TACSR	ZTACSR/AC	ZTACIR	
XTAL				XTACIR
1350-0	ACSS/GA	ACSS/AW		

TABLE IV. CONDUCTOR TYPES RELATING TO CORE AND CONDUCTOR MATERIAL

2.2 HIGH TEMPERATURE CONDUCTOR CONSTRUCTIONS.

Steel-cored conductors (and other non-homogeneous conductors) have what is known as a “knee-point.” This is a temperature above which the higher thermal expansion rate of aluminium causes all the stress of the conductor to be borne by the steel core. Beyond this knee-point temperature, therefore, the conductor experiences a sag increase due to the expansion of steel alone. This new expansion coefficient will be lower than that for the conductor at lower temperatures, resulting in relatively low sag increases when operated at high temperature. Standard ACSR exhibits this property, but usually at a temperature beyond the annealing limit. High temperature conductors make use of this property.

TACSR and (Z)TACIR are stranded in the same fashion as ordinary ACSR. Their electrical and mechanical properties are simply the result of their composite aluminium and steel wire properties.

ACSS can be stranded using either round or trapezoidal shaped aluminium wires. In either design, the conductor depends primarily on the steel core wires for mechanical strength.

The unique installed properties of G(Z)TACSR are the result of both its wire properties and its construction. The innermost layer of (Z)TAL wires is trapezoidal and a small gap to the core is left to allow installation with tension applied to the steel core only.

2.2.1 (Z)TACSR

(Z)TACSR has the same construction as conventional ACSR, with galvanised steel wires for the core and (Z)TAL wires (thermal resistant aluminium alloy wires with zirconium added) surrounding them. TABLE II shows basic characteristics of (Z)TAL wires.

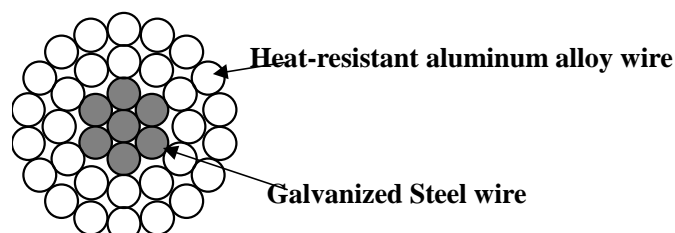


FIGURE I. CROSS SECTION OF TACSR CONDUCTOR

(Z)TACSR conductor is, in almost all respects, identical to conventional ACSR conductors. The aluminium alloy used in (Z)TACSR has a slightly higher electrical resistivity than standard hard-drawn aluminium, but in all other respects the two conductors are almost identical. Unlike the conductors described below, (Z)TACSR is not, by design, a low-sag conductor. It has the same thermal elongation behavior as ACSR. The main advantage of (Z)TACSR is that its aluminium alloy wires do not anneal at temperatures up to 150°C for TAL and 210°C for ZTAL (Temperatures above 100°C would cause annealing of the aluminium strands in standard ACSR).

(Z)TACSR can therefore be used to uprate existing lines where some additional clearance is available. The TAL alloy of TACSR allows the knee point behavior to be exploited. At present TACSR is currently used in place of conventional ACSR in more than 70% of the transmission lines in Japan.

2.2.2 G(Z)TACSR

G(Z)TACSR commonly known as gap type conductor [10] has a unique construction. There is small gap between the steel core and innermost shaped aluminium layer, in order to allow the conductor to be tensioned on the steel core only. This effectively fixes the conductor's knee-point to the erection temperature, allowing the low-sag properties of the steel core to be exploited over a greater temperature range. The gap is filled with heat resistant grease (filler), to reduce friction between the steel core and aluminium layer, and to prevent water penetration.

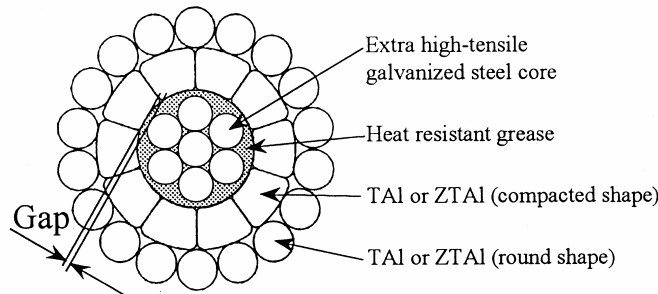


FIGURE II. - CROSS-SECTION OF GTACSR CONDUCTOR

2.2.3 (Z)TACIR

As with (Z)TACSR, (Z)TACIR [3] has a conventional stranded construction (identical to ACSR), making use of material innovations to give properties allowing the conductor to be operated at high temperatures. In place of the steel strands of (Z)TACSR, it has galvanised or aluminium-clad invar alloy steel wires for the core and (Z)TAL wires surrounding them.

TABLE II shows basic characteristics of TAL and ZTAL wires. ZTAL resists annealing up to a continuous temperature of 210°C.

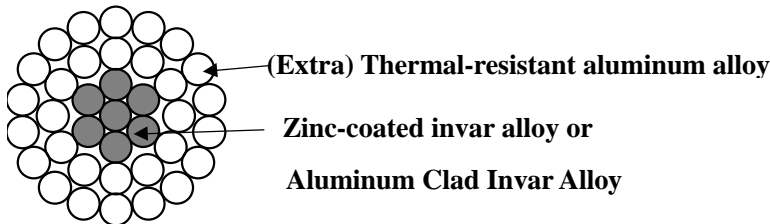


FIGURE III. CROSS SECTION OF (Z)TACIR CONDUCTOR

Invar is an iron-nickel alloy (Fe—36%Ni) with a very small coefficient of thermal expansion. The typical properties of invar wire are shown in TABLE III. The coefficient of thermal expansion of invar wire is around one third that of galvanised or aluminium-clad steel wire.

2.2.4 ACSS and ACSS/TW (Originally designated SSAC)

Aluminium Conductor Steel Supported (ACSS) and Shaped (Trapezoidal)-Wire Aluminium Conductor Steel Supported (ACSS/TW) is described in [4]ACSS consists of fully annealed strands of aluminium (1350-0) concentric-lay-stranded about a stranded steel core. ACSS is not available in conductors with a single strand steel core.

The coated steel core wires may either be aluminised, galvanised, zinc-5%aluminium Mischmetal coated or aluminium clad. The steel core is available in either standard strength or high strength steel. The “high strength” steel has a tensile strength about 10% greater than standard steel core wire. In appearance, ACSS conductors are essentially identical to standard ACSR conductors. ACSS is typically available in three different designs: “Standard Round Strand ACSS”, or with “Trapezoidal Aluminium Wire” in constructions with equal area or equal diameter to conventional round wire constructions. Special high strength constructions are also available.

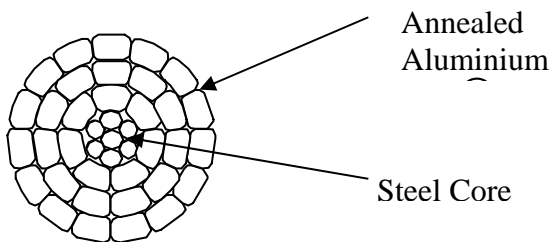


FIGURE IV. - CROSS-SECTION OF ACSS/TW CONDUCTOR.

In all designs, the use of annealed aluminium strands yields much higher mechanical self-damping than standard ACSR of the same stranding ratio.

Because the tensile strength of annealed aluminium is lower than 1350-H19, the rated strength of ACSS is reduced by an amount dependent on the stranding (e.g. 35% for 45/7, 18% for 26/7, 10% for 30/7) compared to similar constructions of ACSR. In fact, a 45/7 ACSS conductor, with standard strength steel core wire has about the same rated breaking strength

as a conventional all aluminium conductors made with hard drawn aluminium wire. The reduced strength of ACSS can be offset by using extra-high strength steel core wires, by using a higher steel core area, or by doing both.

Since the tension in the annealed aluminium wires is so low, the thermal elongation of ACSS is essentially that of the steel core alone. Similarly, given the low tension in the aluminium strands, ACSS does not creep under everyday tension loading. ACSS/TW constructions behave in the same manner as ACSS but have the added advantages [5] of reduced ice and wind loading and reduced wind drag per unit aluminium area.

2.2.5 Conductor Colouring

Conductor colouring is one method of increasing ampacity. The colouring of the conductor increases the radiation of the conductor, which increases the cooling, therefore allowing increase in capacity of the conductor. The increase in capacity is approximately 5-10% if the conductor is operating above 75°C. Below 75°C, there is minimal effect.

Since 1988, 2 methods of conductor colouring have been developed in Austria.

Conductor painting: This process requires a special production line, totally separated from the stranding equipment. First, the conductor has to pass through pre-treatment equipment to clean the conductor from remaining drawing lubricants and to prepare the surface for painting. The conductor is then passed through a colour applicator and placed in a drying chamber. The advantages of this process are high mechanical resistance and the conductor can be coloured many different colours.

The disadvantages of this process are high investment cost, high production cost, and the colouring is very difficult to remove at the fittings locations.

Wire Colouring: The major reason of this development was to find an economical method for blackening overhead conductors. Special drawing lubricants and additives create a black surface on the aluminium wires while passing the drawing line. These black coloured wires will be used for the outermost layer of the conductor. The advantages of this process are low investment cost, low production cost and the colour is easier to remove at fitting locations. The disadvantages of this process are that it is only for aluminium wire and is only in black and the colouring has limited mechanical resistance.

2.3 COMPARISON OF HIGH TEMPERATURE CONDUCTORS

The essential advantage of reconductoring existing lines with high temperature conductors is that the line's thermal rating can be increased with minimal modification of existing transmission line structures [6]. *To limit the need for structural modification, these high temperature replacement conductors must operate at much higher temperature than ordinary bare overhead conductor without exceeding the original maximum sags and without causing a large increase in the original maximum tension and ice or wind structure loads.* Increased sag would require raising the existing structures. Increased structure loads

would require replacement or reinforcement of dead-end and angle structures and perhaps even tangent structures.

Clearly, replacement conductors that have the following characteristics (relative to the original conductor) are attractive:

- a low thermal elongation rate
- can be installed with less everyday sag
- the same or lower outside diameter
- the same or lower resistance

It is less clear what replacement conductor characteristics best avoid increasing the maximum structure tension loads while maintaining an acceptable level of safety with regard to conductor tensile failure under heavy loads. Also, while certain replacement conductor characteristics may be attractive, it is not obvious that such characteristics are “cost-effective” (i.e. that the additional cost of the special conductor is justified by the increase in line rating). In any event, the choice of replacement conductor is largely influenced by the existing conductor type and line design conditions.

Application and comparison of these conductors can be found in [1]

3 IMPACT OF USING HIGH TEMPERATURE CONDUCTORS ON INSULATORS

3.1 INTRODUCTION

As a consequence of the use of High temperature conductors, higher conductor temperatures will be reached that may affect the insulator performance. The purpose of this section is to examine the impact of such temperature increases on the mechanical performance of overhead line insulators, to describe some laboratory tests that have been run to evaluate this impact, and to recommend some steps that should be taken when high conductor temperatures are expected.

This report considers only the effect that high temperature conductors could have on the mechanical integrity of the insulator assembly. It does not deal with the possible effect of these high temperatures on the electrical performance of the insulators. No studies have been found that deal with that effect but it is conceivable that heat conducted from the conductor or warm air currents generated by the conductor temperature could modify the moisture condition of the surface of the insulator along the first few sheds. This effect could happen for conventional or composite insulators, possibly leading to localised dry band arcing activity.

3.2 EFFECT OF CONDUCTOR TEMPERATURE ON INSULATORS

The conductor temperature will influence the temperature of the conductor clamp, links and shackles, the insulator hardware and the insulator body itself. The extent of this influence also depends on the specific design of the insulator. Manufacturers usually specify the maximum operating temperature of their insulators.

For porcelain and toughened glass cap and pin insulators, it is usually the cement that is keeping together the cap, the pin and the insulator shell that dictates the upper limit for safe operation. This limit is around 60°C for sulphur cement and 100°C for Portland and Alumina cements. The composition of the lead antimony alloy used to fasten the caps to the insulating body of long-rod porcelain insulators also determines the upper temperature limit for their safe operation. A temperature limit of about 80°C is obtained with the standard formulation. Changing the lead antimony ratio can increase the temperature limit to that of Portland and Alumina cements.

Normally the mechanical strength of composite insulators is determined by the type of resin used to manufacture the FRP core and the method of attachment of the metallic end fitting to the core. The upper temperature limit for safe the operation of composite insulators is about 80°C.

It should be remembered that solar exposure as well as wind velocity can significantly change the temperature of the insulator for a given conductor temperature.

3.3 LABORATORY INVESTIGATIONS TO ASSESS THE INSULATOR TEMPERATURE

During the last 10 years, utilities, research laboratories and manufacturers of insulators have performed laboratory tests to investigate how a high conductor temperature affects the temperature of insulators and their connecting hardware and therefore influences the mechanical integrity of the insulator structure.

Three examples of representative studies are presented here.

3.3.1 *Test procedures and results*

All three studies have been performed on full-scale insulator-conductor assemblies. The **first study** evaluated the thermal changes occurring on a suspension composite insulator, the **second** one looked at a porcelain cap and pin insulator string and the **third study** investigated the temperature changes of suspension, dead-end and braced line-post composite insulators.

3.3.2 *Study No 1 [7]*

FIGURE V shows the test arrangement for a composite insulator attached to a high temperature conductor loop. The mechanical load on the insulator was reproduced by means of a tensile machine. Temperature sensors were attached to different parts of the insulator as well as to various parts of the hardware. Each run of the experiment lasted over 2 hours in order to reach temperature equilibrium.

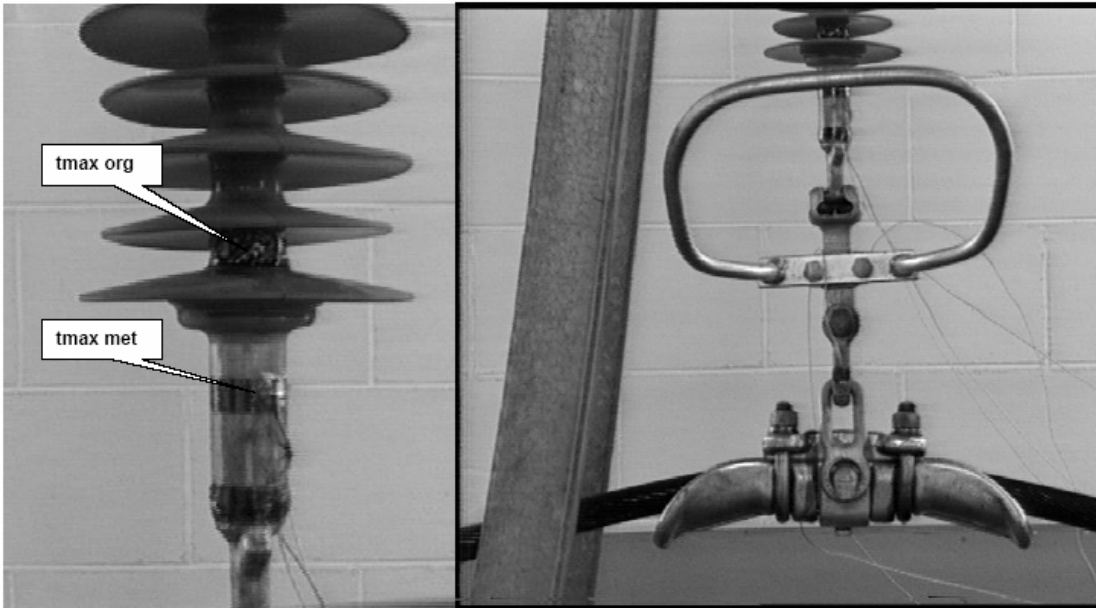


FIGURE V. EXAMPLE OF THE TEST ARRANGEMENT TO MEASURE THE TEMPERATURE INCREASE ON A COMPOSITE INSULATOR CAUSED BY A HIGH CONDUCTOR TEMPERATURE. INSERTS SHOW THE POSITION OF TEMPERATURE SENSORS PLACED ON THE COMPOSITE INSULATOR.

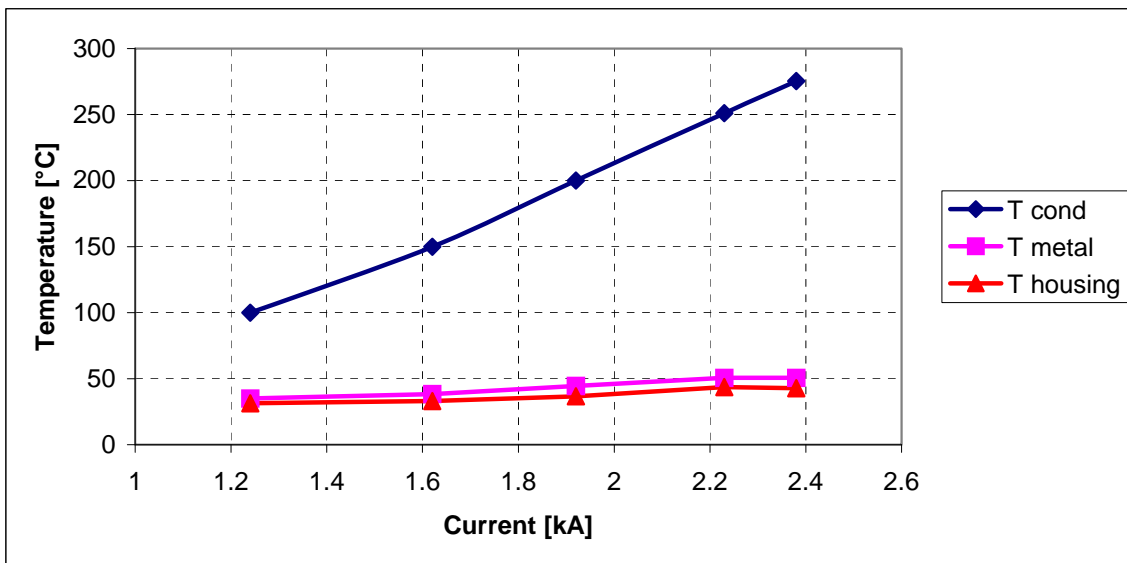


FIGURE VI. TEMPERATURE VARIATIONS OF THE CONDUCTOR (T_{COND}), OF THE INSULATOR CRIMPED END FITTING ($T_{MAX MET}$) AND OF THE EPDM HOUSING ($T_{MAX ORG}$).

FIGURE VI shows the equilibrium temperature of the sensors placed on the conductor, on the metal end fitting and on the housing of the insulator as a function of the conductor heating current.

3.3.3 Study No 2 [8]

In a similar experiment performed with porcelain cap and pin insulators temperature sensors were located on the conductor, the clamp and the insulator pin, cement and porcelain body. An a.c. current was used to heat the ACSR conductor loop.

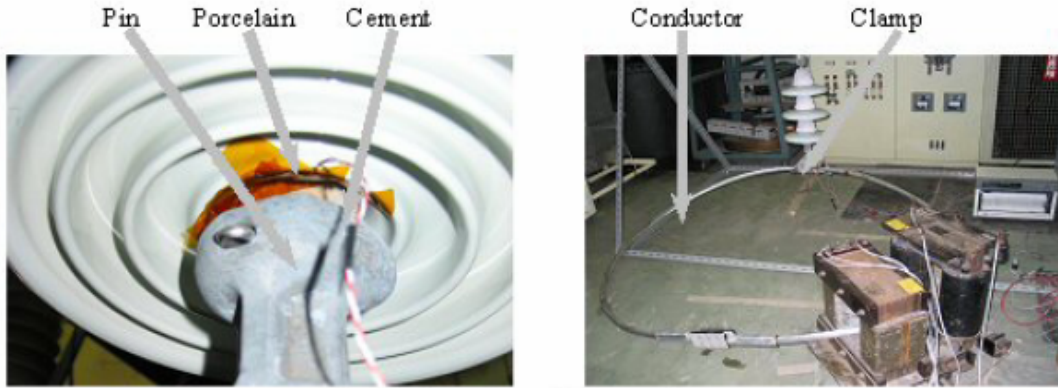


FIGURE VII. LOCATION OF THERMAL SENSORS

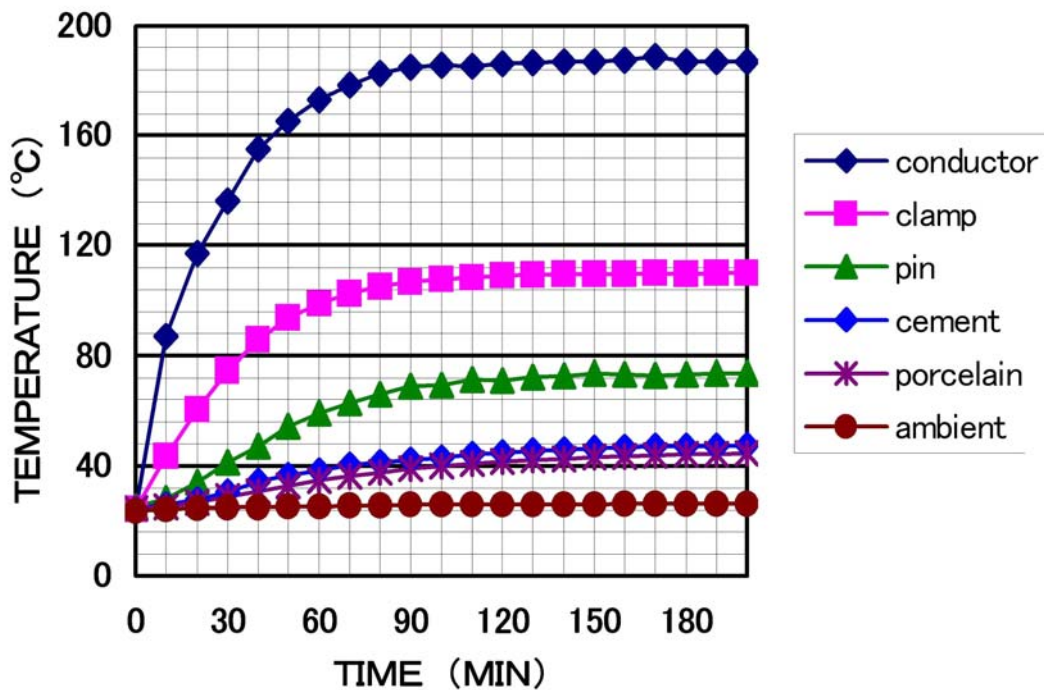


FIGURE VII shows the test set up and the location of the various temperature sensors.

FIGURE VIII. TEMPERATURE INCREASES VERSUS TIME

FIGURE VIII shows the measured equilibrium temperature of the various sensors and TABLE V gives some specific temperature measurements.

Table 1

Sensor location	Conductor	Clamp	Pin	Cement	Porcelain	Ambient
Temperature [°C]	187,0	110,0	73,6	47,4	44,5	26,3

TABLE V. LOCATION AND MAGNITUDE OF THE MEASURED TEMPERATURES

3.3.4 Study No 3. [9]

The third study investigated the temperature elevation caused by high temperature conductors of three type of composite insulators :

- suspension insulator
- dead end insulator
- braced line post insulator

A d.c. current was used to heat the conductor. The temperature sensors were located at various places on the conductor, hardware and insulator.

Of the three types of insulators tested, the worst case was the “I” string suspension insulator, which had the most direct connection to the conductor. Only one piece of connecting hardware, an eye-socket connection, was used between the suspension clamp and the insulator end fitting. FIGURE IX shows that the maximum temperatures reached with this assembly was 59°C after approximately twelve hours with a conductor temperature reaching 210 - 215°C.

Continuing the test for an additional 48 hours did not result in a further temperature increase.

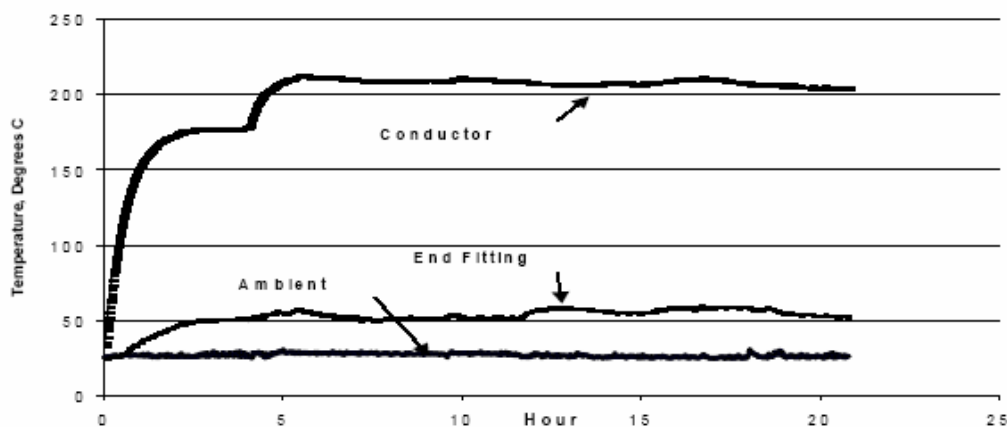


FIGURE IX. TEMPERATURE INCREASES VERSUS TIME

This assembly consisted of a Falcon 1590 MCM conductor and a simple aluminium suspension clamp. In practice, a utility would typically use armour rods for conductor protection, and a larger suspension clamp to accommodate the increased diameter. Testing of this more typical system resulted in an end fitting temperature of 50°C, a reduction of almost 10K. Insertion of an additional piece of hardware (approximately 70mm in length) between the suspension clamp and the insulator resulted in a further temperature decrease to 38°C.

The tests performed on the dead-end assembly and the braced line post resulted in significantly lower end fitting temperatures. The maximum end fitting temperatures recorded

for these configurations was 40°C. These were done without armour rods (worst case condition). TABLE VI shows the results.

Configuration	End Fitting Temp, °C	Conductor T, °C
Braced Post	27 (tension insulator)	200
	40 (post insulator)	
Dead End	26	250

TABLE VI. TEST RESULTS

The above testing was done in an indoor laboratory at an ambient temperature of 20-22°C. In order to evaluate the effects of higher ambient temperatures, an enclosure was built around the insulator assembly in order to raise the ambient to 45°C. With the conductor temperature at 211°C, raising the ambient temperature by 25K resulted in a temperature increase at the insulator end fitting of about 7K for the suspension assembly (without armor rods). This testing was designed to simulate a worst case situation with little or no air movement around the insulator assembly and without armour rods. In practice, even very low wind speeds will have a significant impact on the results.

3.4 DISCUSSION

The examination of the results of the three series of tests leads to the following similar observations :

- for a conductor temperature of about 180°C the temperature of the pin and of the cement or the porcelain body of the cap and pin insulator are respectively about 5K or 20K above the ambient temperature,
- for a conductor temperature of 200°C or more, the temperature of the metal end fitting and of the polymer housing of the composite insulator is less than 30 K above the ambient temperature.

However, it is important to note that there may be some specific cases where the above findings are not directly applicable as indicated by the third study. This would be the case when few and very short and solid connections between the conductor and the insulator are used, or if significant solar heating is present as is found in tropical and sub-tropical areas. Using arc protection devices may also have an effect on the heat balance of the system.

3.5 RECOMMENDATIONS

When the conductors of overhead lines are expected to be run at high temperatures, it is advisable to take into consideration the following steps :

- • Estimate the expected conductor temperature of the line. The conductor manufacturer normally can supply relevant current/temperature curves. Direct heating by the sun or warm air conditions, should be included where applicable,
- • Obtain the necessary data from the insulator manufacturer regarding the maximum allowable insulator temperature at normal mechanical load. A safety margin should be taken into account,
- • When a laboratory evaluation is performed, it is recommended to conduct the tests with a used insulator arrangement to simulate correctly the heat conduction through the hardware. Grease, which may be present in newly installed hardware, should be

removed to achieve service-like conditions. Wind may be omitted to obtain an upper limit,

- • The power grid operator should attempt to match the maximum conductor current to the maximum allowable insulator temperature. When this cannot be done with the existing insulators, they should be replaced by insulators able to cope with the expected maximum conductor temperature.

4 USE OF HIGH TEMPERATURE CONDUCTORS - WORLD-WIDE PRACTICE WITH FITTINGS.

4.1 INTRODUCTION

In recent years the usage of high temperature conductors has increased. Cigre SCB2 WG121 has studied high temperature conductors whilst WG 11, Task Force 3 has undertaken the task of determining experience with fittings installed on high temperature conductors. To obtain this information, a questionnaire was developed and circulated to various utilities throughout the world. The questionnaire was distributed in 2001 and responses were collected throughout 2002. this paper covers the results of the survey. The questionnaire covers both the present installations and proposed future installations within the next 10 years.

4.2 NUMBER OF UTILITIES IN STUDY

In 2002, a total of 68 questionnaires were returned from utilities in Asia, North America, South America, and Europe. The complete list of countries responding to the questionnaire is given in TABLE VII.

Country	Number of Responses	Circuit km installed	Circuit km planned
Austria	3	0	149
Canada	4	10	0
Croatia	1	118	30
Czech Republic	1	40	0
Denmark	1	0	0
Egypt	1	0	0
Finland	3	0	0
Germany	1	900	900
Hong Kong	2	85	0
Ireland	1	0	0
Italy	1	0	0
Japan	35	39,889	4,287
New Zealand	1	0	100
Portugal	1	0	0
Republic of China	1	0	80
Saudi Arabia	1	156	102
Spain	2	0	550

United Kingdom	1	8	300
United States*	6	146	360
Venezuela	1	0	0
TOTAL	68	41,352	6,858
* Note that the input from the United States was not considered as a representative answer. Independent enquiries with manufacturers indicated approximately 10 000km of ACSS is in use.			

TABLE VII. SUMMARY OF RESPONSES TO QUESTIONNAIRE

Of these, the largest number of responses came from Japan where 35 (53%) responses were received. Of the 68 responses, 32 (47%) indicated they had installed high temperature conductors and 26 (38%) indicated they planned to install high temperature conductors within the next 10 years. Ten utilities have no plans to install high temperature conductors.

As with any survey, this paper reflects the results of the questionnaire and therefore does not reflect a complete picture of the industry. As a result, the values of installed high temperature conductors may be substantially understated. As an example, in discussions with conductor manufacturers in the U. S., it is believed over 10,000 km are installed while the survey indicated 146 km are installed.

4.3 OPERATING VOLTAGES

The results of the survey indicate high temperature conductor has been installed at line voltages from 66 to 500 kV. See FIGURE X.

Occurrence Method – The most common voltages were below 140 kV (43%) and above 345 kV (42%).

Circuit Length Method – The most common voltages were between 140 and 345 kV (54%).

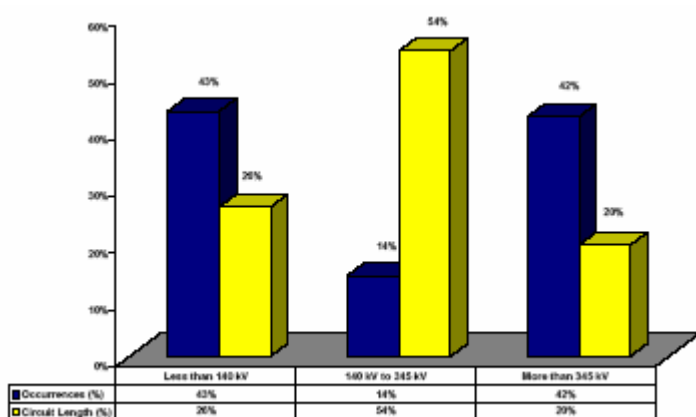


FIGURE X. LINE VOLTAGE – OCCURRENCES AND CIRCUIT LENGTH (%)

4.4 CONDUCTOR TYPE AND INSTALLED LENGTH

The most common high temperature conductors use TAL, which accounted for 48% of the responses. Invar cored made up 21%. Gap accounted for 6% and ACSS accounted for 15%. The present installed circuit length of high temperature conductor is 41.352 km of which 39,900 km is installed in Japan. Due to tight restrictions on right of way and growth of demand, Japan chose to standardize on high temperature conductor starting in the late 1960's.

Based on the responses, it is estimated that an additional 6,800 km of high temperature conductor will be installed throughout the world within the next 10 years.

4.5 DESIGN TEMPERATURES

The results of the survey indicate that the normal operating temperatures for high temperature conductors vary greatly from 45° to 230°C continuous operation. In addition, the emergency operating temperatures range from 165° to 310°C.

4.6 DATA ANALYSIS OF TYPES OF FITTINGS USED

The questionnaire requested information on which types of fittings were used for dead-ends, suspensions, spacers, splices and dampers.

The data from the questionnaire was evaluated with two different methods. The first method, which will be referred to as the occurrence methods, analyses the data based on the number of responses and treats each response equally.

The second method, which will be referred to as the circuit length method, analyses the data based on a weighing of the responses by circuit length of installed conductor. For this method, the circuit length for each response was added to the circuit length from every other response to determine the total circuit length. The data was then weighed based on circuit length for each category. Since Japan has over 96% of the installed high temperature conductor, the circuit length method is heavily influenced by the Japanese practices.

4.7 SUSPENSIONS

Occurrence Method – The most common type of suspension reported was a bolted clamp over armour rods, which were used in over 70% of the responses. Bolted clamps were used in 19% of the responses and elastomer cushioned clamps were used in 11% of the responses. See FIGURE XI.

Any elastomer in a suspension or clamp used on high temperature conductor must be able to perform satisfactorily at the temperature required. The elastomer must not degrade over time at these extreme temperatures.

Circuit Length Method – The most common type of suspension reported was a clamp over armour rod, which was used in 84% of the circuit length. Bolted clamps comprised about 16%.

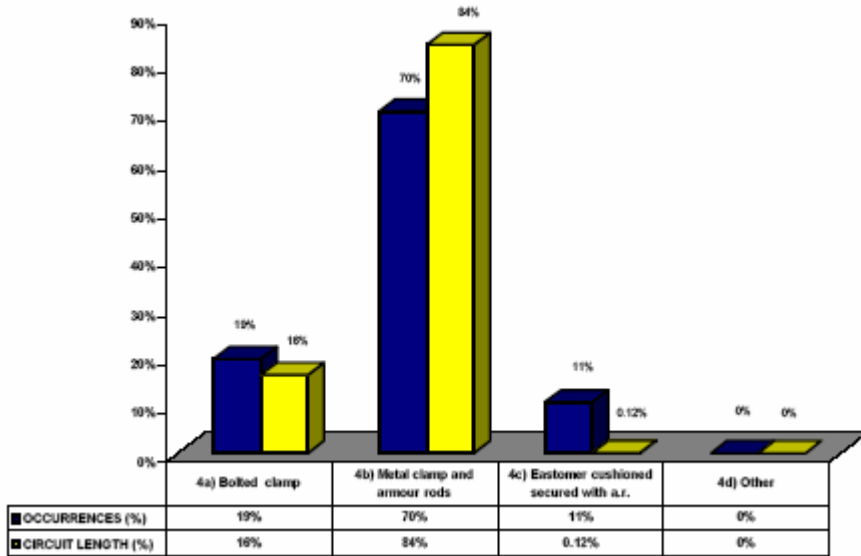


FIGURE XI. SUSPENSION – OCCURRENCES AND CIRCUIT LENGTH (%)

4.8 DEAD-ENDS

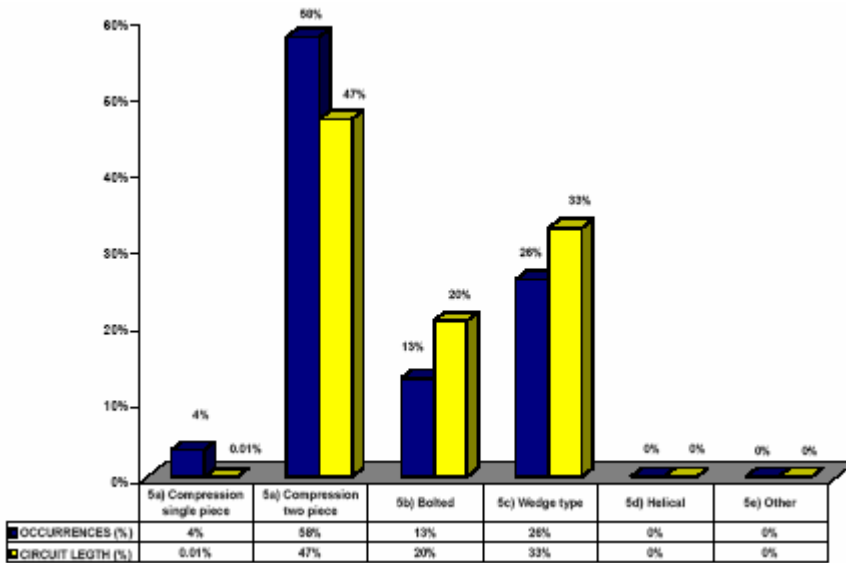


FIGURE XII. DEAD END – OCCURRENCES AND CIRCUIT LENGTH (%)

Occurrence Method – The most common type of dead-end reported was a compression dead-end, which as used in 62% of the responses. The balance of the responses used a wedge type and bolted dead-end. See FIGURE XII.

Circuit Length Method – The most common type of dead-end reported was the two-piece compression dead-end, which was used for 47% of the circuit length. The balance of the responses used a wedge type and the bolted dead-end.

4.9 SPACERS

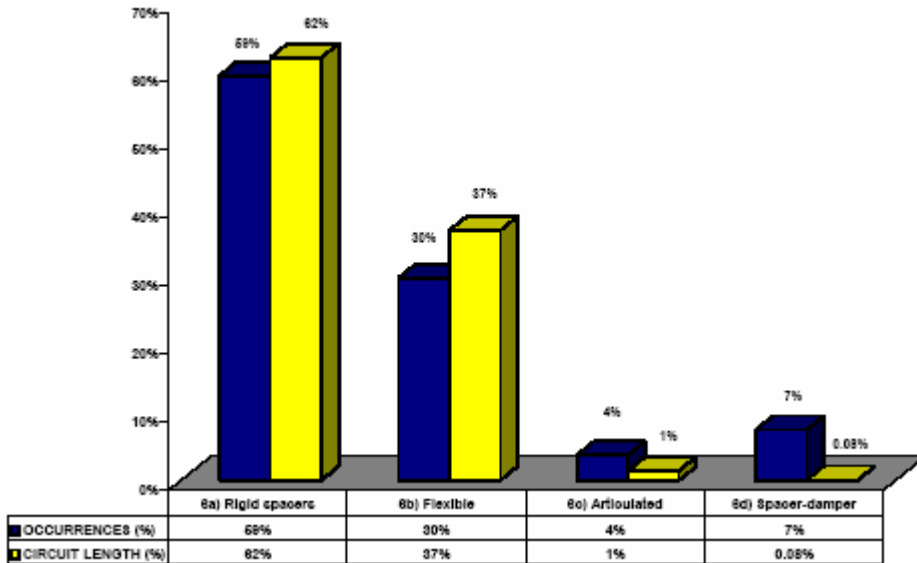


FIGURE XIII. SPACERS – OCCURRENCES AND CIRCUIT LENGTH (%)

Occurrence Method – The most common type of spacer reported was rigid (59%), followed by flexible spacers (30%). Articulated and spacer-dampers made up the balance. See FIGURE XIII.

Circuit Length Method – The most common type of spacer reported was rigid, which was used in 62% of the cases. Flexible spacers were the next most common type.

4.10 SPLICES

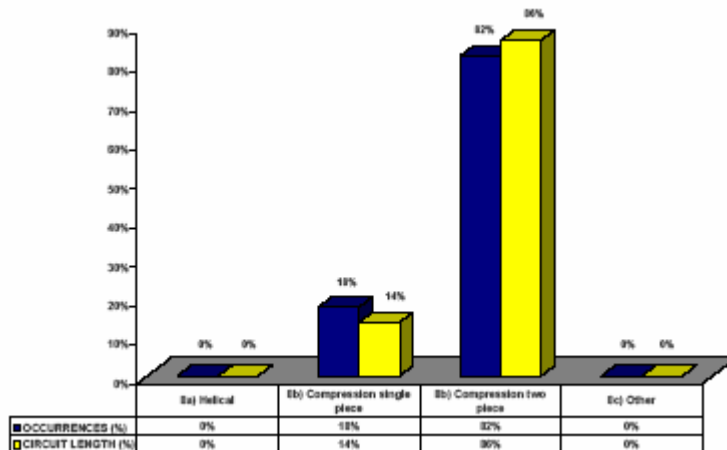


FIGURE XIV. SPLICES – OCCURRENCES AND CIRCUIT LENGTH (%)

Occurrence Method – The two-piece compression splice was by far the most reported type used with 82% of the responses. Single-piece compression splices made up the balance. See FIGURE XIV .

Circuit Length Method – The most common splice reported was the two-piece compression type, which was used for 86% of the circuit length. The balance consisted of single piece compression splice.

4.11 DAMPERS

Occurrence Method – Stockbridge type dampers were used in 32% of the responses. In some applications, a short set of armour rods was placed on the conductor before installing the clamp of the damper. Double torsional dampers, FIGURE XV, were used in 54% of the cases (all of these cases came from Japan). No dampers were reported in 7% of the responses. In some cases helical dampers or festoon dampers were reported. See FIGURE XVI for summary of results.

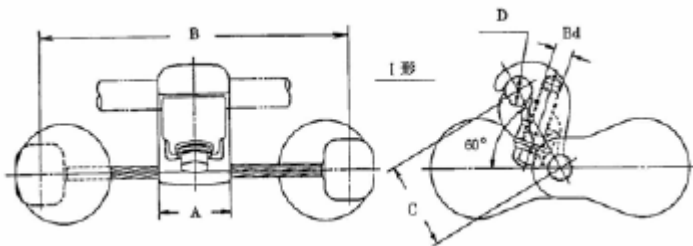


FIGURE XV. DOUBLE TORSIONAL DAMPER

Circuit Length Method – Double torsional dampers were used on 95% of the circuit length.

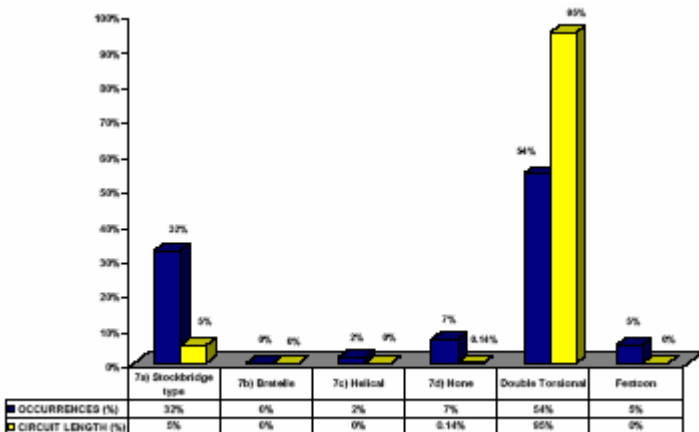


FIGURE XVI. DAMPERS OCCURRENCES AND CIRCUIT LENGTH (%)

4.12 FIELD EXPERIENCE

The questionnaire requested information with regard to the field experience with high temperature conductor and fittings. The questionnaire asked if there were any handling issues, special erection techniques, installation issues with the fittings and overall field performance of the cable/fittings system.

Since 1969, high temperature conductor has been used. The survey indicates there have been very few problems with high temperature conductor. The responses show there have been some occurrences of minor wire damage and bird caging on some ACSS installations. In addition there have been some performance issues at splice locations with ACSS.

(Z)TACIR The installation methods and accessories for the conductor are virtually the same as those used for conventional ACSR. A slight lengthening of compression type accessories is required only to satisfy increased current carrying requirements.

4.12.1 Handling and Installation issues

4.12.2 ACSS Conductors

The survey indicated there were some handling difficulties with ACSS due to the soft surface. ACSS cable requires rubber lined stringing blocks to avoid damage to the aluminium wires. It was also reported that there was an increase in stringing time due to pre-tensioning of the ACSS.

4.12.2.1 Gap Conductors

The survey also reported that there was a high skill requirement for installation of dead-ends on GAP conductor.

During installation [10] of G(Z)TACSR, the aluminium layers of conductor must be de-stranded, exposing the steel core, which can then be gripped by a come-along clamp. The conductor is then sagged on the steel core, and after compression of a steel clamp, the aluminium layers are re-stranded and trimmed, and aluminium body of the dead-end clamp compressed. Although this special additional erection technique is different from that employed with conductors of standard construction, the compression splices and bolted suspension clamps are similar. In addition, due to residual stresses in the alloy layers, special hardware is required. The residual stresses result from the friction forces between the steel and alloy layers and between the alloy layers at the blocks at the suspension insulator sets. This is exacerbated by long sections with many spans. It is therefore recommended by the conductor manufacturer that where the number of continuous spans exceeds five, the special suspension clamp is to be installed every three spans. This is achieved by installing yoke plates at the bottom of the suspension string. This is shown in FIGURE XVII.



FIGURE XVII. SEMI TENSION SET ARRANGEMENT [10]

4.12.2.2 Coloured Conductors

It also noted that there were special measures taken to protect the coloured conductors to ensure colouring is not removed during stringing. In addition, special earthing procedures needed to be used with coloured conductors. Also, the coating needed to be removed at clamp and joint locations

4.12.3 Specifications for Fittings –

Results of the survey indicate there are very few specifications for high temperature conductor. What few specifications there are relate to current carrying capacity or temperature. Specifications normally relate to requiring longer compression fittings and armour rods.

4.13 CONCLUSIONS FROM QUESTIONNAIRE

Since the majority of answers were received from Japan, and they have 96% of the installed route length, the results of the questionnaire largely reflect Japanese practice and experience. The use of high temperature conductor is expected to increase throughout the world due to growing restrictions on the right of way.

Of the high temperature conductors in use, conductors using TA1 was the most popular followed by Invar Cored, Gap and ACSS operating over a wide range of temperatures under both normal and emergency conditions.

The fittings used on high temperature conductors were largely conventional and reflected Japanese practice in the predominance of rigid spacers, double torsional dampers, compression dead-ends and bolted suspension clamps over armour rods. However, other fitting types such as spacer dampers, elastomer cushioned suspension clamps and wedge clamps have been successfully used.

Based on field experience, there have been very few problems with high temperature conductor. There have been some occurrences of minor wire damage and splice performance issues on some ACSS installations.

Specifications for high temperature conductor fittings as such were very few and tended to concentrate on current carrying capacity and temperature effects.

Of the high temperature conductor types, GAP and ACSS required particular care and high skill levels in both stringing and the installation of some fittings. Any installation difficulties with fittings were regarded as conductor rather than fitting design related.

Experience to 2002 with high temperature conductors and their associated fittings has been good and this technology presents a viable solution to the problem of increasing line capacity where right of ways are restricted.

5 SUMMARY AND CONCLUSIONS

High Temperature low sag conductors are a vital tool in any utilities list of options for increasing the rating of lines. The application of these conductors as well as the types of uprating methods available for transmission lines is covered in [1]. The research performed

by WG11 and WG03 complements this work and provides the utility engineer with an idea of the present practice worldwide as well as the effects of high temperature conductor operation on insulators.

It is therefore intended that this document, together with [1] will provide a full understanding of the application and use of these conductors.

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