CIGRE SC22, September 2, 1998

“Survey on future use of conductors”

TF 12-1

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Executive Summary:

The survey conducted by TF 12-1 contains relatively few surprises. In general, utilities seem to find that the new economies of open access and competition require operating transmission lines at higher ampacities than before. The survey responses show a mostly conservative industry approach of moving in gradual steps regarding the questions of higher operating temperatures, somewhat more aggressive rating assumptions, and gradual changes in adoption of new conductor materials. The intended objectives seem generally to be achievable by evolutionary rather than revolutionary developments of new conductors.

The dominant conductor type used by the industry remains ACSR because of its fundamental economies, and there are few indications that this condition will change in the future. There are slight trends towards ACSR with a lower % of steel and use of special types of ACSR, as well as a slight increase in the use of ACAR and AAAC conductors. Compact conductors are of interest.

A substantial number of utilities are now rating their lines for normal temperatures in excess of 100°C, although it is not known how often conductors are actually operated at these elevated temperatures. In general, the operating experiences for ACSR conductors in this temperature range seem to be adequate, although some cautions have been raised on reliability of splices at these higher temperatures.

Nevertheless, there is a general recognition that more accurate data of conductor performance is required for the increased operational temperature range. There is a realization that performance of conductors and joints at the new higher operating temperatures is largely based on extrapolation of data which was based on operation of lines under less demanding conditions. The uncertainties of higher temperature operation make survey respondents stress more accurate information of performance of present conductors at higher operating temperatures as their most important need.

A need for improved conductor performance was also expressed, although the defined requirements are less certain, except that in general, "conductors with less sag at high temperatures" would be a desired objective. The attainment of this objective is tempered by the allowable economics. Most responders would allow only very marginal cost increases over present conductor costs, with the exception of the limited number of cases where upgrades in environmentally sensitive or urban surroundings could justify high cost differences.

Objective and data collection

Terms of Reference for TF 12-1 defined as Task 2.4:

• Conduct a survey to determine the possible future use and needs of conductors in addition to those already mentioned above.
• Develop further action items to be carried out based on the survey results.

The Task Force developed a questionnaire which was sent for comments by the involved working groups (WG11, WG12 and WG13). The questionnaire format was finalized in May 1997. Data collection was initially organized using WG12 and TF 12-1 members who were assigned regional responsibilities to contact utilities in their geographical area. In North America, the IEEE WG on Thermal Aspects of Conductors was used to assist in data collection.

Because of poor response from several countries, the questionnaire was also distributed to SC22 members at Sendai meeting. Followup calls, mail, and email were used to try to improve response. Approximately one half of the responses required followup calls or email to clarify answers or to fill in missing details.

Responses have been received from 71 utilities in 15 countries. No responses were received from South America. Coverage of Asia, except for Japan and South Korea, is lacking. In Europe, responses were received only from seven countries. Nevertheless, the respondents of the survey cover those areas where development of transmission line technology is most active and most advanced.

An interesting sign of the effect of competitive posture on technical information sharing is that seven utilities specifically required that their responses should be kept confidential.

1. Responses

Responses have been received from 71 utilities, divided into the following groups:

Group	Utilities	Transmission circuit km	% of country transmission
USA	29	224000	28%
Canada	7	102000	95%
Japan	10	60000	100%
Australia/NZ	7	50000	80%
UK/Ireland	8	31000	90%
Scandinavia	5	25000	75%
Other*	5	117000	N/A
TOTAL	71	609000	

* South Africa, France, South Korea, Thailand, Iceland

The total circuit kilometers installed by these utilities consist of:

Question: *"Conductor material in use of existing installations over 100 kV (circuit-km)"*

Conductor type	Circuit-km	
ACSR	496000	82%
AAC	22000	4%
AAAC	38000	6%
ACAR	13000	2%
Copper	22000	4%
Compact types	300	
High temperature types	14000	2%
High strength/anti-motion	4000	1%
TOTAL	609000 circuit-km	

Comments:

USA has the widest variety of practices and essentially all conductor types (except very high temperature types) are used. In U.S. utilities, "special conductors" such as SD, ACSS, TW, compact, and VR (T2) are generally considered as ACSR, because most such conductors are no longer considered "novel". Thus, compact, ACSS, SD, and other special ACSR conductors are underrepresented in the above statistics. The vast majority of high temperature conductors are in Japan (13000 km). The main user of conductors for special high strength or dynamic properties is Canada (3,600 km). AAAC is widely used in France, Sweden, U.K., and Australia, and is not used very much in other countries. In some countries (e.g. Sweden), the responses do not cover voltages below 130 kV well, because these lines are owned by "distribution utilities".

2. Operating temperatures

Question: "*Maximum operating conductor temperature of existing lines*"

Normal and emergency operating temperatures vary substantially between regions and individual utilities. The following summarizes the practices:

ACSR

	Normal average/range	Emergency 1 average/range	Emergency 2 average/range
USA	88/(49...115)	109/(80...150)	115/(80...150)
Canada	90/(75...100)	110/(90...150)	
Japan*	90*	120*	
Australia/NZ	85/(50...120)	95/(70...120)	
UK/Ireland**	50...75**	90**	
Scandinavia	70/(50...90)	70...130	
Other	40...90	60...100	

Notes:

* Japan has ratings of 150°C normal and up to 360°C emergency for high temperature conductors.

** U.K. ratings are very difficult to compare to others because of an entirely different rating method.

U.S. uses temperatures up to 150°C normal for ACSS. Also, some utilities which did not respond to the survey are known to use normal temperatures of up to 130°C for ACSR.

Emergency ratings are difficult to compare without a detailed analysis. Most emergency ratings limit either maximum duration, maximum number of hours per year of conductor life, or both.

AAC, AAAC, ACAR

	Normal average/range	Emergency 1 average/range	Comments
USA	80/(49...105)	95/(80...130)	
Canada	90	90	Only one user
Australia/NZ	85/(50...120)	95/(70...120)	
UK/Ireland	50...75		
Scandinavia	70/(50...90)	70...130	
Other	60...75	60...90	Only two users

Comments:
AAC, AAAC, and ACAR conductors are generally rated at lower temperatures than ACSR. Most users also seem to be concerned with annealing.

Copper

	Normal average/range	Emergency 1 average/range	Comments
USA	70/(49...115)	100/(75...140)	
Japan	90	100...200	
Australia/NZ	50...75		Only two responses
Scandinavia	50	70	Only one response
Other	75	75	Only one response

Most users of copper seem to be concerned with annealing.

2b1. Reasons for ratings

Question: *"Are your thermal limits caused by sags (clearances) or by annealing?"*

The responses are divided into three groups.

1. All others, excluding Japan and France.

- Clearance was cited as the main reason by 52 responders. Annealing was cited as main reason by six responders. The reason for the annealing response is not evident, because in these cases the maximum conductor temperature ranges from 75 to 85°C, which is commonly considered to be below the annealing threshold temperature. It may represent a conservative approach of these responders. Three responders cited grease migration/dripping as an additional reason.

2. Responses from Japan indicate:

- Eight based on annealing. One based on sag and annealing. One sag for normal, annealing for emergency. [A later clarification indicated that both factors are accounted for]

3. EdF bases its limits for 60°C (normal) on account of joint problems. Emergency limits (75°C/20', 90°C 10') are based on grease migration and annealing.

Comments:

1. The question was probably not formulated well enough to give the best answers. Several astute responders made comments such as:

- The maximum temperatures are based on annealing, but individual lines are designed for clearance.
- Maximum temperature is based on statutory requirements, but individual lines may have lower templating temperatures.
- Some lines are limited by clearance to much lower temperatures (50-60°C).

It appears that in most cases, clearance is the dominant line-specific requirement, but maximum design temperatures are used to guard against annealing, grease loss, joints, and other considerations. Followup questions have indicated that even in those U.S. utilities where the response indicated a maximum temperature of 95°C and above, the majority of individual lines are limited to temperatures of 50-75°C because of clearances.

2. Some utilities seem to have a much greater concern of annealing than others. There are some cases where the reason for a maximum limit of 75-80°C for ACSR is based on annealing concerns.

2b2. Sag calculation methods

Question: *" What methods do you use for high temperature sag calculations"*

The vast majority of users calculate line sags using the equivalent of the "graphic method" (e.g. Alcoa Sag10). Almost all utilities in North America and most utilities elsewhere use the graphic method with a "kneepoint" for ACSR (assuming a temperature at which the all tension is carried by steel). Because of recent findings on aluminum compression, some utilities now take aluminum compression into account in their sag calculations, which means that they reduce their ampacity ratings for some ACSR types. For ACSR, some utilities use a constant (final) modulus and a constant (composite) coefficient of thermal elongation. Two Canadian utilities use a sag program with advanced stress-strain assumptions. Five utilities correct high temperature sags for ruling span errors, using multi-span sag programs. There are modest differences between users regarding values of elastic moduli and coefficients of thermal elongation for the same conductor.

It appears that there are significant educational needs regarding the use of high temperature sag calculation, as some of the used methods seem to contain major error sources.

3. Assumptions for rating calculations

Question: *"Thermal ratings are presently calculated using the following assumptions"*

Again, assumptions vary significantly by country and by utility.

3.1.Wind speed

USA

- Effective wind speed assumptions vary from zero to 1.3 m/s. The most commonly used wind speed is 0.61 m/s (13 responders) followed by 0.91 m/s (8 responders). One utility assumes 1.55 m/s wind at 45°. Three utilities use 0.6 m/s for most lines, but on selected lines in open or windy areas, they use higher wind speeds - in one case up to 1.55 m/sec.

There are regional differences, such that utilities in open areas (e.g. Midwest) use higher wind speeds. On the other hand, some complete power pools assume the same wind speeed (e.g. New York, 0.9 m/s). Two utilities use zero wind speed for normal and 0.9 m/s for emergency ratings.

Canada

Most utilities use 0.61-0.65 m/s, but one utility uses 1.1 m/sec at 20°, and another utility uses 1.4 m/s perpendicular.

Japan

All utilities use 0.5 m/s.

Australia

Four utilities use 0.5-0.7 m/s and two utilities use 1 m/s. Additionally, one utility assumes 2 m/s during emergency conditions.

UK/Ireland

National Grid ratings are based on 0.5 m/s wind at 12°, although the probabilistic rating method makes this difficult to reconcile with deterministic assumptions. Regional utilities in U.K. have varying criteria, typically 0.5-0.7 m/s. Ireland assumes 0.9 m/s.

Scandinavia

The most common rating assumption is 0.6 m/s, although one utility assumes 1.0 m/s during emergencies.

Other

All other utilities base their ratings on 0.5-0.6 m/sec, except EdF, which uses 1 m/s for normal and emergency ratings.

3.2. Ambient temperature

Most utilities, independent of region, seem to use a temperature which is close to the expected maximum average daily temperature of the hottest month. Some utilities use a temperature which is close to the highest annual maximum, typically about 3-4°C higher than the maximum average daily temperature of the hottest month.

Slightly more than one half of the responders adjust their temperatures between summer and winter. Five utilities use actual measured temperatures. Two utilities assume different day/night temperatures.

3.3 Solar radiation

Almost all utilities take solar radiation into account in calculations. The most typical assumption is full sun (c. 1000 W/m^2), but a number of utilities, especially at high latitudes, use solar radiation of 600-700 W/m^2. Two utilities use values of 1100-1250 W/m^2, citing effects of reflected and sky radiation. U.K assumes no sun, but their probabilitic rating method is very different.

3.4 Emissivity and absorptivity

The majority of utilities use either 0.5 or 0.6 for both emissivity and absorptivity. In the U.S., a number of utilities use combinations of 0.7-0.8 for emissivity and 0.8-0.9 for absorptivity. Some utilities use higher values for copper conductors, typically 0.8 and 0.9. Two utilities use lower emissivity values for the first 1-2 years of service.

4. Rating methods and rating examples

Question: "*Describe the method of calculation of ratings (i.e CIGRE, IEEE, etc., deterministic, probabilistic). What are 3-4 most common conductors you have installed in the past 5 years and their ratings?*"

The most common rating method is IEEE Std. 738, followed by House/Tuttle, and the CIGRE method. Other methods cited include the company's own methods and Morgan's method. Almost all of the methods show rating results which differ less than 1-2% from the essentially equivalent IEEE and CIGRE rating methods. Only two utilities apply probabilistic rating methods.

Substantial differences are noted in some calculations. The major differences include:

- The rating method in Japan uses a very different convection formula than used in other countries. The ratings by Japanese standards are 5-7% lower than those by CIGRE/IEEE standards.

- The ratings used by National Grid cannot be easily reconciled with IEEE/CIGRE ratings.

– One utility in Canada uses their own ratings program which results in 5-10% higher ratings than CIGRE/IEEE formulas.

5. Actions during past 5 years

Question: *"Have you done any of the following in the past five years? Provide a short description or attach a detailed report of the method and your experiences."*

	Yes
a. Increased operating temperature?	36
b. Changed ratings by changing assumptions?	21
c. Reconductored for higher ampacity?	47
d. Retensioned or selectively upgraded spans?	39
e. Applied special conductor materials?	15
f. Applied real time rating methods?	21
g. Special conductors for dynamic/environmental	19

Comments:

It appears that utilities are trying different ways to increase ratings. Increase of operating temperatures with selective fixes in limiting spans seems to be the most common method. Reconductoring with generally the same type (but larger) conductor is another common practice. With the exception of Japan and Korea, there appears significant reluctance in changing basic conductor materials. Several utilities are making less drastic changes (e.g. compact conductor).

Special conductor materials are mostly used in Japan for high temperatures. Other utilities are using special purpose conductors on a limited scale. Examples of conductors which are used outside Japan

include TW (4), ACSS (4), VR(T2) (4), selfdamping (4), non-specular (3), surface-modified (1), and oval (1). Twenty utilities claim to apply real-time rating methods.

6. Plans during the next five years:

Question: *" During the next five years, do you expect to:"*

	Yes
a. Increase operating temperatures of existing lines?	50
b. Build new lines with higher operating temperatures?	23
c. Use special conductors for dynamic or environmental reasons?	10
d. New conductor types for special needs?	17

Comments:

a. "Increase operating temperatures" is a very relative term. In <u>most</u> cases, additional information shows that typical interest is for temperature increases to 100°C or less. In some cases, increasing temperatures means from 60°C to 75°C.

Several responders state that their main interest is in increasing "emergency' temperatures to 100-150°C. Nevertheless, the majority of responders are looking for at least a modest increase in the operating temperature of their existing lines.

b. There is no clear explanation of what "higher temperature" means, but other explanations indicate that planned gains are mostly modest. Five responders refer to higher emergency ratings. Three responders cite the use of ACSS.

c. Responses included ACSS (3), T2 (2), oval (2), surface modified (1), and special shapes for low noise and/or low drag (2).

d. “New conductor” seems to be an individual position depending on present practices and economies! The responders cite as new conductor types (number of reponders):

ACSS (5), compact (5), low expansion coefficient (4), oval (3), low loss (3), high strength (2), anti-corrosion (2) covered (1), composite core (1), high phase order (1), TACSR (1). Most of these conductors have been applied for a long time at some utilities. Several utilities that have applied ACSS and compact conductors for over 20 years did not include these in their responses as “novel” conductors.

7. Interest in future information needs or new product developments:

Question: “*For the guidance of the Task Force, rank your interest in the following future information needs or future product developments”*

	Very high interest	High interest	Some interest	No interest
a. Better information on high temperature sags of present conductors	32	16	7	1
b. Information on high temperature creep or annealing of present conductors	34	14	8	2
c. New conductors for higher operating temperatures	20	20	21	1
d. Conductors with reduced sag at high temperatures	26	21	14	1
e. Compact conductors (e.g. trapezoidal wire	10	20	23	8
f. Conductors with improved damping or fatigue resistance	8	20	12	13
g. Reduced visual or environmental impact	8	11	19	19

Comments:

Everyone who responded to this question considers something of very high interest. Actually, three responders marked everything of very high interest! A number of responders did not answer any of the questions or only some questions. The responses to question 6 and comments below explain some of the differences.

7b. Most important needs for new conductors?

Question: “*What are your most important needs for new conductors”*

Responses are shown below by region grouping. Many responders did not answer this question.

USA

Lower losses and less sag at present limiting temperature (100°C).
Less high temperature (120°C) sag.
High temperature performance.
Do not need new conductors as plenty of options are available.

Need better methods to predict sags at high temperature.
Present compression connectors not reliable above 100°C.
Competitive costs.
Improved sag with low cost premium (defined later as 3-5%).
Less 100°C sag with higher ampacity.
Less sag at high temperature with no more than 3% cost difference.
Compact conductors to limit loads.
Better performance (with 5-10% cost premium).
New conductors must be consistent with inventory and work methods.
No galloping and less wind load.
Need to be consistent with materials inventory.
Low cost.
Antigalloping with modest price increase.
Better high temperature performance.
10-20% ampacity increase with compatible technology.

Canada
High ampacity/low sag. Antigalloping properties.
Sag vs. current capability.
Less sag at same tension.
Low sag at 120-150°C.
Lower cost without lower performance.
Conductor on which ice does not form.

Japan
Capacity vs. price.
Large capacity and sag control.
Low price.
Small sag and low loss.
Increased current capacity.
Low cost.

UK/Ireland
Increase ratings with minimal need for structure strengthening.
Higher reliability and life over 60 years.
Reduced creep and sag reduction at fixed power level.
Replace corroded conductors.
Lower coefficient of thermal expansion.
High capacity with low resistance.

Australia/New Zealand
Lower price (of a special conductor).
Reconductoring for increased ratings.
Improved vibration/fatigue performance.
Lower losses and same sag at higher load.
Reduced losses.
High thermal rating with low sag.

Scandinavia
Conductor replacement without structural changes.
Longer lifetime.
High strength conductor for ice load areas.
Lower losses.

Other
Cost effectiveness. Consistent characteristics. Stability of characteristics.
Reconductoring with up to 50% ampacity increase.
Increase in capacity with less than proportional cost increase.

7c. What is acceptable price premium compared to present materials?

Question: *"What is the price premium (in % compared to present materials) which you would consider acceptable for reconductoring or new lines, if these needs were met?"*

In hindsight, this was not a very smart question. Most responders did not answer it. The majority of those who responded did not present a number, but referred to a need to do a thorough cost study to justify the price premium. Some responders concentrated on loss reduction while others stressed the cost as a higher capacity replacement conductor. Interestingly, four responders stated that new conductors are needed to reduce the present conductor costs.

Of those who provided a specific answer, the largest group gave numbers between 2% and 10%. Some responders cited possible premiums of 30-120% and in one case even over 200%, if the conductor would be used for upgrading without any structural changes. In the case where high premiums were acceptable, the requirement seems to be for short lines in environmentally restricted or urban locations.

Some responders commented on needs for special conductors for single special spans (e.g. river crossings) and cited premiums of 10-30%.

8. Cost of conductor as % of total line cost?

Question: *"What is the cost of conductor as a % of total line cost?"*

This question was added at a late stage to the questionnaire and was thus sent to only a part of the responders, mainly in North America and in U.K/Ireland. Only 15 responses were received to this question.

The responses show the following pattern:

North America: 16-35%, with an average of 26%
UK/Ireland: 15-25%

It would seem that the relative cost of present conductor material is indicative of what is the acceptable cost level of a novel conductor.

8A. Clearance buffers

The following questions were asked from North American utilities only: "*What additional vertical buffers do you add to statutory clearances in new line design? What buffer do you apply when rerating old lines after survey?"*

32 utilities responded. The present lowest allowable clearance buffers for new lines are:

Buffer, ft	Utilities
0	0
1	2
2	8

2.5	1
3	9
3.6	1
4	5
5	2
6	2
7	1
8	0
9	1
Total:	31

The following individual comments are of interest:

• We changed our buffer from 5 ft. to 2 ft (as a result of uprating a number of lines to 100°C)
• Changed from 4 ft. to 2 ft.
• For old lines uprated after survey 0 ft. instead of 2-3 ft. in new lines (2 responses)
• For old resurveyed lines 1 ft. vs. 2 ft. in new lines (2 responses).
• 3.6 ft. for wood structures, 2.7 ft. for steel structures.
• 4-5 ft. for wood poles, 3 ft. for steel structures.
• Above values are used for 115-138 kV, larger buffers for 230-500 kV (4 utilities)

9. General comments

Question: *"Please add any general comments which you feel would be helpful for the direction of the Task Force."*

The following general comments were received (abbreviated below):

Task force should also look at high temperature effects on hardware and joints.
Questions regarding accuracy of high temperature sag calculations of ACSR are important (seven responders).
Lines are now designed for short economic payback and economic calculations need to take this into account.
Would like the task force to develop "more impartial comparisons" between claimed benefits of conductors.
Life cycle costs are important.
Better methods to calculate losses. Method to calculate time constants for emergency operations.
There is a need to look at real time ratings methods (4 comments).
Thrust today is for higher ratings without any changes in the line (2 comments).
Our aim is 50% capacity increases vs. old lines.
Need to reduce construction costs by limiting wind loads and galloping.
This is a very important topic which needs to be discussed in detail.

CIGRE SC22, September 2, 1998

"Survey on future use of conductors"

Selected comments by individual Task Force members and WG convenors

The majority of the task force members and the convenors of WG11,12 and 13 consider that the survey fairly reflects the present interests of the utilities of the world in novel conductors. Three members -from countries and companies which have active development programs of novel conductors- have expressed their disappointment with the results, as they do not support a worldwide interest in novel conductors. The following individual abbreviated comments are recorded:

1. There are two directions in the responses. The first is that we need to present a guide to use for standard conductors as present... The other approach is to provide guidelines for low loss, low sag conductors for manufacturers. It appears, though, that the original thought that novel conductors such as matrix and exotic alloys are of interest ... is not correct.

2. It may be come as a surprise that most of the responded utilities indicated that there is no need for novel or very special conductors..... What this is implying is that there is a need for better utilization of conductors. One of then outcomes of this survey should be a recommendation for the next task of the WG to come up with generic design requirements of conductors.

3. ... all power utilities have interest in uprating for existing lines. ... it is very difficult to make conclusion by majority without any investigation of circumstances.
You should indicate in the response the utilities who respond in your paper and send your paper to major utilities (like as EdF, ENEL, National Grid, Tokyo Electric, Kansai Power etc.) to get their comments.
Four of the five of the above utilities responded. Note that : (1) The survey was conducted based on promise not to identify responders and (2) Based on t<u>ransmission circuit miles</u> the two last utilities should be classified as medium size, not large.

4. We feel that the data considering (our country) should be reported distinctly. The situation of (our country) where on singe very big company, (our company) is in charge of all transmission network, is very particular in the world nowadays, and the data from (our country) deserves to be clearly identified.

I think that most utilities known very little today about the benefits of novel conductors... Given this, they have answered that they are most interested in getting information to operate classical conductors at high temperature.

This does not mean that there is no need for novel conductors and some major companies such as [ ] are carrying out development of novel conductors with cable manufacturers.

5. The economies derived from exotic conductors under the present economic environment are very questionable and will only apply to a few isolated instances. Most utilities are looking for incremental improvements specific to their engineering and economic environments. The TF should not become the promoter of specialized technologies, proprietary for companies such as [ ].