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Increasing Capacity of Overhead Transmission Lines

- Needs and Solutions -

Working Group
B2/C1.19

August 2010

Increasing Capacity of Overhead Transmission Lines – Needs and Solutions

CIGRE JWG B2/C1.19

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ISBN: 978-2-85873-113-8

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1 Executive Summary

This Technical Brochure explores the subject of achieving large capacity increases on existing transmission lines. The difficulty with identifying, obtaining and building transmission facilities on new rights- of-way or of replacing facilities in a wholesale manner on existing rights-of-way is often more time-consuming than system operators can tolerate. Therefore, they are often forced to turn their attention to modifying the existing facilities in a manner that is simpler and more acceptable to all stakeholders and that also provides cost-effective relief to a challenged transmission network.

The primary focus of this Technical Brochure is not strictly technical but rather explores the unrealized value that is available through improvements in relationships between groups that play a role in creating increased capacity on existing transmission lines. The content of the Technical Brochure is as follows: First, the roles and interrelations of two important groups of people – the planners and designers of transmission lines – are explored as they relate to capacity increases. We make the suggestion that a higher degree of interaction between these two groups will lead more quickly to effective capacity increase solutions than occurs with what we believe is a generally exercised limited interaction.

The Technical Brochure then goes on to offer a fairly lengthy discussion on the technologies than can be used to increase the capacity of existing lines. The discussion is lengthy but is less technical than information that is provided in other, recent CIGRÉ documents. The other documents on similar subjects are referenced within this Technical Brochure. They tend to be documents written to educate transmission line designers and engineers. This Technical Brochure has a different audience and purpose. The audience for the description of technologies in this Technical Brochure is the planners. Our goal is to give them enough of a broad-brush description of the range of technologies to develop a context for each technology relative to the others. It is an example of what the designers should be able to tell planners on a case-by-case basis so that the planners can approve and pursue the most cost-effective solutions to capacity increases.

Finally, at the end of the Technical Brochure another relationship is discussed with the purpose of showing that improvements of the described sort are useful to achieving transmission line and network capacity increases of significance. This is the relationships between line owners, operators, the public (customers) and their elected representatives. We show by an example that collaboration between these groups is the key to getting things done for everyone’s benefit.

1.1 The Planner-Designer Relationship

Figure 1 provides a graphic illustration of the working relationship between transmission line planners and designers. For the purposes of this discussion ‘planners’ refers to long-term system planners, not the daily operations planners. ‘Designers’ refers to transmission line design engineers and their technical staff. Figure 1 suggests that planners react to an event. The event can be the results of a proactively undertaken study that predicts a future shortcoming on the system. It can refer to an unplanned outage caused by a natural event or an aged component’s failure. It can refer to anything that signals an existing or pending system deficiency.

The point of the figure is to illustrate that it is the planners who go into action first in response to an event. The planners devise a solution and the figure suggests that engaging line designers in the exercise of discovering the most cost-effective solution is beneficial. It is not difficult for any experienced person within the industry to point to situations where the engagement between these two parties was insufficient to lead to the best solution. The reasons for lack of sufficient engagement include the lack of realization that a technology exists. It includes the organizational structure where at times, the planners and designers do not even work for the same company and engagement requires the creation of a contract and scope of work document. The effort to create engagement can be considered too cumbersome to render engagement valuable. Finally, it can be the case that internal politics or the force of personalities interferes with engagement between these two parties. It is the system owner and operator's decision to overcome these obstacles and this Technical Brochure suggests the value in doing so exists.

1.2 Ampacity Increase Technologies

Capacity increase technologies are discussed under the broad headings of ampacity based solutions, voltage based solutions, large scale actions and miscellaneous actions. There is an effort made to quantify the relative cost-benefit of each technology. There is such a wide range of factors effecting the costs and benefits of any particular technology in each attempt to apply it that the generic statements of value are necessarily vague.

The most common approach to capacity increases has been via ampacity increases. These are discussed under two subheadings – by design change and by operational change. A design change amounts to analysis of the capacity of the line with its existing conductor choice and design criteria/constraints. A detailed analysis of a line by designers can quantify any untapped capacity in the conductors in terms of ampacity. This ampacity is always defined in terms of compliance with local regulatory safety clearance limits. It is therefore a thermal limit that is imposed on the line's operation. It is not useful to contemplate change to a line's thermal limits if the line is limited by impedance or other non-thermal factors. So, the pursuit of thermal limits on a system's lines is not always the useful objective.

The range of capacity increase that is available through addressing the line's conductors thermal capacity extends from zero to enormous. The operating temperature limit of an existing conductor can be increased until clearance limits are challenged by raising a few structures, raising many structures, installing new structures and relocating existing structures, and so on. As the actions increase, so increases the cost. The value needs to also increase and analysis reveals the best combination of actions. As costs become high, the attraction to conductor replacement rises.

There are recently developed high technology conductors with improved strength to weight ratios, with higher operating temperature limits and with better high temperature sag performance. They all come at a higher purchase price and the cost-benefit analysis that identifies value should be exhaustive. They also come with performance characteristics that are outside the norm commonly understood by line designers. As with any new products and materials, these characteristics need to be understood. It must be recognized that all of these conductors with high temperature capabilities derive from the willingness to operate the line hotter. This leads to higher losses and the decision as to the acceptability of this is a necessary consideration.

It is possible to find value in replacing the existing conductor with a larger conductor that will run as cool as the existing conductor. A size increase generally forces the strengthening or replacement of the support structure. This approach is considered to be one step short of a wholesale replacement of the line and it can be considered that all that is salvaged by the change is the right-of-way itself.

The Technical Brochure addresses the subject of operational change extensively. This is a discussion on probability-based operation decisions and real-time monitoring of a line's reserve capacity. There are many approaches to probability-based operation and there are many real-time monitoring systems on the market. There seems to be no end to either the desire to implement a technology that removes the shackles of a simple, deterministic definition of line capacity, and there seems to be no limit to the inventiveness of the solutions. However, the capacity gains made by such technologies are very often limited when expressed as a percentage of present capacity. These technologies can extend the useful life of an existing line. The extension can be many years if the line's load growth is slow enough. In the long term, these technologies are not often the ultimate solution to a large capacity problem.

1.3 Voltage Increase Technologies

If addressing capacity increases via conductor analysis and possible change does not lead to an attractive solution, then a voltage increase can be contemplated. This approach requires either the presence of voltage options at the line's ends (stations) and the move of the line from one voltage grid to another, or it requires a considerable expenditure on this end equipment to accept the line's new voltage. In other words, it is a significant reshaping of the network at a significant cost.

It is not often that a line's voltage can increase significantly without revising the structures. Generally, the space is not available on structures to accept longer insulators and still provide the clearances required for the higher voltages. This is increasingly true as the existing voltage increases.

1.4 Large Scale Solutions

The Technical Brochure discusses two actions that can be implemented on a limited opportunity basis. These are technologies that apply where thermal limitation is not the problem and a voltage increase is not the solution. These are technologies that apply almost exclusively to long, EHV lines. These types of lines are generally limited by impedance. The Technical Brochure discusses the nature of HSIL designs. The discussion describes the reshaping of the line's physical configuration to revise its natural surge impedance to the advantage of its capacity. This technology is useful only on very long lines.

Another technology that is returning to favour is the use of HVDC systems. New lines that will operate as HVDC are becoming more popular. Equally, the consideration for converting existing lines from AC to DC is equally under consideration if owners consider the gross reshaping of their networks. The pitfalls and benefits of such conversion are described in the Technical Brochure. Figure 25 summarizes the capacity increases in cost-benefit terms that can be expected from all of the technologies discussed.

1.5 System Development Strategy

The final subject of the Brochure is an expansion on the point of the Brochure's first subject. The Brochure's initial subject was the benefits available via better interactions between the system planners and the system's line designers. By way of a Danish example, the Technical Brochure describes the value of a coordinated approach to transmission network expansion by its owners, operators, the regulators, the public and their elected representatives.

Energinet (Denmark) has implemented a program that involves all of these parties in the development of the future grid design based on agreed goals. As a result, the implementation of the plan calls for actions for which there will be fewer legitimate grounds for disagreement and lack of acceptance.

The global issues described in this Technical Brochure are intended to shed light on the value of certain relationships and on a host of technologies that with intelligent implementation, should assist in significantly extending the life of the existing network of transmission lines that serve our communities. Please reference the 31 documents listed that discuss related topics, often in greater depth.

1.6 Conclusion

The following figure summarizes the capacity increases in cost-benefit terms that can be expected from all the technologies discussed.

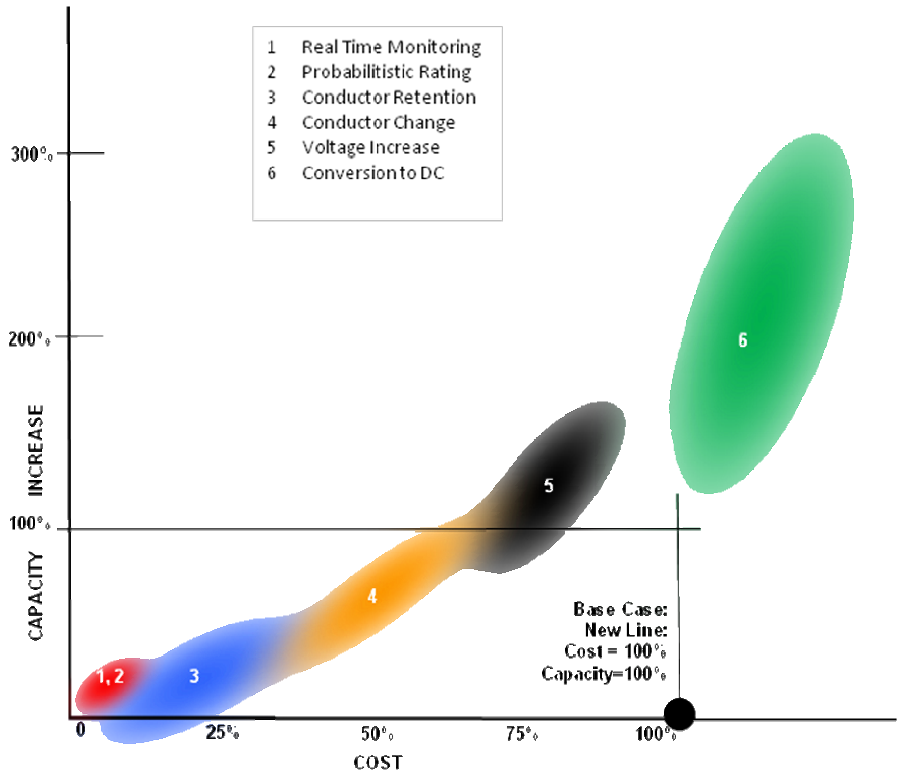


Figure : Relative cost and ability of technologies to increase capacity

2 Purpose and Scope

This Technical Brochure is the result of work by CIGRÉ B2/C1 JWG19. The subject contributes to CIGRE's current subject of interest which is maximizing the use of existing facilities while maintaining and improving service reliability. Service reliability is mentioned because extending the use of existing facilities by increasing their capacity can be achieved by trading off or cutting into that facility's structural, safety or operational integrity. Such a sacrifice must be made knowingly.

The Brochure assumes that it is so difficult to expand the transmission network with new lines that network capacity increases must come in large part from renovations to the existing lines in the network. A considerable amount of this Brochure's contents are technical in nature but, the important message offered is not the technical information. The two words of the document title "needs" and "solutions" refer to people in relationships. This Brochure discusses two sets of relationships between parties involved in transmission line network capacity increases. The main objective of the Brochure is to point out the value of greater interaction within these relationships for the sake of achieving more useful actions that expand the capacity of an existing transmission system.

The first focus of the Technical Brochure is to describe the roles, responsibilities and the value of interaction between transmission line system planners and designers. It is believed that an improved understanding of each other's roles and responsibilities and interaction at the right times leads to the most effective solutions addressing significant capacity increases of transmission lines.

To assist the relationship between planners and designers, the middle part of the Brochure offers two things in detail. The Brochure identifies the information that planners and designers require from each other. This information is described as questions to be asked and answered by the two parties. The Brochure offers a comprehensive description of technologies that are capable of significant capacity increases. These are technologies that designers understand in much greater detail than described in the Brochure. The technology descriptions are meant to be sufficient to gain a basic and suitable understanding of each. It is our intention that this information sets the stage for a high quality, interactive effort by system planners and designers.

The final part of the Brochure returns to the relationship subject. Line owners and operators recognize via their business operations when and where system capacities are needed. Yet, the affected parties – the public and their elected representatives have no such information and see few reasons to accommodate requests for new facilities within their domains within a timeframe that is useful to the network's service function.

By way of a Danish utility example, the Brochure describes an attempt to enroll the public, their elected representatives and the major stakeholders in the business of identifying system expansion needs and planning. It is presumed and logical that engaging the affected parties in these processes will mitigate much of the opposition when the time comes to implement the plan and request occupation of other peoples' domains.

In the overall, the Brochure is meant to point out the value of interactions between parties that have the responsibility for and are affected by transmission line systems. For transmission planners and designers, it also takes the first step in educating the two parties about each other's needs and capabilities.

3 The Planner – Designer Relationship

3.1 Identifying the Planners and Designers

It is necessary to understand the document's use of the words: planner and designer. Planner refers to system planners who address the long term needs for the transmission system and propose the necessary actions and reinforcements for the following year and out to the coming decades. It does not include operation planners who address the very short term use of the existing network today and for the forthcoming months ahead. Designer refers to the engineers and their associates who understand and develop the detailed features of transmission lines within the system.

3.2 Roles and Responsibilities

There are many other parties besides planners and designers involved in the creation and operation of transmission lines. These include the owner, operator, affected public, customers, constructors, maintenance personnel and so on. The planners and designers are distinguished from all of these other parties by their responsibility to understand and deal with the physics of electricity and materials in detail that is associated with transmission lines.

Figure 1 illustrates the relationship between Planners and Designers when the two parties participate in the business of developing and operating transmission lines. The chart intends to illustrate the relationship in a generalized manner. This means that it should apply to the two parties regardless of their relative placements in a company organization, including when they are not within the same organization at all. It describes the tasks performed and information used or provided by each to show the links between the two parties.

The work flow starts with an event (1) that triggers a system study. An event is anything planned or unplanned such as a proposed connection of a new generation or load source, a revised long term forecast of load growth or a change in projected fuel prices. We note that sometimes a failure event puts the designers to work on a failure analysis exercise without a request from the planners. The results of such an investigation could initiate subsequent work requests for remedial action by planners or other parties.

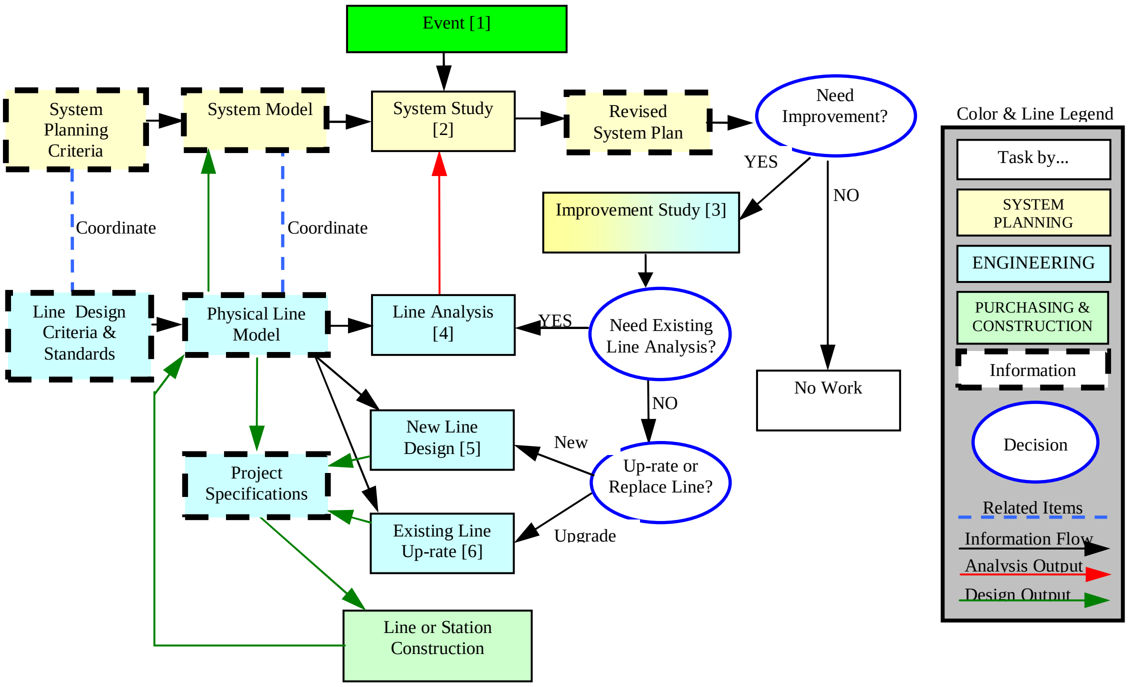


Figure 1 *indicates the basic roles of planners and designers and illustrates the general interaction between the two parties. This figure is described in detail below.*

A system study (2) initiated by an event, will test the impact of this event to the real system on a system model. The implications of this event are assessed against the system planning criteria which describes the standard to which the network should be maintained.

If this standard is not maintained following the event then the study identifies the necessary development options to the system to do so, and these will be included in the revised system plan. In this example these options are limited to the requirement to develop (including the uprating of) existing or new line(s). If standards are maintained then the plan might reveal that the existing system can accommodate the event without change therefore no further action is taken.

Once a need for development arises, a joint planner/designer improvement study (3) is initiated. This joint effort is considered the essence of achieving an optimal result. It is here where the needs and the solutions expressed by both respective parties are discussed. The study may indicate whether there is a need to analyze any existing lines because the plan sees a possible solution using only existing lines and different existing additional measures or methods.

If the *line analysis* (4) of existing lines is required, that work is performed by designers and the work is supported by line models, design/analysis criteria and design standards. Such analysis can be simple and quick or long, detailed and complex. A line analysis effort revises the values in the system model and consequently triggers a revised system study and the work flow begins again with a system study by the planners.

Alternatively following the initiation of an improvement study, line analysis may not need to be, or already has been done, and it may be concluded that system reinforcement will be necessitated. This may be in the form of either up-rating of existing line(s), build a new line(s) or another method such as new operating methods.

Both new line design (5) work and existing line uprate (6) design work is supported by line design criteria, standards, and project specifications for procurement and construction. Any achieved change, whether an up-rated line or a new line requires revision to or addition of the associated physical line model and system model and finally, the work flow is completed caused by the event is complete.

It can be understood that planners respond to an event and in the relationship with designers, the designers respond to a request from the planner. The planner's request is for information or a solution. On the whole, designers perform two activities. They analyze a situation/condition and report findings or they design a solution and provide installation instructions. Figure 1 uses both of these labels for designer activity. In the relationship between the two parties, the planners are in the initiating role and designers are in the response role.

Planners are responsible for understanding the transmission line network as a whole and developing changes to it that address the future requirements that are known or expected to be asked of it. This requires a comprehensive understanding of the electrical nature of each line in the system and their interaction with other circuits, substation components, generating facilities and loads on the system. This understanding extends from the existing network to predicted future network configurations as far ahead as possible.

By contrast, the designers need only a limited understanding of the same facilities' electrical interaction characteristics but they need a detailed understanding of each line in the system in an isolated manner. Designers are responsible for the development of line characteristics that are solicited by planners and also by other parties such as the owner, the public, the constructor and the maintenance people.

There is often little overlap in the elements of interest between the two parties. For example, planners understand the relative impedances of lines, the load growth changes occurring on each line, and the power delivery performance of each line and the effects of events on one line towards the other lines on the system. By contrast, designers know little of this information but they understand the physical strength and behaviour of all line components, the costs of options, their constructability and long term survivability in their environment, and they understand how to affect reliability and public and worker safety.

Yet, the knowledge and capabilities of both planners and designers are necessary to develop and maintain an efficient transmission system.

3.3 The Points of Planner-Designer Interaction

Figure 1 indicates the key points of coordination between the planners' information and designers' information. These are their respective system and line models and respective criteria for planning and designing. The tasks of studying the system and analyzing or designing lines must use coordinated guidance to be efficient. These models and criteria are points of coordination. The two groups must have common definitions of line capacity and power delivery characteristics.

It helps that designers understand in detail the expectation of the planners. Otherwise, incorrect actions will be taken causing delays in achieving the required goal or worse, the creation of an ineffective change/addition to the transmission system.

The key time for interaction between planners and designers is at the time of the improvement study that intends to answer the questions: is there a need for analysis of existing lines and is the most effective solution the uprating of an existing line or the installation of a new line? Since planners may not be sufficiently knowledgeable on the physics and technologies of analysis or solution and since designers may not know the nature of the problem without it being described by the planners, the questions cannot be answered by either party in isolation.

3.4 Information Needs

Thus, the useful interaction is a sharing of information between the parties. Planners must describe the problems and ask questions about technology capabilities and limitations. Designers must ask for information that the planners may not realize is relevant to the technology options. Problems arise when one party does not know what to tell and the other does not know what to ask. This document is written to educate both parties on the capabilities and limitations of all useful capacity increasing technologies. That information is provided in Section 4 of the Technical Brochure.

To provide a foundation for the informational requirements of Planners, an international survey was undertaken by JWG19 to identify the questions always asked by Planners to Designers concerning the various capacity increase technologies. A similar survey to identify the questions always asked by Designers to Planners was not undertaken. The section on the latter subject is derived from the experiences of Working Group members.

3.4.1 Information that Planners Need from Designers

The information gathered from the international survey responses are summated in Table 1. The respondents were asked to identify what questions they would typical ask from a prepared questionnaire for a related technology. There were four technological headings, ‘Probability Ampacity Calculation’, ‘Monitoring System and Operational Optimization’, ‘Increasing Voltage of Overhead Line’ and ‘Low Sag conductors.’ Respondents were also given the opportunity to add additional questions if these did not arise in the questionnaire.

For simplicity this information has been summarized in Table 1 to show the number of survey responses received for each question provided under the relevant technology heading. Colour coding is used as a visual aid to assist in identifying those questions which are consistently asked by planners. Orange denotes where over 50% of respondents (whom responded on the technology) indicated they would ask the question, yellow denotes over 25% to 50%, and green 25% and below.

This table therefore may provide a useful aid to designers and manufacturers when addressing uprating technologies, presenting what questions are likely to be asked of them by international/national planners to address their needs in project selection.

The information that planners seek is utilized to feed into the system model and system studies and into the dynamic system plan, as shown in Figure 1. This provides them with information that they can bring into the interactive process with designers through the improvement study stage of work. As these questions show the information needed is multi faceted, including basic technical information for modeling purposes, economic data for cost comparison, legal requirements, and timing information for ensuring network compliance through phased development of the system plan.

Questions	Probability Ampacity Calculation	Monitoring System and Operational Optimization	Increasing Voltage of Overhead Line	Low Sag conductors
Electrical/mechanical effects				
Maximum operating temperature (°C)			7	11
Conductor type				11
Resistance (R) per km (in ohms)			9	10
Maximum current at maximum temperature during emergency operation of line – ambient temperature 25℃(A)			8	10
Maximum period of time emergency operation can be sustained (hrs)			7	10
Reactance (X) per km (in mH)			9	9
Susceptance (B) per km			9	9
Maximum current at maximum temperature during emergency operation of line – ambient temperature 15℃(A)			8	9
Estimated lead time (in mths) to obtain Permit/Easement/Planning Permission (as applicable)		3	8	8
Maximum current at maximum temperature during emergency operation of line – ambient temperature 5oC(A)			7	8
List of component parts of the line construction that can be effected by introduction of new technology		3	4	5
Modifications and specification to support structures (as applicable)		1	2	3
Maximum predicted increase in normal line rating (%)	8	8		
Input data type (current data, ambient temperature, line temperature, etc)	6	7		
Input data requirements (historic and/or real time)	8	6		
Input data frequency (real time, ¼ hourly, hourly, etc)	5	6		
Prediction update time (Secs/Hrs)	5	6		
Maximum permissible distance for measurement from line conductor (m)		4		
Thermal parameters of conductors			**1**	**2**

Legal				
Permit/Easement/Planning Permission requirements (as applicable)		2	6	6
Revised EMF level (V/m over freq range in Hz)		4	5	6
Revised maximum noise level (in db's)			4	4
Reliability and safety				
Expected asset life of the system (yrs)	7	9	7	8
Longest period of service in a real transmission system (yrs)	8	7	6	7
Longest period of service in clients transmission system (yrs)	7	6	6	6
Number of years available commercially (yrs)	6	5	5	5
Impact to maintenance method statements (as applicable)		6	5	4
Method/type of calculation/measurement	8	8		
Tolerance for error in predicted increase in normal line rating at point of measurement (+/- %)	6	7		
Tolerance for error in predicted increase in normal line rating along line length (+/- %)	5	7		
Does system have inbuilt diagnostic capabilities	4	7		
Is the system fail safe		6		
Reliability and Economics				
Expected outage time of the circuit to complete the scope of works (days)		8	9	10
Expected outage time of the circuit for routine maintenance (days)		9	8	8
Expected completion time for routine maintenance (days)	3	9	8	8
Expected routine maintenance period (yrs)	3	8	8	8
Expected completion time for scope of works (days)	8	7	8	8
Economics				
Estimated total cost of completion of scope of works	6	8	8	9
Estimated profile of the expenditure over the life of the project	6	7	6	7

Table 1

It should be noted that greyed out cells occur against questions indicate that none of the respondents indicated that the question was relevant to that technology. The detailed results of this survey are provided in Appendix 1.

3.4.2 Information that Designers Need from Planners and the Collaboration Process

The questions that Designers ask, or should ask of Planners that are presented here are not the results of a survey. Rather, they are the result of the experiences of Working Group members. It should seem obvious that a designer of experience (whether a person or a team) will offer solutions of greater value if he knows when and why the results of his work are needed. The important questions to ask are:

- *When is the line needed?*

This is a simple and necessary question. The answer is often troublesome because it is typical for conventional processes of requesting and delivering a solution to have trouble meeting the deadline. Thus, a supplemental question must be asked. That is:

- *What are the consequences of not meeting the schedule?*

The proper answer to the question is a description of the line's (new) purpose and a description of the contractual penalties that exist for being in service or up-rated late. Sometimes, real contractual penalties exist and sometimes the deadline is very soft – for example, being only the result of a calculation of long term load projection.

- *Is there benefit to completing the line early?*

This is the flipside of the previous question. If there is a penalty for being late, perhaps there is value to being early. If there is value to being early, maybe the approach to construction can be revised to accommodate and this can revise the design. Perhaps the person who chose the completion date has not left the period too short but, conversely thinks that line refurbishments take a long time when they may not. The question provides valuable insight.

There is not a simple list of questions that can be developed. The question and answer interaction between the designer and planner requires several things to be successful:

- *An iterative process* because some work will likely to be needed by one party or the other along the way to help focus the discussion into a productive direction. Plan on a series of meetings over weeks or months with considerable work executed between meetings.
- *Experienced and respectful participants.* Experience is the best source of intelligent and productive *questions* and answers. Respect is the attribute that will allow participants to believe that the other party really does know his side of the business.

Useful questions are such as the following:

- *What is the line's purpose?*
- *Is it a radial line or a line in parallel to other lines (electrically and physically?*
- *Is this for load transfer, security of load or system stability?*
- *If it is for load transfer, for what time period are you trying to develop capacity?*
- *Is there value in creating even more capacity or the most possible, within reason?*
- *Can you express your needs in functional terms rather than via pre-determined solutions?*

Express planner needs in functional terms like amperes, annual and daily load profiles, impedance needs or desires, voltage limits, outage rate limits (planned and unplanned), years of expected value, etc. Expressing needs in deterministic terms of only conductor size and type and voltage – which is often the case – is a good way to be denied any useful input from the designer. In such cases, the planner has effectively done the designer's job. That may be acceptable if the planner is a good designer. Answers to these questions will reveal worthy points of discussion:

- *Will the line affect other lines in the grid if the design is…*
  - *Placed in physical proximity to…?*
  - *Configured as…?*
- *Is there a cost to taking the line out of service to affect the refurbishment?*
- *Are there other lines that the refurbishment effort may affect (such as take out of service) that carry similar cost constraints?*

Finally, each party in a collaboration effort must learn where their boundaries of expertise meet. It is all too common for planners to establish design features that do not control performance but affect cost. Similarly, it is all too common for designers to not realize that a design has real impact on performance. In some cases, designers may choose well and no harm is done but that should not be assumed. If you find that there is a gap of knowledge within the group of planners and designers – neither seems to know what a valued solution would be – then, the group should get some expertise that fills that gap.

4 Capacity Increase Technologies

Line capacity is measured by deliverable power in MVA units. Since MVA is the product of (Million)Volts * Amperes, capacity increases between two terminal points of the system are achieved by increasing deliverable voltage or amperes, or both. Increasing both the voltage and amperes (ampacity) of an existing line probably requires the replacement of conductors and structures. This is an expensive proposition and generally defaults to the complete replacement of the existing line with a new line. In other words, the result is a new line and the only retained feature of the existing line is its right-of-way. This means that, generally but with rare exception, capacity increase changes to existing lines are achieved by increasing either the voltage or the amperes, but not both.

An obvious solution for delivering more power between terminals is the addition of a circuit to a line to a right-of-way. It is sometimes possible to add a circuit to an existing line of structures and it is sometimes possible to add a new line onto an existing right-of-way. The former constitutes the up-rating of a line as opposed to a circuit. The later constitutes the uprating of a right-of-way, as opposed to a line or a circuit. This array of choices can be summarized by the following list:

- Increase the voltage of a line (up-rate a circuit)
- Increase the ampacity of a line (up-rate a circuit)
- Add a circuit to a line (up-rate a line)
- Add a circuit to a right-of-way (up-rate a right-of-way)
- Combination of 1 and 2 (probably will be a new line. ie: bullet 4)

Each of these methods – circuit addition, voltage increase or amperes increase can produce capacity increases that are very significant or quite small depending on the existing conditions of the subject line(s) and on the rules associated with the line's operation and very existence. Other techniques are available that require no changes at all to the physical components of existing lines. These are operating procedure changes or the use of various mechanisms. As with the listed actions above, the resulting capacity increases can be significant or small.

Each of these capacity increase technologies are discussed below under the general headings of: Ampacity-based Solutions and Voltage-based Solutions. Other technologies follow under the headings of Large Scale Actions.

In recent years, there has been considerable focus placed on service reliability. Regulating bodies and design criteria both intend that transmission line performance be measured in reliability terms. Designers measure intended reliability by understanding the probability of related loads and strengths. In other words, designers measure the structural reliability of the line's components. System planners and system operators measure reliability in operational terms of power delivery availability. We operate on the assumption that the two measuring systems are related. The capacity increase technologies described in this Technical Brochure generally tend to impact transmission line reliability, both structural and operational.

Typically, the structural reliability of a transmission line is reduced when its capacity is increased under the pressure of doing so with minimal expenditure. Therefore, it is very important that planners and designers understand how technologies affect reliability in each other's terms.

4.1 Ampacity Based Solutions

Ampacity-based solutions are available in two basic types. Conductor-based methods find ways of sending amperes along the line in excess of the existing ampere limit. This is done by raising the thermal limit of the existing conductors or replacing the existing conductors with new conductors of higher capacity. These technologies are described in section 4.1.2. Operation-based methods find ways to make more frequent use of any reserve capacity in the existing conductors but without physical change to the line. These technologies are described in section 4.1.3. First, a discussion on the importance of accuracy is provided. This is meant to guide the designer and planner to effective analysis and decisions.

4.1.1 The Value of Accuracy

Figure 3 illustrates that every 10Cº of temperature rise that a 400 mm^2 (795 kcmil) conductor can be subjected to at the upper end of its range equals about 50 amperes of capacity. This value is about 80 amperes for an 800 mm^2 (1590 kcmil) conductor. At 230 kV, these values equate to 20 MVA and 33 MVA. For ACSR and most typical conductor types, changes in sag at high temperatures occur at the rate of about 10 cm to 15 cm per 10Cº. This means that every 10 to 15 cm of clearance that is not recognized as an opportunity or a constraint is equal to 50 to 100 amperes that cannot or should not be accessed.

If the uprating analysis work is performed using an understanding of conductor sags and ground profile that is vertically accurate relative to facts in the field only within 1 meter, then the understanding of amperes that are legitimately available for any uprating method is very poor indeed. For this reason, the need for accurate input data to the uprating design work should be obvious. An uprating design exercise that is based on record drawings or representative spans is generally worthless. Accurate survey techniques such as LiDAR have been essential to useful uprating design work.

Conversely, while the accuracy of LiDAR equipment is actually much better than ±10cm, the accuracy of other elements of the work is not as accurate as the LiDAR technology itself. These elements include our formulas and data for calculating and predicting sag, our knowledge of the meaningful temperature of the conductors at the time of the LiDAR survey, the human decisions made during the modeling and analysis of the line with LiDAR data as the basis for the model and the subsequent construction work. After all is said and done, it is reasonable to say that when great care is taken, the designer can know the relative location in space of conductors and the obstructions around it to within about 15 cm – but no better. This means that the uprating analysis and design work can, with all reasonable care taken, identify the present and/or potential capacity of a line within 50 to 100 amperes, depending on conductor size(s), but no better.

Table 2 indicates that the capacity increase available by method 1a can be negative. When any uprating is considered, the first step of the analysis work is the development of an accurate model of the line using a technology such as LiDAR. Such an accurate survey will reveal the realities of the installation. These realities can include new buildings, new roads, new low voltage crossings under the subject line, line renovations such as changes to structure locations, ground profiles not previously recognized, and construction features such as sags other than intended.

Any of these revealed realities can be a source of electrical clearance violation that was until that moment not known. It is not uncommon for an accurate survey of a line to reveal numerous such violations and the result is a face value line capacity that is lower than believed and even zero. It is relatively common to find locations on lines that are in constant and sometimes serious violation of clearances. The undertaking of accurate line modeling and analysis must be prepared to deal with this issue. Doing so defines the start point for refurbishment and capacity increase work.

4.1.2 Conductor-based Methods

Ampacity (amperes) increases are achieved through a whole range of methods. The methods range from no change to the existing line to a virtually complete change. The cost of the change tends to increase with the amount of change and the additional amperes made available to the system tend to also increase with the cost of the change. All of these methods are listed in Table 2 and are described in detail below. They are listed in the general order of increasing complexity, cost and ampacity increase possibility and are discussed below. Category 1 changes can achieve near double the existing capacity under ideal conditions. Category 2 can achieve the same range of results at a higher cost but under more frequent circumstances. Category 3 has much larger increase capabilities under most condition.

As you transition from category 1 to 3, more changes are made to the line, the cost increases and the ampacity increase achieved tends to rise accordingly. The third category is effectively a new line replacing an old line on an existing right-of-way.

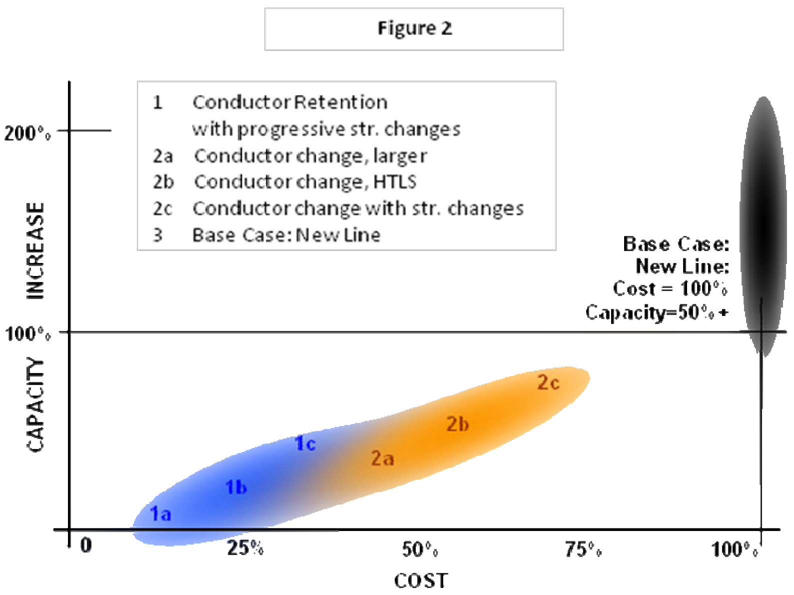
In theory, the choice of method to increase ampacity is determined by a study that finds the highest amperes/expenditure ratio from all possible options. In practice, only a few of the options are logical for any particular line/situation and the preferred choice can be rather obvious.

Refs. [1], [2], [3], [4] and [23] provide valued discussions on conductors and line uprating methods. These references are more technical and directed to designers.

Category	Ampacity Increase	Nature of Change	Details & Comments
1		Conductor Retention:	Increase operating temperature and sag…
1a	Negative[1] to modest		with no structure changes
1b	Small to modest		raise/change structures as required: a few
1c	Modest to medium		raise/change structures as required: many
2		Conductor Change:	Increase size or change type
2a	Medium to large		Increase size (diameter & weight)
2b	Large		Change to HT type
2c	Large to very large		Combine with structure changes as required
3	Large to very large	Conductor + Structure Change:	This is a new line

TABLE 2

Figure 2 illustrates the types of gains that each level of effort (category as listed in table 2) can typically provide.



[1] The negative increase is explained in the section "The Value of Accuracy"

4.1.2.1 Category 1 – Conductor Retention

Conductor replacement is expensive. A very rough estimate is that conductor replacement costs in the range of 25% of the cost of a complete new line, ignoring right-of-way issues. Therefore, category 1 is attractive if that much money is not freely available and the increase requirement is modest. Increase requirements are modest if the line serves a load that will not grow significantly in the medium and long term and a short term uprating is acceptable.

The necessary requirement for realizing an ampacity increase via conductor retention is adopting an increase in the operating temperature of the conductor to a new upper limit. This implies a sag increase and a clearance decrease. It requires that the thermal capacity of the conductor is not yet fully utilized. It also requires that the thermal capacity of the conductor controls the power delivery capacity of the line rather than does the line's impedance. For this latter reason, this method tends to be useful only to shorter and/or lower voltage transmission line – typically below 300 kV.

The cost of conductor retention is minimized by keeping the required structure changes to a minimum. Structures are changes because they must be raised to avoid clearance problems created by the increased operating temperature and sag. The difficulty and cost of raising structures varies with type. Wood or modest length concrete poles are relatively inexpensive and easily changed out for taller versions set in practically the same locations. Latticed towers can be raised by adding in a body section or longer leg extensions. New foundations may or may not be required. That work can be expensive.

The most costly structures to raise or change out are steel poles on foundations. Raising them is very impractical and changing them is expensive. Therefore, the attraction to a conductor retention plan that targets a large ampacity increase favours a type of structure on the line that can be easily changed or raised.

Modest increases in conductor height above ground can sometimes be achieved by modifying the insulator assembly style. For example, arm and suspension string arrangements can be revised to braced- or cantilever post arrangements on every second structure. The height improvement at mid-span equals about half the length of the replaced insulator string.

Most lines have been designed to operate to maximum temperature of at least, and as low as 50ºC. Newer lines have typically been designed to operate at higher temperatures. Since standard alloy aluminum conductors are limited to a long term, continuous operating temperature of 90ºC to 100ºC, depending on owner criteria, the maximum operating temperature increase available via conductor retention methods is 50Cº or less. Figure 3 illustrates the opportunities with 400 mm^2 (795 kcmil) conductors as the example.

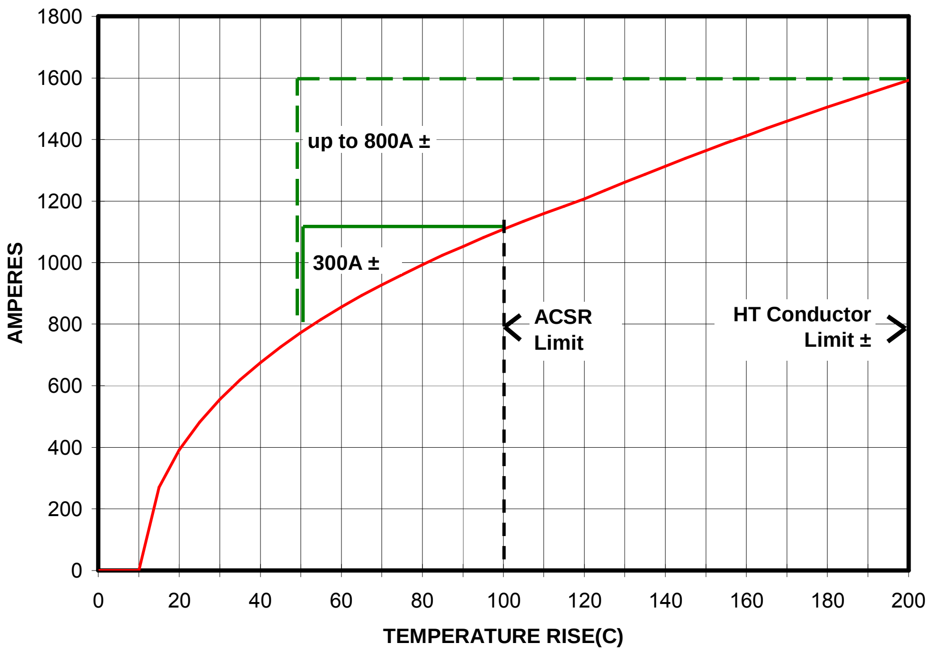


Figure 3: *Ampacity versus temperature rise.*

The figure plots with an ambient of 0ºC to allow the horizontal axis unit to be understood as temperature rise. Other ambient temperatures can be understood by effectively sliding the temperature scale laterally. For example, to consider the example of an ambient temperature of 30ºC, add 30 to all values on the temperature rise axis of the figure.

Figure 3 shows that the capacity of a 400 mm2 (795 kcmil) ACSR conductor is about 1,000 amperes with an 80Cº temperature rise above ambient. This approximates the vendors' typical catalogue rating. However, the ambient temperature and difference between present thermal limit and proposed thermal limit define the ampacity increase available from this conductor under specific conditions. Table 3 illustrates that capacity increase results can vary dramatically.

As implied above, it must be understood that large thermal range increases cause large maximum sag increases and the need to make structure changes increases as the thermal range gain increases. Thus, the large capacity gains probably require that added cost to be realized. This is understood as moving from Category 1a to 1c as described in Table 2 and Figure 2 above.

Ambient Temp (°C)	Present Thermal Limit	Proposed Thermal Limit	Thermal Range Gain (C°)	Present Ampacity	Proposed Ampacity	Gain in Ampacity (%)
25	50	100	50	490	950	94%
25	80	100	20	810	950	17%
35	50	100	40	260	890	242%
35	80	90	20	720	810	13%

Table 3: *Ampacity gains as a function of existing conditions and goals.*

Table 3 illustrates the effect of ambient and thermal limit change from present limits on achievable amperes. Values are based on the Figure 2 plot. The top row of data is a rare situation in which the ambient temperature is cool and the opportunity to raise the limit is large. The third row also shows massive improvement. This is because the present condition is a very inefficient combination of high ambient and low thermal limit. Notice that the combination of any ambient and an thermal limit that is already high such as presented in rows 2 and 4 can produce only modest improvements.

Amperes are also available if the ambient temperature can be lowered or the upper limit extended considerably. The ambient temperature can be lowered periodically by a more complex operating method or a study that justifies a change in criteria. The upper operating temperature limit can be increased considerably by a change to a high temperature (HT) conductor. Figure 2 indicates that about 500 additional amperes are available if the conductor's thermal limit were 200ºC rather than 100ºC. Both of these methods are discussed below.

4.1.2.2 Category 2 – Conductor Change

Conductor change becomes attractive if the line has reserve strength in its structures to carry a larger and heavier conductor, if the structures can be strengthen for low cost or if the existing conductor offers no cost-effective ampacity increase because it is already at or near its thermal limit as described above.

Even if the conductor replacement is a costly solution, we must note that there may be additional benefits with regards to the line lifetime as long as the other line equipments (towers, foundations) allow it [3].

Once the uprating method is committed to the cost of changing conductors on the line, the opportunity to avoid even more costs is limited to avoiding structure changes. Some conductor types that offer dramatically higher thermal limits and ampacity limits with few or no structure changes are more expensive than standard conductors – some being very expensive. Therefore, the low cost option within this category may be to replace the existing conductor with a standard conductor of a larger size.

4.1.2.2.1 Larger, Standard Conductors

An optimizing feature available to maximize the value of a larger conductor of standard alloy, standard construction and modest cost is to change from round strands to trapezoidal or other compact strands. This effectively packs more aluminum into a common overall diameter by displacing the airspace voids inherent to a round strand conductor type. Modest weight is added to the conductor but the diameter is retained. Since conductor diameter affects wind load on structures and weight affects maximum design tension, it is typically advantageous to accept the weight increase and minimize the diameter increase as wind load on towers typically increases line cost more than does tension increase the cost. Even so, the ampacity increases related to this type of conductor change are typically modest if structure changes are to be avoided.

To gain larger ampacity increases, money must be expended on the conductors or the structures – or both. The cost of changing structures varies with structure type as noted above. Above, it is noted that the cost of raising or changing structures varies with type with steel poles being the most expensive to raise or replace. Ampacity increases associated with a conductor change often do not require the raising of structures but the strengthening of structures. As with raising structures, the easiest types to strengthen are wood poles and latticed towers. The most difficult to strengthen are concrete poles and steel poles.

Concrete and steel poles are difficult to strengthen but it is also difficult to discover the inherent strength of an existing steel or concrete pole if records are lost or not trusted. This means it is difficult to discover the need to strengthen. Unlike latticed towers, the materials cannot be easily quantified for strength or thickness. This may be true for old wood poles as well, where the information stamped into the pole is no longer legible. This difficulty in discovering the strength of structures and the presumed expense of strengthening structures by member additions or wholesale replacement creates the attraction to new conductors with features such as high ampacity rating, small diameter to stay below existing wind load limits, light weight and reduced sag characteristics.

4.1.2.2.2 High Temperature (HT) Conductors

The attractive features of HT conductors come at a higher cost. The higher cost of the HT conductors is acceptable if they create the reduction in or avoidance of structure change costs. There are several basic categories of HT conductors now on the market. Table 4 illustrates. Each is a combination of structural core material and conducting material that is always aluminum. Tables 5 and 6 describe certain features of the core and conducting material options respectively. Some of these choices use materials other than steel as the core material. These conductor types are described in the next section.

Table 4 includes conductors with standard alloys and strong alloys all with the standard, long term thermal limit of 90ºC to 100ºC. The thermal limit is established by the fact that further heating anneals (weakens) the conductor. To avoid annealing, two techniques are used in conductor design. One technique is to anneal the conductor’s aluminum intentionally in the factory before purchase and installation. The other is to provide an alloy that is immune to annealing by high temperature.

Factory annealed aluminum uses the acronym ACSS. It has been available for decades and once used the acronym SSAC. It is created by manufacturing a standard ACSR conductor and then cooking it. The strength of the aluminum is reduced to about one third of its pre-annealed state. It becomes very soft and stretches considerably under tensile load before any risk of breaking. ACSS conductors have the identical construction, weight and diameter as their ACSR namesakes but they have lower strength and lower increases in sag with temperature increase because the aluminum ceases to contribute to the thermal expansion characteristics of the conductor at higher temperatures. To counteract the strength loss in the aluminum, it is optional to use a higher strength steel in the core.

An ACSS conductor’s aluminum can be operated very hot (250ºC continuously) to the point where added protection against heat damage is necessary for the usually galvanized or aluminum clad steel core material. Without that protection via mish metal, the thermal limit of the ACSS is reduced somewhat from its maximum capability.

The alternate technique to avoid annealing damage and access higher operating temperatures is to alloy the aluminum with zirconium. This is done in varying degrees to produce TAL, ZTAL/UTAL and XTAL designated alloys. Table 6 illustrates the increasing thermal capacities of each. Only the XTAL version reaches thermal limits as high as the annealed standard alloy. This alloying also modestly increases the aluminum’s resistance whereas annealing reduced the resistance slightly. These alloyed conductors are combined with standard or specialty steel core materials to form conductors with complex acronym identities. These conductors have the same weight to diameter ratios as ACSR counterparts and almost the same sag-temperature relationship as ACSR except that they can get hotter without incurring damage. The sags are large at high temperatures because the thermal expansion characteristics are basically unchanged from the standard ACSR values.

4.1.2.2.3 All Aluminum Conductors

All aluminum conductors – AAC (ASC), AAAC (AASC) and ACAR are not categorized as high temperature conductors since these alloys are not resistant to damage (annealing) from exposure to temperatures above about 100°C. However, they are sometimes used to achieve capacity increases. AAAC and ACAR are similar to AAC except that all (AAAC) or some (ACAR) of the strands are a higher strength alloy. All types have the common thermal expansion characteristics of aluminum but have varied strength to weight ratios.

The higher strength, all aluminum types (AAAC and ACAR) can be pulled to higher tensions than the AAC counterpart and lower sags than their ACSR counterparts without violating common tension limits that are expressed as percentages of rated strength. This can lead to pushing them advantageously to their thermal limit with little tension or sag problems. However, the problem adopted and that needs management is the increased propensity for Aeolian vibration at the lower sag installation.

It is unlikely that all aluminum conductor types can provide the amount of ampacity increase that HT conductor types can provide, but they do provide their benefits at a low cost.

Table 4

		Core Material										
		HS	EHS	EXHS	Alum Clad	Galv. Invar	Al. Clad Invar	Mish metal	Al Matrix	Carbon Fiber	No Core	
Aluminum Material	Hard Drawn 1350-H19	ACSR ACSR/TW	ACSR/ EHS		ACSR/AW						AAC	ACAR
	HS Alloy 6201-T81	AACSR	AACSR/ EHS								AAAC	
	1350-O	ACSS/GA ACSS/TW		ACSS/ HS285	ACSS/AW			ACSS/MM ACSS/TW		ACCC/TW		
	TAl	TACSR			TACSR/ AW							
	KTAl	KTACSR			KTACSR/AW							
	ZTAl (UTAl)	ZTACSR GZTACSR				ZTACIR			ACCR ACCR/TW			
	XTAl						XTACIR					

Table 5

Core Materials					
Description	ASTM Spec	MOE (GPa)	TS (MPa)	Cf (x10-6 /Cº)	Unit Wt. (mg/mm^3)
HS Steel	B498	200	1379-1448	11.5	7.778
EHS Steel	B606	200	1517	11.5	7.778
EXHS Steel, Galfan Coated		200	1965	11.5	7.778
Alum Clad (20.3% IACS)	B502	162	1103-1345	13.0	6.588
Galv. Invar Alloy	B388 B753	162	1034-1069	1.5-3.0	7.778
Mishmetal (Std, HS)	A856 A857	200(I)-186(F)	1379-1448 1517-1620	11.5	7.778
Al Oxide Matrix		215	1310	6.0	3.322
Carbon Fiber		124	4295	1.61	1.938

Table 6

Aluminum Conducting Materials						
Description	Name	ASTM	%	TS	Thermal Limits, ºC	
		Spec	AICS	(MPa)	Cont.	<10 hrs
Hard Drawn	1350-H19	B230	61.2	162-172	90	120
MS Alloy	5005-H19		53.3	248	90	120
HS Alloy	6201b-T81	B398		317-331	90	120
Fully Annealed	1350-O	B609	63	55-96	250	250
Thermal Resistant	TAL		60	165-186	150	180
High Strength Thermal Resistant	KTAL		55	186-252	150	180
Ultra Thermal Resistant	ZTAL & UTAL		60	165-186	200	240
Extra Thermal Resistant	XTAL		58	165-186	230	260

To compensate for the high sags, a core material such as an Invar alloy that is more thermally inert can be used or the standard steel core can be mechanically disconnected from the aluminum of the conductor. This mechanical disconnection creates conductor types called *gap type* conductors. They adopt more advantageous sag-temperature characteristics similar to ACSS conductors.

4.1.2.2.4 New Material Conductors

After the options seem exhausted in combining aluminum options with steel core options, some manufacturers are exploring and offering non-ferrous and non-metallic core materials. Table 5 describes two such core materials. One is a metal oxide matrix (ACCR provided by 3M) and the other is carbon fiber (ACCC/TW provided by CTC). The subject of viability as a line product for these two materials is left out of this discussion. Both are being installed commercially around the world.

Presently, there is one manufacturer of these core choices for conductors. The attraction to these material combinations is light weight, high strength and appealing sag-temperature characteristics compared to their ACSR counterparts and ACSS or alloyed aluminum competitors. The detraction is cost and/or limited understanding of long-term viability. These detractions are being addressed by the vendors and by interested users. Success in overcoming these detractions is quite likely. If the products are viewed from a technical, sag and thermal characteristics viewpoint only, they offer very advanced opportunities for large ampacity increases on existing lines via conductor change.

One further point on high temperature operation is worth noting. As operating temperature rises, material resistance rises slightly driven by the increase in amperes. Since losses rise with I^2r, the losses at high temperature are increased considerably. The cost of the losses is more acceptable if the line capacity increase is for N-1 reasons than if the increase is for base load reasons. Capacity increases via ampacity increase and thermal limit increase are more attractive to the contingency case than the base load case. Planners are aware that losses at high temperature shall be specifically modeled when performing technical and economical assessment of new conductors.

4.1.2.3 Category 3 – New Line

This technique for providing a capacity increase is simple to comprehend and difficult to implement. It comes in two forms – add a circuit to an existing line of structures on a right-of-way or add a new line onto an existing right-of-way. The attraction is the significant increase that comes from a new line compared to what is often available by adjusting an existing line. Any line of a voltage above 100 kV can easily deliver 100 MVA or more. Such significant increases are not always available from other increase methods.

It is rare to find space on existing structures that would allow the addition of another circuit without serious revision to the structures. The most promising situation is the conversion of a single circuit pole line of vertical or delta configuration to a double circuit configuration. Conversion of an existing single circuit framing to a double circuit framing requires that the phase and ground spacing of the single circuit be quite liberal with room to use up the excess space when fitting the three new phases into that space. This tactic creates an increased risk of electrical flashover with the new arrangement and the security of the two new circuits is reduced from that of the original circuit by some measure.

The addition of a new line onto a right-of-way requires that there be space beside and/or between existing lines. If no change to the existing lines is made part of the work, the new line is probably quite compact and/or of a lower voltage than might be desired. The same increase in risk typically occurs if a space on the right-of-way is used that was not for this purpose originally.

With either approach, the rules that define the rights of the line owner to modify or add to the facilities on the right-of-way will control the ability to make use of any ideas that are otherwise technically possible. Right-of-way rules vary around the world and from location to location from no changes allowed whatsoever to freedom to do practically anything at all.

The final category (3) for increasing capacity via ampacity increase is really an extreme extension of category 2. If the conductors are changed out and enough structures are also changed to either carry the new conductors or raise them further above the ground for clearance reasons, then the line is effectively a new line.

Once a new line is considered as a viable option, then the door opens to other features beyond simply increasing ampacity via conductor choice. If right-of-way rules allow, the voltage can be increased or the number of circuits can be increased. Accordingly, the new line can have an enormous capacity compared to the existing line that it replaces. The transition from Category 2 to a new line (Category 3) is made with the cost and availability of these features in mind. Voltage increase is discussed below.

4.1.3 Operation-based Methods

Section 4.1.2 dealt with solutions based on conductor change. The following section deals with operation of existing assets without any change to the current carrying equipment.

4.1.3.1 Moving Beyond a Deterministic Definition of Capacity

The true thermal rating[2] of a line varies continually. It depends on a number of factors including the weather parameters prevailing at a particular time and the current flowing in the conductor [4], [31], [23]. CIGRÉ TB299 "Guide for selection of weather parameters for bare overhead conductor ratings" discusses the influence of these factors [12].

Figure 3 illustrates the influence of weather parameters on line rating. The vertical axis represents the ratio of true thermal rating/static rating[3] in %. The horizontal axis represents ambient temperature (°C). The static rating condition is represented by the blue dot. The curves show how real time rating[4] varies with ambient temperature, considering different wind speeds (0.6, 1 and 2m/s respectively). Note that as explained in [12], other variables such as solar radiation [W:m²] are taken into account by utilities to compute thermal ratings.

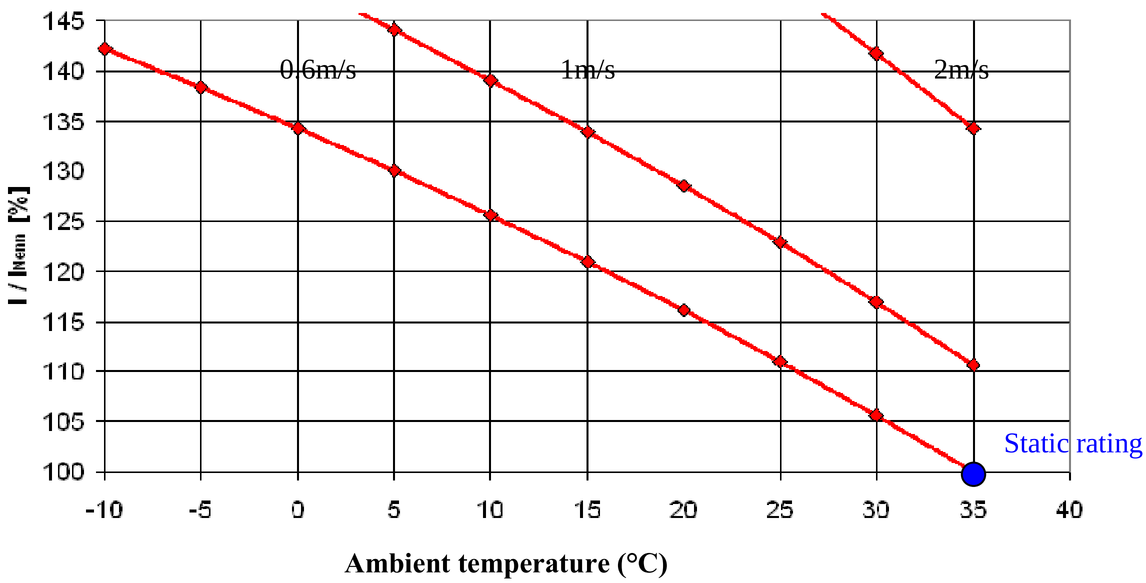


Figure 3 *Real time thermal rating/Static rating (%) as a function of ambient temperature (°C) for different wind speeds, courtesy from Eon*

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[2] Thermal rating: The maximum electrical current which can be carried in an overhead transmission line under specified weather conditions (same meaning as ampacity) [12]

[3] Static (thermal) rating: A static rating is normally based upon "worst-case" weather assumptions, and specified conductor parameter [12]

[4] Real-time (thermal) rating: This is the thermal rating calculated based on real-time weather data [12]

Figure 4 shows real time weather condition records over one year in Germany. The axes of the figure are wind speed and ambient temperature. The static (deterministic) rating is represented by the blue dot. The figure shows that most of the time, the static rating defining combination of temperature and wind leads to more conservatism than the real time conditions would allow. A worst combination of conditions than on which the static rating is based were never met during this recording period.

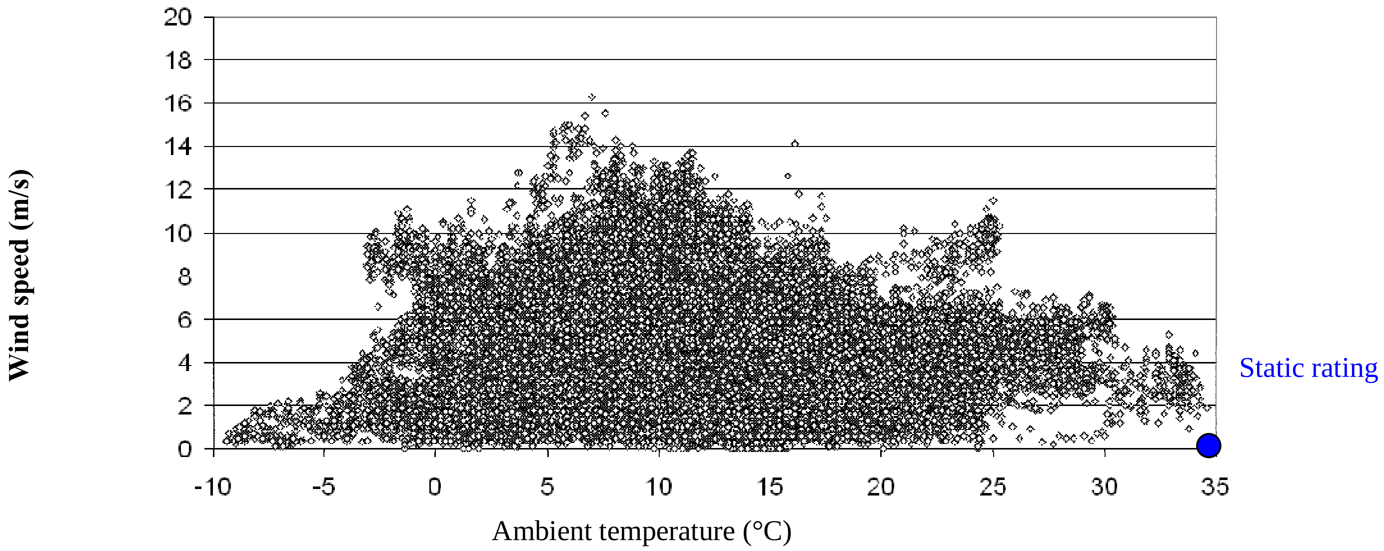


Figure 4 *Real time weather data recorded in Germany during 1 year. Courtesy of Eon*

Experience shows that in practice, actual ambient conditions are less constraining (generally more than 98% of the time) than those envisaged in most deterministic-based standards (e.g. ambient temperature 35°C, wind velocity 0.6 m/s, full solar radiation). This means most of the time there is a capacity reserve available for lines which are operated using static rating. Consequently, an increased ampacity of the conductor based on the actual weather condition is thus available most of the time.

It should be noted that CIGRÉ TB144 defines the word "ampacity" as follows: "The ampacity of a conductor is that current which will meet the design, security and safety criteria of a particular line on which the conductor is used"

There is an immediately recognizable advantage for operational planners to have increased ampacity at their disposal thanks to real time monitoring systems (RTM) or probability based ratings [30], but the advantages for a long-term planners are less recognizable. All deterministic equipment ratings used for planning purposes in system models accept an inherent level of risk. Moving to a real time and/or probabilistic rating method from a deterministic method provides an improved measure of the risk.

Real time monitoring and probability-based ratings are solutions that are quickly applicable at a reasonable cost. When reserve capacity is available, these solutions allow line owners to increase capacity quickly compared to solutions involving major infrastructure changes. When the worst case weather assumption happens (in the example given in figure 3, for a wind speed of 0.6m/s and an ambient temperature of 35°C) , real time rating will not result in an increase of line capacity for that time. Under such circumstances, whatever the line rating method, it is advantageous to have a monitoring device that is able to send an alert to the opeator.

Power transfer of a line may be constrained by considerations of stability, voltage and thermal limitations. This technology addresses thermal limitations and consequential line rating only.

4.1.3.2 Differentiating Probability Based Ratings from Real Time Ratings

Purposes and characteristics of real time monitoring solutions and probability based ratings are not the same. Table 7 compares these characteristics.

The purposes and characteristics of RTM and probabilistic rating	RTM	Prob. Rating
Risk maintained constant during use because dynamic rating and not deterministic is used	X	
Avoids unnecessary operator actions during contingency events	X	
Alert to dispatching centre (sag, average temperature)	X	
No real time monitoring equipment needed		X
Assist system operator	X	X
Better utilisation of load current capacity of overhead lines	X	X
Ensure that clearance above ground is always met	X	
line operated closer to the thermal limits for a longer period of time	X	X

Table 7: *Purposes and characteristics of Real Time Monitoring and Probabilistic Rating*

4.1.3.3 Probability-based ratings in practice

Probabilistic based rating is described by an example from National Grid (UK) [6]. Consider setting line ratings using the deterministic method. A set of co-incident values for wind speed, wind direction, solar radiation and ambient temperature are chosen so that conductor temperature constraint s are expected to always be met. The co-incident values used are generally *conservative*. For example, before 1970, National Grid did not allow the conductor to exceed 50°C.

When the statutory regulations were revised 1970, the limitation on conductor temperature was removed. The new regulations required that the conductor height above ground *"…shall not, at its likely maximum operating temperature, be less than the appropriate height specified…"* [6]. In other words, clearances should be respected regardless of the temperature. Following these new regulations, conductor profiling temperatures were increased and both 65°C and 75°C were introduced.

In reality, significant variation in weather parameters according to the season, to the time of the day, to weather, exist. In 1974, National Grid redefined its parameters as expressed in the following table:

	Rated Temp. (°C)	Summer rating (A)	Spring/autumn rating (A)	Winter rating (A)
Before 1974	50	610	770	950
After 1974	75	912	1000	1090

Table 8: *Seasonal deterministic rating at National Grid (UK) before and after 1974*

Three main methods of probability based rating are described in CIGRÉ work [7]:

- o the "exceedence" methods,
- o the "determination of the absolute probability of an accident occurring"
- o a method based on simulations to assess safety.

Exceedence is the percentage of time that a conductor temperature exceeds its design temperature. Using the exceedence method implicitly involves accepting that some % of the time, the thermal limits of a line may be exceeded, i.e. during a temperature excursion, the conductor may reach a temperature causing mechanical damages and/or clearances violation.

National Grid and CEGB (Central Electricity Generating Board) undertook a research program in the late 1970's. The aim of this program was to study the statistical distributions of measured conductor temperature for various values of electrical load, together with the value of the co-incident weather parameters. The data was analyzed in terms of exceedence. The results are illustrated in Figure 5, which show the conductor temperature as a function of time for three different constant loads. The design temperature of the line is 75°C. The lowest load provides zero exceedence, the next leads to approximately 11% exceedence and the highest load, to some 40% exceedence.

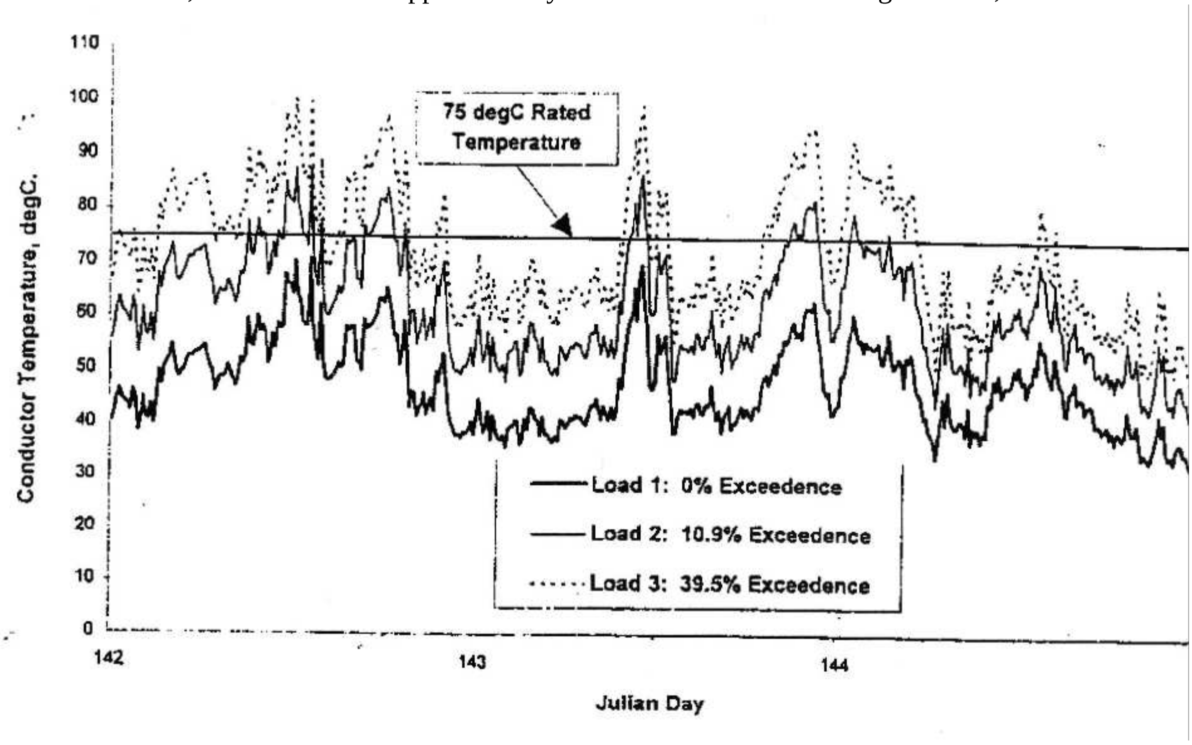


Figure 5: Calculated conductor temperatures over 3-Day period for various constant electrical loads

Table 8 was derived assuming that the load profile is flat i.e. that the line is carrying the maximum load at all times. The exceedence method takes into account the real time profile of a load which is generally not constant. The benefits are shown in Table 9. It could be seen that even with the deterministic rating, a very small exceedence probability remains.

Design Temp.	Exceedence (%)	Summer		Spring/autumn		Winter	
		Previous deterministic rating AMPS	Probabilistic rating AMPS	Previous deterministic rating AMPS	Probabilistic rating AMPS	Previous deterministic rating AMPS	Probabilistic rating AMPS
75	0.1	912	906	1000	981	1090	1025
	3		989		1071		1118
	6		1020		1105		1153
	10		1048		1135		1185

Table 9: *Comparison of deterministic and probabilistic ratings for 428-A1/S1-54/7 "Zebra"[6]*

It is possible to make use of a load profile that is not flat to increase the rating of the line with the same exceedence level. This allows for uprating of the line without any intervention other than the checking procedures mentioned earlier. [8].

4.1.3.4 Real Time Monitoring Solutions

The aim of monitoring devices is to optimize the ampacity of existing overhead transmission lines. Such optimization must recognize that the power transfer of a line may be constrained by considerations of stability, voltage and thermal limitations. In the case of the latter constraint, the current rating is limited by the sag or annealing properties of the conductor. Today utilities monitor their lines to gain a better knowledge of the line capacity, to check clearances or to improve outage planning.

In order to make efficient use of data recorded by a monitoring device, the data must be:

- analysed appropriately,
- sent securely and in due time to a control center,
- presented in a form that is meaningful to the operator, for example "a 15MVA reserve load is available for 20 minutes".

Validity in terms of the time for which the prediction is provided is an important factor.

Possible Capacity Increases with Real Time Monitoring systems:
The average gain in ampacity can be estimated from the difference between the ambient temperature used for the line design (e.g. 35°C) and the average ambient temperature of the region (e.g. 10°C). On average, the increase in the thermal rating of lines using real time systems is about 10 to 15% [9].

When increasing the ampacity of a circuit, it is important to check that all components of the circuit are appropriate for the new ampacity and if necessary exchange some of them (e.g. circuit breakers, current transformers, joints and clamps). Additionally (because of legislation on EMF levels), the magnetic field increases associated with the ampacity increase may have to be checked.

Time Required (from initial concept to commissioning):
Permits to install monitoring devices depend on local legislation. Generally, Real Time Monitoring solutions may be implemented quickly. The dynamic line ratings can be operational in a few months to a few years if line protection equipment needs to be changed. Monitoring devices allow a more extensive use of the line without any major infrastructure change.

Approximate Cost:
The price of monitoring equipment includes the devices, their installation, their integration into the decision-making process and secure data transfer protocols. In some cases, the cost to change line protection equipment (switchgear, etc.) must be included.

The cost of the monitoring equipment itself is reasonable but an important item in the total budget is telecommunication: information must be sent securely to a dispatch center in real time in a usable form. Compared to reconductoring or modifying existing lines, the cost of monitoring is low. Practical aspects should always be considered when pricing and choosing a monitoring device so as to maximize the benefits:

- When a communication system is available, it is important to check its reliability and compatibility.
- For systems without an autonomous power supply, the supply system might need maintenance to ensure its reliability.
- For autonomous systems, the integrity of the power source must be maintained.
- Consider whether an outage of the overhead line is needed for installing and/or maintaining the monitoring device.
- Consider whether the system needs on-site recalibration.

Classification of devices:
Existing Real Time Monitoring solutions are classified according to the physical principle on which they are based:

- conductor temperature measurement
- tension measurement
- tracking the location of points on the conductor
- vibration analysis
- real time weather data collection

Operational software must be adapted to the monitoring device in order to compute ampacity - preferably using CIGRÉ [10] or IEEE [11] recommended models. To be able to compute ampacity (in terms of power reserve), weather data is essential in most cases.

4.1.3.4.1 Solutions Based on Conductor Temperature Measurement
These solutions (Figure 6) perform either a localized or distributed temperature measurement, for example, using optical fibers. For optical measurement, only specific fibers can be used (with a “Bragg grating”, that is, a periodic variation in the refractive index of the fiber core). Optical fiber sensors are mostly used for underground cables. The challenge in this case is to perform a measurement of average conductor temperature, given that the conductor temperature varies along the span, radially and circumferentially. Other similar systems have been recently developed and shown during the CIGRE 2006 session in Paris (see e.g. papers B2-304-2006 and B2-302-2006).

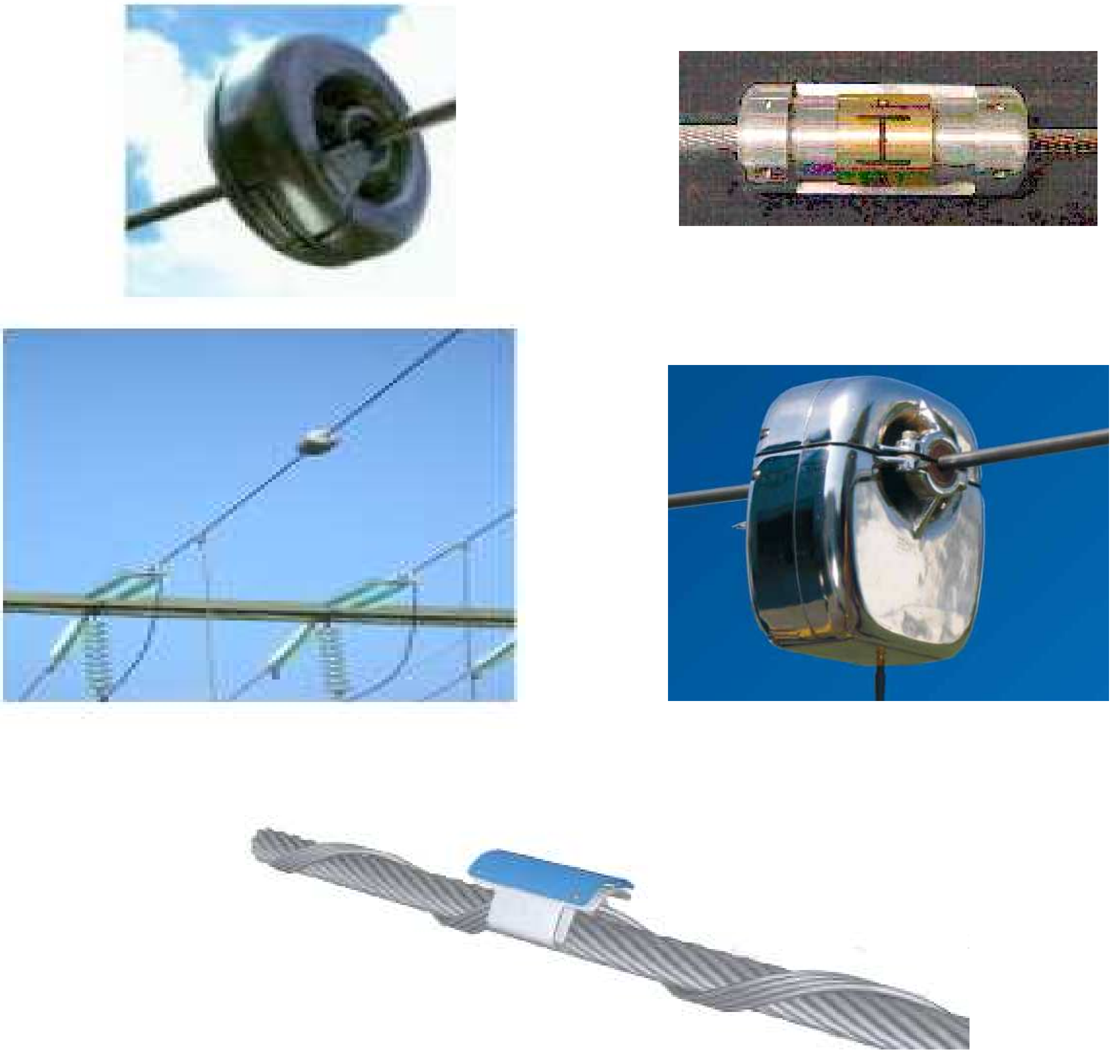


Figure 6: *Examples of conductor temperature measurement systems. Donut system (upper left), Darmstadt University system (upper right), SMT (sensor de medida de temperatura) (lower left), TMT System (lower right), RIBE-Ritherm system (bottom).*

4.1.3.4.2 Solutions Based on Tension Measurement

A load cell located in the dead-end of a tension insulator string is used to determine the conductor tension which in many cases may be representative of the whole section. It is a direct tension evaluator. Near the load cell location, a weather station is installed to evaluate local solar radiation and wind speed, as well as air temperature. Photovoltaic (PV) cells are used to maintain the charge in the batteries powering the system. The challenge with this system is to deduce sag in each span from a tension measured at the dead end of the section. Moreover, the sag-tension relationship depends on weather parameters along the section, permanent elongation, creep, overloads (possibly asymmetric), span lengths throughout the section, insulator lengths, etc [13].

There is a further challenge for the planner: the line must be out-of-service for two weeks to allow for the installation and calibration of the system.

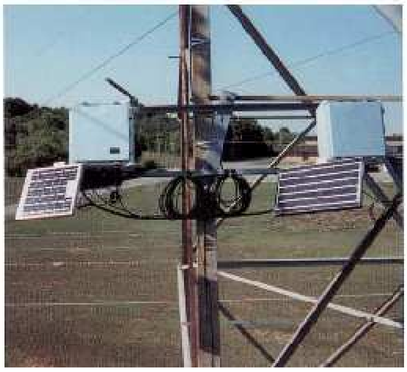
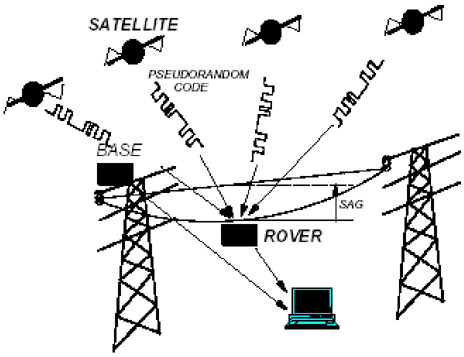


Figure 7: *Cat-1 system including weather station*

4.1.3.4.3 Solutions Based on Conductor Tracking

These systems either use differential GPS, register the movement of a target located on the span with a camera, or perform a laser, radar or sonar measurement. The challenge for these devices is to track a point on the conductor (e.g.: a target, a GPS placed on the conductor, etc) when the visibility is low or when the conductor vibrates. The conductor sag is calculated from the tracking information of one point in the span.



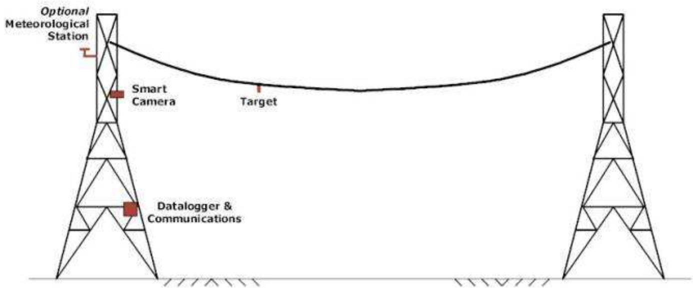


Figure 8 : *Arizona differential GPS prototype (left) and Video Sagometer (right).*

4.1.3.4.4 Solutions Based on Vibration Analysis

This device, which can be seen in Figure 9, may be installed anywhere in the span, relies on the fact that the frequencies of vibration of a conductor are directly linked to its sag. It intrinsically includes the effect on sag of all local conditions (wind speed, solar radiation, ambient temperature, conductor load, creep if any, presence of snow/ice, etc.) without direct measurement. Once installed in the span, the sensor is supplied by induction. No information related to span topology or to conductor material is needed and no calibration is needed as sag is deduced from the frequencies detected, not from the amplitude of the signal. It is a direct sag evaluator.

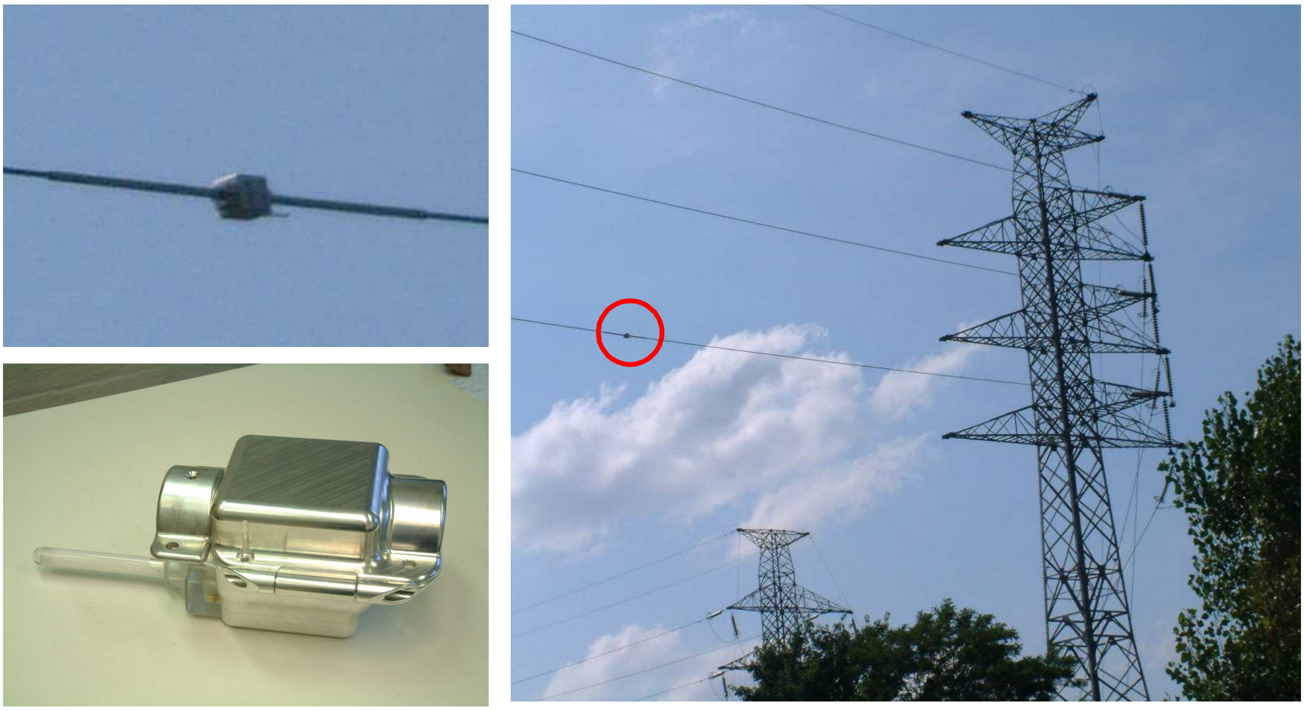


Figure 9 : *Ampacimon (University of Liège)*

4.1.3.4.5 Solutions Based on Real Time Weather Data

These solutions rely on calculating a heat balance for the conductor. They can use real time weather information or a conductor replica. In the latter case, two samples of same conductor are installed near the line – one heated, the other not; the temperature difference between the two samples gives the influence of external parameters.

Because of the variability of weather parameters such as wind or sun along a line, the challenge is to acquire usable weather data that is typical for the weather condition along the line. This is why worst case estimation for sun radiation and wind direction are used most of the time. Suitable locations for weather stations can be determined by meteorological institutes. These devices do not give actual information on real time sag.

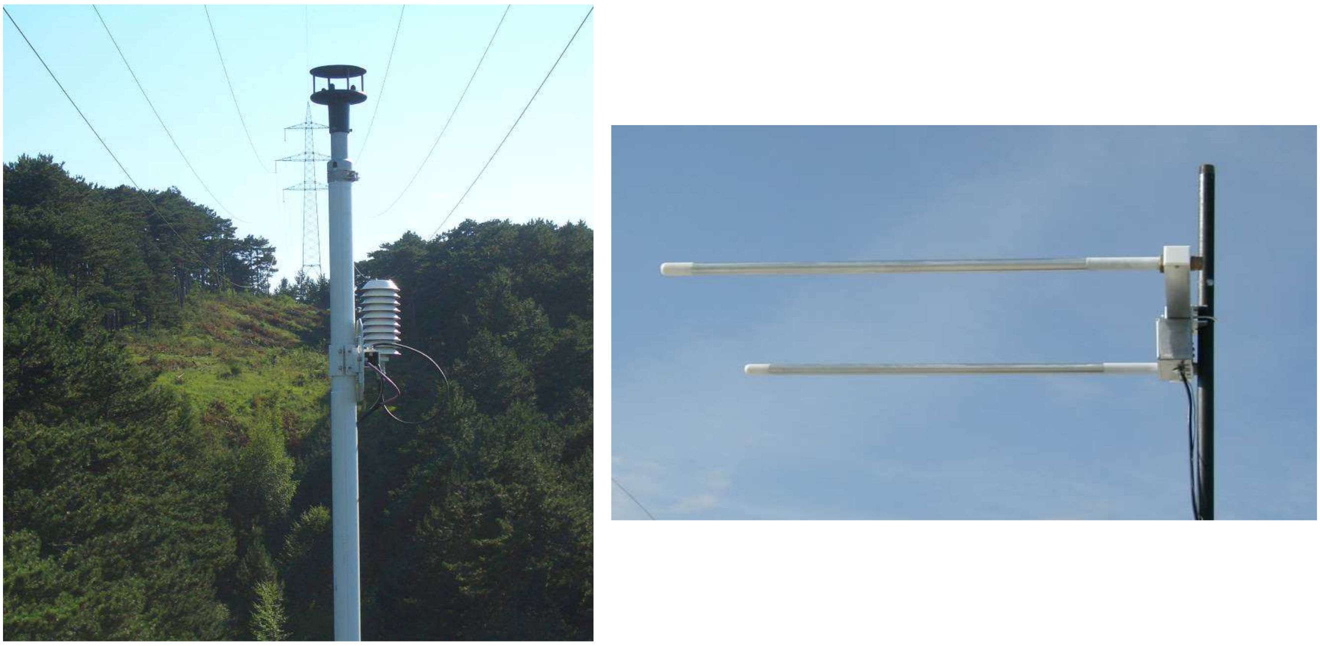


Figure 10: *Weather station in Austria (left). Conductor replica (SHAW technologies) (right)*

4.1.3.5 Life Expectancy / Risk / Reliability

As far as risks are concerned, with deterministic ratings the situation should be safe the vast majority of the time and thus risks still exist when weather conditions are more deleterious than those envisaged by the standard and extreme ampacity is needed. This issue is discussed in more detail in ref [9].

Also, unpredicted clearance problems may occur because of normal variations in line construction, conductor creep, annealing of conductor, etc. [12, 13].

This is why Real Time Monitoring devices can help with risk management. With the information they provide, one has a better idea of clearance violations. Moreover, the risk can be held more constant during operation of the line because extra ampacity is only available when the conditions permit.

4.1.3.6 Application / Number of / Location / History

Examples of predictive ratings studies in Italy, USA, UK, South Africa and Canada are described in [14]. UK's probabilistic approach to line ratings is described by Hoffman and Tunstall in [15].

Monitoring technology include a products at different stages of development. The oldest concept is weather monitoring which has been used for decades. Presently, most of the monitoring systems installed are tension monitoring systems and weather stations (USA and Europe). Temperature monitoring devices and tension monitoring system have a maturity of approximately 10 years. Other devices are still concepts (GPS) or at the final development stage (Ampacimon) or at the beginning of commercialization (Ritherm, Arteche, etc.). Lots of players are entering the market.

Table 10 provides an overview of the present systems usage.

Device	Application	Number of	Where	History
Weather station	Widely used	One for all spans located in the region of the weather station	Off the line	>30 years
Tension monitoring	Mostly used in the USA	One device per section[5]	On the line, at an anchored end, between insulator and tower	< 20 years
Conductor local temperature measurement	Very limited	It is necessary to use many devices along the line because only a local temperature value is measured	On the line Anywhere along the span	< 20 years
Distributed conductor temperature measurement (optical fibers)	Very limited	NA	Either Integrated fiber or wired afterwards	< 10 years
Conductor tracking	In the USA	One device monitors a few spans	Off the line, on the ground	< 10 years
Vibration monitoring	2 Pilot study at 400 kV in 2008	One device per critical span	On the line Anywhere along the span	< 2 years

Table 10: *Present usage of Real Time Monitoring Systems*

4.2 Voltage based solutions

4.2.1 Effectiveness of voltage uprating

Operation of an overhead line at a higher voltage level is a very effective way to increase the transmission capacity. While current uprating increases the ampacity modestly on average, changing to a higher voltage level will increase the ampacity by the direct ratio of the voltage change. It also reduces the energy losses by the voltage ratio squared. Typically, voltage changes are doubled or more, thus the capacity increase are very large. Often, conductor size may limit voltage uprating. It may be necessary to replace existing conductors with new ones while increasing the voltage because of Corona effect.

Figure 11 shows an example of voltage uprating at Union Fenosa in Spain [16] where a 66 kV single line was upgraded to 220 kV with the use of the original conductor and foundation, resulting in a 233% capacity increase.

[5] a section is a set of suspension spans comprised between two anchored ends

Figure 11: *Uprating a 66 kV lines to 220 kV with minimal cost and construction time*

A disadvantage of voltage uprating is the fact that a circuit of lower voltage must be sacrificed. This can cause redundancy problems in the grid, which in many cases must be resolved by other means. Another disadvantage is the long lead time of modification which is not always acceptable.

Although in some cases erection of a new line is cheaper than voltage uprating, it still has advantages. Voltage uprating of an existing overhead line will result in the much better use of the same Right of Way (ROW). In general, there are fewer objections against the reconstruction of an overhead line. This means less time consuming procedures and a much faster solution. Meanwhile, voltage uprating requires some strict conditions. Basic voltage increase design considerations are discussed in the following points.

Safety clearance to the ground and obstacles:
One of the main criteria for a transmission line is to provide sufficient vertical clearance to the ground and to obstacles. The clearance must be in compliance with at least national regulations. Figure 12 shows an overview of clearances. Increasing the height of the towers is the most common solution to maintain clearances. In most cases tightening the conductor will not be sufficient nor within the capability of the consuctors, partially due to the longer insulation strings which are needed and the fact that tightening needs stronger towers [17].

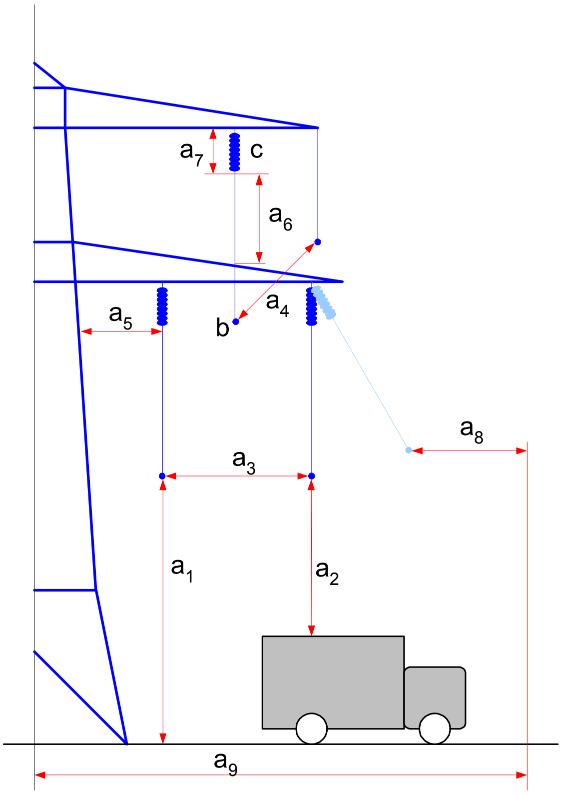


Figure 12: *Overview clearances (a), electric field on the conductor (b) and creepage (c).*

Clearance between phases and phase to earth wires:
There are a few items that determine the phase to phase and phase to earth distance [24]. These are over-voltages, blowout, galloping and creepage. In the case of voltage uprating, the conductors need an increase in space. This can be created by broader cross arms or by converting a double circuit into a single circuit. To limit the size of the cross arms and reinforcements of the tower, special in–span insulator arrangements can be used.

Different voltage levels have different requirements for protection against lightning. In general higher voltage levels have a higher protection level. Usually this means that to fulfill the requirements for the higher voltage level, reconfiguring the earth wire(s) is necessary. Therefore broader cross arms and reinforcements of the tower are needed.

Often, a large voltage increase is restricted by the ability to maintain standard clearances at the new voltage. This can trigger the discussion on the ability and willingness to downgrade the standard of clearances in order to achieve the voltage uprating. Figure 13 shows an example of this.

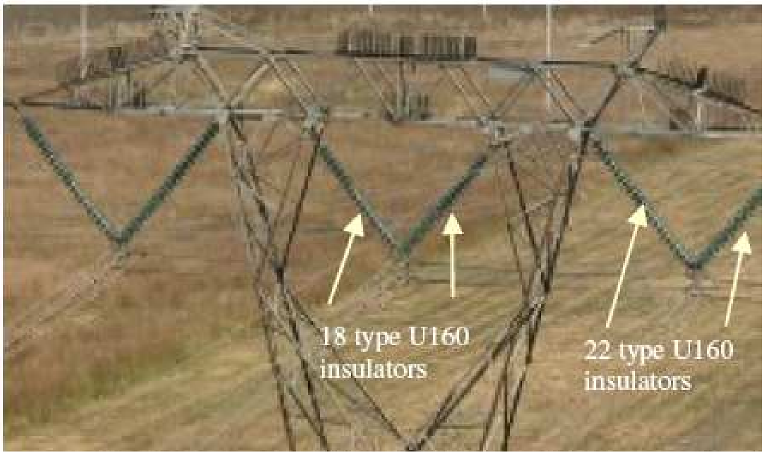


Fig. 13: *Re-insulation of a single circuit at the Lethabo power station, Eskom, South Africa.*

Width of the safety strip of land:
In general, a higher voltage needs a broader safety strip of land. The size of the safety strip of land or ROW depends on the design of the tower and the length of the spans. In some countries, the land is bought by the utility, in some a compensation fee (at once or annual) is paid to the landowner. In both cases, extension of the ROW could be expensive. A redesigned overhead line which can fit into the existing ROW is less expensive. If an extension of the ROW is necessary and if buildings or trees are on the edge of the existing ROW, then restrictions can arise.

Insulation requirements:
For steady state voltage, the creepage distance is of interest. Each insulator disc has a limited surface and the number of discs determines the total creepage distance. In consideration of uprating an existing overhead line, the historical pollution performance of the existing line provides important information for the requirements of the new line. Careful insulator selection can help mitigate clearance constraints.

Electrical field strength at the conductor:
The conductor surface voltage gradient is an important point to be considered when voltage uprating an overhead line. For voltage gradients above a critical level, the conductor will initiate the corona phenomenon resulting in continuous discharges in the air around the conductor. The negative effects of corona are energy losses, audible noise and radio interference.

Voltage uprating is relatively easy if the same conductor can be used, but for uprating to 220 kV or higher, this is dependent on the corona onset voltage. Larger diameter or additional conductors per phase are needed to eliminate corona. This could results in the necessity for stronger towers and foundations. To avoid such reinforcements, voltage uprating is especially suited to converting a double circuit line into a single circuit line. Also, the phase to phase distance can be easily obtained by the conversion of a double circuit line into a single circuit line. See Figure 14 for an example.

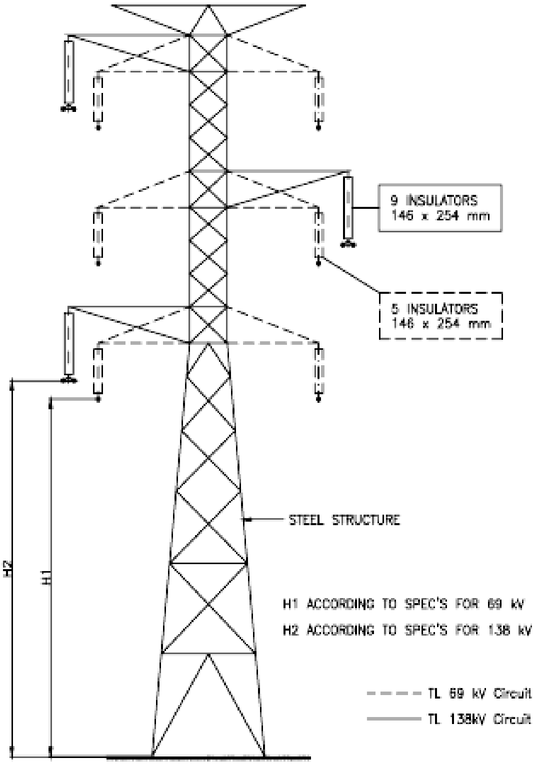


Figure 14: *Conversion of a double circuit 69 kV line into a single circuit 138 kV line.*

Implication of transformers in association with voltage uprating:
At first glance, it may appear attractive to convert a double circuit line into a single circuit line of higher voltage. For example, consider a 300 MVA 170 kV double circuit converted into a 1600 MVA 400 kV single circuit. This means an additional transmission capacity of 1000 MVA. But, consider that there is only one circuit with a higher voltage in a meshed grid that needs transformers at both sides. Figure 15 shows an example of this.

Due to the relatively high impedance of the transformers, the power flow distribution is disproportionate across the circuits. The circuits with the lower voltage are naturally overloaded, while they have the least transmission capacity. This problem can be solved by the use of a phase shifter or series reactors, but will results in an unbalanced grid structure. A failure of one of the lower voltage circuits or a transformer failure will heavily overload the remaining low voltage circuit. In addition, the method is very expensive due to the transformers costs and also less reliable.

This method is more suitable for connecting generators to the grid. Due to the power injection, the impedance of the transformers does not influence the power flows. The choice of the uprating voltage is more open and can be optimized with the economics of the overhead lines.

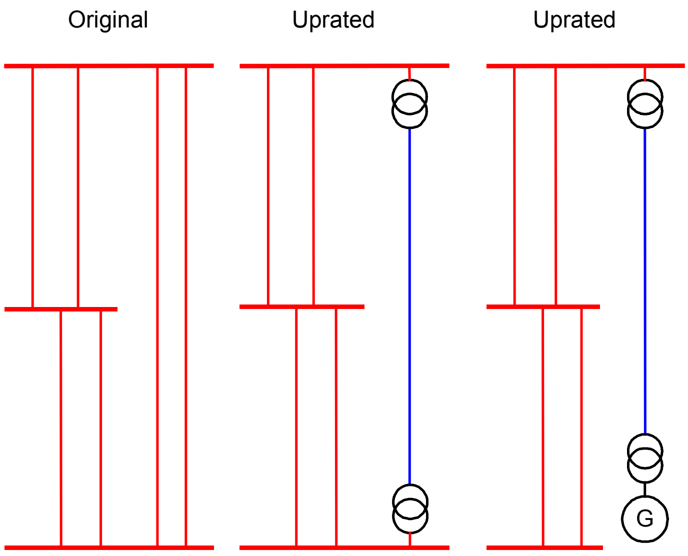


Figure 15: *conversion of a double circuit line into a single circuit line. The blue colour is the higher voltage level.*

4.3 Large Scale Actions

4.3.1 HSIL lines

The transmission capacity of overhead lines (OHL) is limited for different reasons. Figure 16 shows a brief overview of those limitations. The voltage drop constraints occur with longer lines because of the reactance (X_L). When such a limitation occurs, HSIL (High Surge Impedance Loading) lines help to limit the voltage drop and thus increase the power transfer capability.

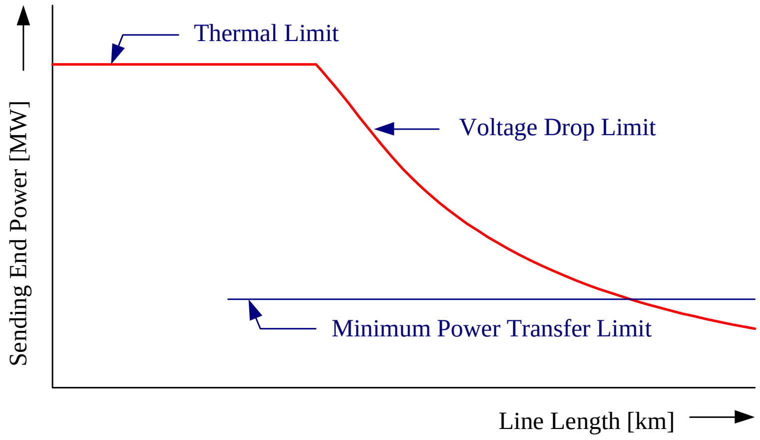


Figure 16: *Maximum line loading versus line length*

HSIL lines [18], [19], [20], [26] have been developed as an efficient feature of very long lines. It provides a higher Natural Power or Surge Impedance Loading (SIL) than conventional line configurations offer. The HSIL lines concept can be applied either to new lines or to existing lines. Countries with very long lines (>250 km) like Brazil, Russia and China have HSIL lines in successful operation. An example of an HSIL line is shown in Figure 17.

Figure 17: *Experimental HSIL line in Brazil: the right circuit is conventional. The bundle of the left circuit has been expanded as to increase the surge impedance loading.*

The concept of HSIL is based on increasing the Surge Impedance Loading PSIL.

$PSIL = V2 / Zc$ and $Zc = \sqrt{L/C}$	PSIL = natural power (MW)
	V = phase to phase voltage (kV)
Where	Zc = characteristic line impedance (Ω)
	C = line capacitance per unit length (F)
	L = line inductance per unit length (H)

The formula indicates that an increased natural power can be reached by increasing the capacitance (C) and decreasing the inductance (L). In practice, this can be done by:

- Adding sub-conductors per phase
- Increasing the bundle size for each phase (Expanded Bundle Technology (EXB))
- The use of asymmetric bundles
- Decreasing the phase to phase distance

While adding more sub-conductors, the total conductor cross section may remain the same. The HSIL lines structure (see Figure 18) does not require any significantly new method of line construction. Conventional sub-conductors, insulators and fittings can be used. Only the number of sub-conductors, their position in space and the tower structure are unusual. In cold climate areas where ice loads can arise, this concept is less appropriate.

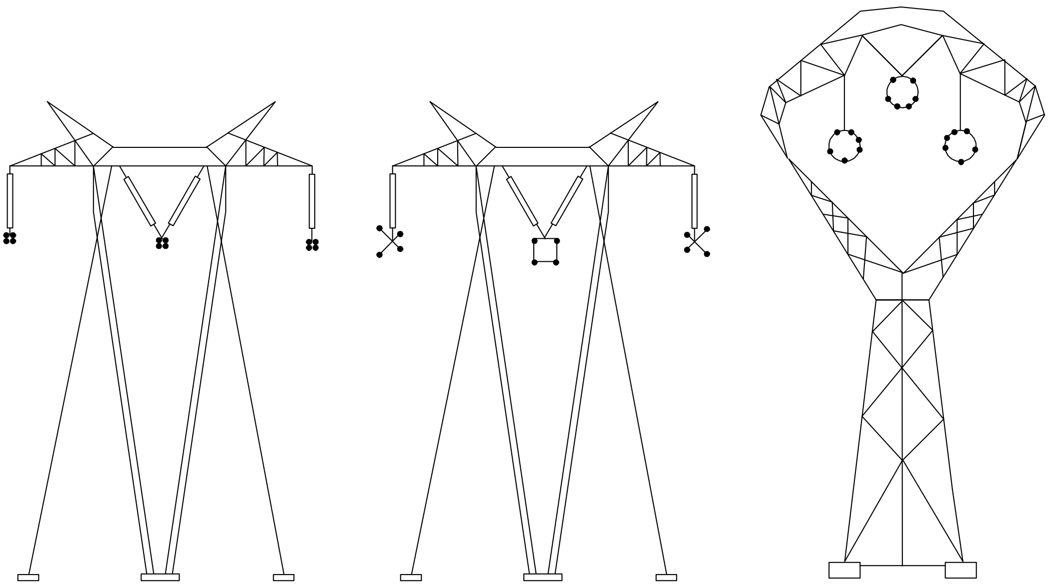


Figure 18: *Some examples of HSIL lines for 500 kV in Brazil.*

The charge on the conductor is related to the electric field strength. A higher field strength means more charge. However, for voltage gradients above a critical level of approximately 12 kV/cm., depending of the weather conditions, the conductor will initiate the corona phenomenon resulting in noise and power frequency energy loss. Figure 19 shows some conductor arrangements with maximized and equalized electromagnetic field distribution on the conductor.

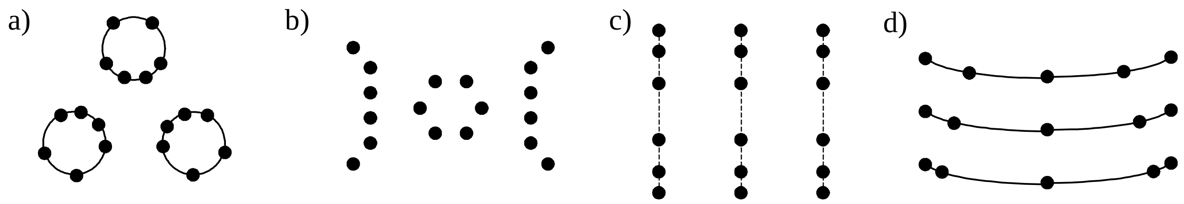


Figure 19: *Asymmetric bundle arrangements to reach minimum characteristic impedance*

The HSIL line concept can be useful for different applications. Table 11 shows the applications and the traditional way to solve problems. Compared to all other kinds of compensation, HSIL is a "natural" technique. The modified impedance properties are "built in" so the reliability of the system is not changed. This delivers high reliability to the grid and avoids the need for maintenance that traditional solutions require.

Application for HSIL Lines		
Application	**Issue**	**Traditional solution**
Very long lines	Increasing stability	Series capacitors (Limited due to sub–synchronous resonance)
Highly loaded lines	Decreasing transfer of reactive power	Shunt reactors
Parallel lines	Optimizing current distribution	Series reactor

Table 11: *Different applications of HSIL lines*

HSIL lines are most effective in the cases of high power generation or transfer of energy over long distances. For short and heavily loaded lines, HSIL lines become too expensive. Due to reconstruction delays and costs, this technique is more suitable for new lines rather than uprating existing lines.

Finally, HSIL lines can increase the efficiency of corridors made with parallel lines of various electrical characteristics by balancing power flow by way of changing the intrinsic impedance of one or all the parallel branches.

4.3.2 AC to DC Conversion

Three phase AC systems are the norm for worldwide transmission systems while DC systems are practical in large countries or for connecting dissimilar grids or different market areas. In some cases and under specific conditions, existing AC lines may be converted to DC links with the addition of AC-DC converters for the benefit of the system.

4.3.2.1 Power increase by HVDC conversion

To examine the effectiveness of an AC conversion to DC [21], [22], a comparison of the capacity is made between a three phases AC double circuit and a bipolar DC system using three conductors per phase, both equipped with the same conductors as seen in figure 20.

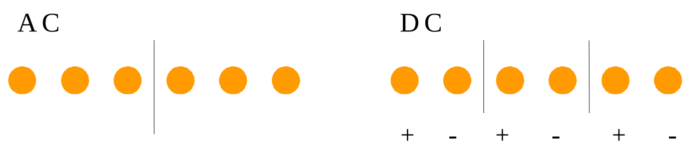


Figure 20: *Comparison of conductor configuration of power transmission capability between AC and DC systems*

In theory, the peak value of the AC voltage requires the same insulation level to earth as the system voltage of a DC system, neglecting the fact that the insulation level for overhead lines mainly depends on creepage and on switching and lightning voltages as described in Figure 21.

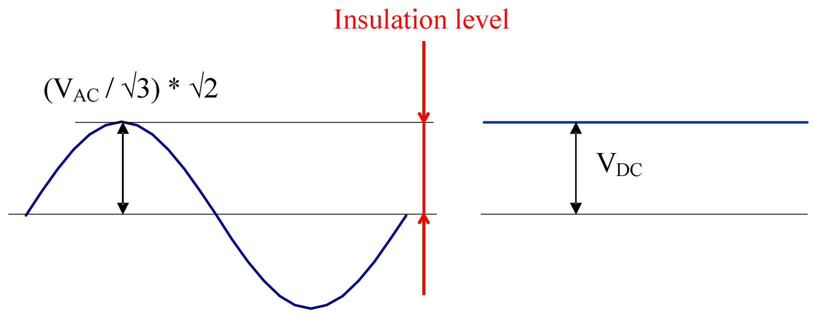


Figure 21: *AC and DC voltages related to the insulation level*

The conversion of AC to DC as described above produces a new power transmission capability of PDC = √2 PAC

This is not the most impressive improvement for AC to DC conversion. Although the rms current rating of a conductor for DC is slightly better than for AC due to the absence of skin effect (approximately 10%), the absence of reactive power in a DC system is of greater importance. With an assumption of more than 15% of losses in AC systems due to reactive power, especially when lines are heavily loaded, the conversion benefits from the absence of reactive power. Given the previous example, $P_{DC} = \sqrt{2}\, P_{AC} / 0.85 = 1.8\, P_{AC}$

4.3.2.2 Differences between AC and DC Lines

At first glance there is no fundamental physical difference between an AC and a DC overhead line. Besides the number of conductors, the operation of an AC and DC overhead line is similar. Both use air as insulation, need enough clearance between conductors and between conductors and earth, and both must be protected against lightning. In detail, there are differences like the type and length of the insulators, the level of corona and the magnetic field. These differences influence the opportunities for uprating AC into DC lines.

The most significant difference between AC and DC links is the need for converter stations at both ends. In the scenario of converting an AC circuit to a DC link, it is important to include the cost of converters which can be expensive and thus, generally impede the profitability of such conversion.

4.3.2.3 Monopole versus bipolar DC systems

Due to the fact that a DC system can transfer significantly more power with the same conductors, converting an existing AC overhead line into a DC overhead line may be beneficial, even accounting for the additional cost of converters. In order to reduce the costs, monopole systems which use the ground as return path may be considered. This is economically very attractive because it means the full use of all the conductors of a single AC line and using the earth as a return path. Although an earth return is possible, there are only a few monopole systems in operation because of risks to damaging underground systems like pipelines and telecommunication cables.

This problem is solved by using half of the AC system conductors as an insulated earth conductor, but then the capacity of the connection is halved. However, a bipolar system restores the capacity by using a positive pole and a negative pole. With this system, the same amount of power can be transferred over the same conductor cross section as a monopole system with an earth return. This is of interest and useful for uprating an AC double circuit due to the useful (even number) conductor quantity. It is not so useful for an odd number of conductors such as a single circuit line.

4.3.2.4 Tri-pole DC system

Converting a three phase AC single circuit into a two phase DC single circuit does not produce much capacity gain. Using the figures mentioned above, the gain is only 2/3 x 1.8 = 1.2. DC systems which can use the three phases offer more benefit and lower losses.

A theoretical idea exists to employ a 'tri-pole' terminal, as shown in Figure 22. If pole 1 is positive, poles 2 and 3 could be negative, sharing the return current. Theoretically, as the thermal rating of pole one is exceeded, the temperature of the two return poles is below that rating, and the overload is rotated around the poles by bridges. That way, each conductor sees a high current a third of the time, relieved by a low current two thirds of the time. This is called the 'hot potato system.' The levels of the currents can easily be adjusted to assure that on aggregate the resulting current on each pole does not exceed its rated rms current.

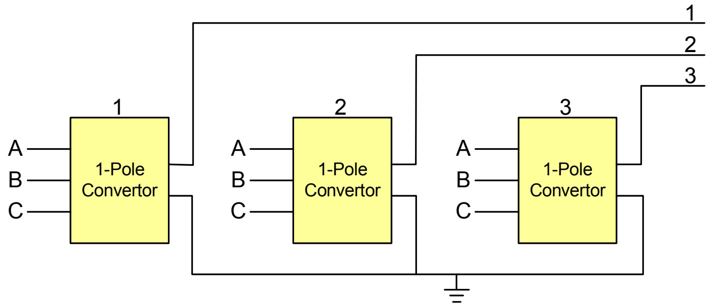


Figure 22: *Tri-pole DC system using three conductors*

Different modulation techniques can influence the maximum power transfer and losses. Figure 23 shows a tri-pole three conductor modulation form, which transmit 37% more power than an equivalent bipolar system using only two of the three conductors available.

In this modulation form, the conversion to a tri-pole DC system is equal to 1.2 x 1.37 = 1.6 capacity increase compared to an AC system. For the same transmitted power, its losses are 20% less than an AC system.

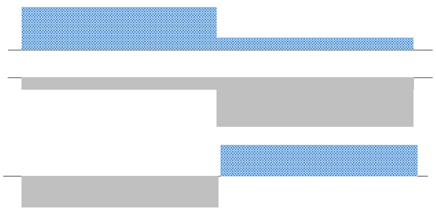
Pole	Current Modulation	I_{max}	P_3/P_2	L_3/L_2
1				
2		1.37	1.37	0.8
3				

Figure 23: *Current modulation on a tri-pole DC system.*

4.3.2.5 Efficiency of DC compared to AC

Joule losses become increasingly important as electricity prices rise. The consideration below shows the losses in the case mentioned above. Assuming that you wish to transmit the same power is either DC or AC, then it can be shown that the power losses in DC are half that of AC, as shown below:

$$P_{DC} = P_{AC} \quad \rightarrow \quad I_{DC} = (1/\sqrt{2})\, I_{AC}$$
$$P_{L\,DC} = (1/\sqrt{2})^2\, P_{L\,AC} \quad \rightarrow \quad P_{L\,DC} = 0{,}5\, P_{L\,AC}$$

Although the joule losses in the DC system are significantly lower, the losses of the two converter stations must be overcome. This will only be the case for very long transmission lines.

4.3.2.6 Supplemental properties of a DC link

A DC link in an AC network has several advantages [25]. It lowers the energy losses over long lengths, it limits the short-circuit current levels and system oscillations, and has the opportunity to control the voltage and power flow.

A very positive property of converting an AC line into DC link is the freedom of choice for the DC voltage. By using this freedom, an existing line can be economically optimized for clearance requirements, insulator lengths and audible noise due to corona.

As discussed above, converting to DC is very expensive due to the converter station requirements. Normally, the cost of this is better supported with merchant lines than with regulated lines. Typically, regulated lines must be able to feed an electrical island without power generation. Conventional HVDC technology requires generation in the area of load, as shown in Figure 24 (left). HVDC Voltage Source Converter (VSC) has the ability to operate without generation, as shown in Figure 24 (right), but has a limited power capability of 1.100 MW per system.

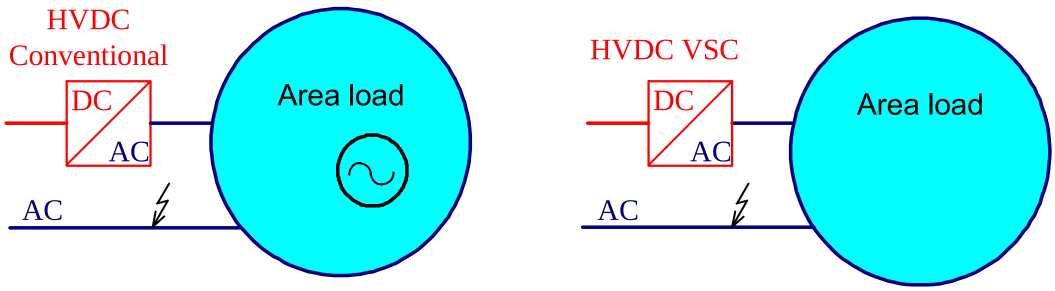


Figure 24: *HVDC conventional needs power generation to feed the load area if the last AC circuit fails.*

AC networks are very flexible to modification, allowing insertion of new stations into existing circuits. This is not true of breaking into the middle of a DC link to connect a new station. This requires the addition of converter station(s) at each insertion.

4.4 Miscellaneous Solutions

There are a host of other capacity increase technologies, but none of these provide large capacity increases at a competitive cost. For this reason, they are not discussed in this Technical Brochure except by brief mention. These include the technique of selectively re-sagging a conductor by what is called " nip and tuck" or 'slip and clip.' Here, the technique is to move small amounts of conductor from one span into another by moving a support clamp slightly, or to cut our small lengths of conductor. These adjustments are to the sags and therefore to the critical clearances. Large movements of a support clamp cause the insulator strings to go out of plumb and put new loads into the structures. At some point the operation becomes unpalatable to most people.

The other technique is to install sag compensators on the line. These are mechanisms that can actually shorten a span of wire as heat is increased. There is a limit to their capability and they make little economic sense on a large and important application.

5 Summary of Technology Capabilities and Applicability

Figure 25 illustrates the relative abilities of the technologies described above to increase the capacity of an existing circuit between two nodes on a transmission network. The capacity of each is compared to a new line that delivers a base capacity of 100% at a cost of 100%. The capacity increase capability range of each technology is expressed as a percentage of the base capacity. The cost of implementing a technology is expressed as a percentage of the cost of constructing a new line with the base capacity.

The length and width of each technology's plotted 'cloud' on the figure represent its range of capacity increase and comparative cost. The dimensions of the blocks are qualitative estimates to which there are undoubtedly exceptions.

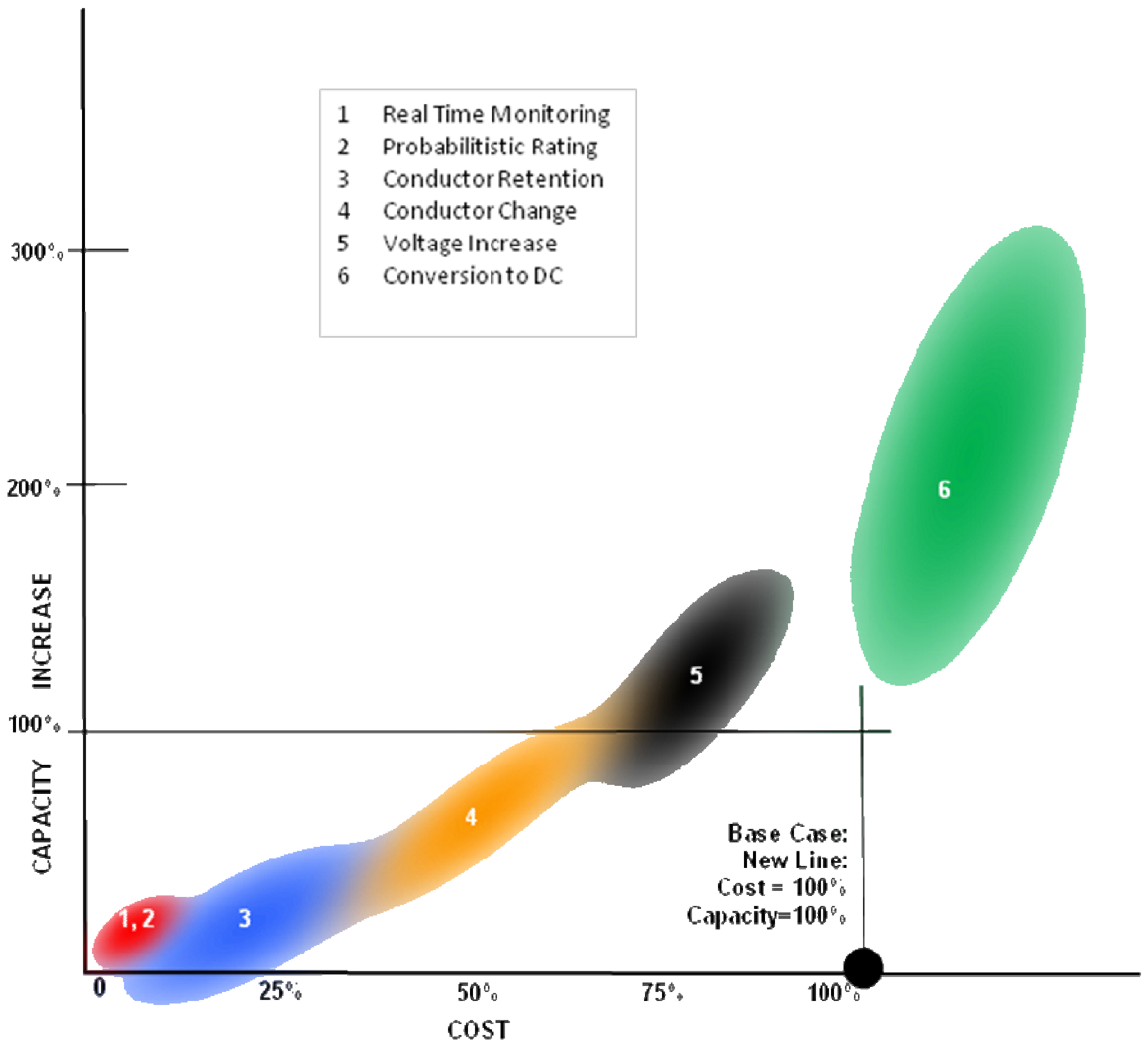


Figure 25: *Relative cost and ability of technologies to increase capacity.*

6 System Development Strategy

Finally, when the resistance against any means of line capacity increase leads the governmental organization to block any kind of line upgrading, an overall restructuring strategy for the network can be a method to cope with the environmental issues and finally allow future network expansion. The main features of an overall restructuring strategy are the following:

- **Think globally and not locally:** do not study projects one by one, but make a large scale analysis of network development in a whole region. This implies the need to take the different grid voltage level into account, (even the distribution level).
- **Start early cooperation between planners and designers**: success will depend on the ability of each to present, communicate and negotiate solutions which in one way or another takes the environmental issues into account. An early and equal relationship between planners and designers will raise the probability of coming up with solutions which are different from traditional choices at acceptable costs. Identifying "optimal capacity/environment at acceptable cost"-solutions requires an iterative working process.
- **Make strong ties with central authorities:** think globally means that lobbying becomes a more important matter. By spending time at collaborating and educating central authorities, one often experiences that local authorities may revise their attitude to the new situation and cooperate better.
- **Initiate a strategy process:** a way to initiate a strategy process is to let the transmission system operator (TSO) have a key role in organizing the work. For instance :
    1. TSO sets up goals for the grid owners for example guidelines for reinforcing the grid or a master plan for the grid (for instance a 5 or a 10 years plan)
    2. TSO sets up an internal organization to be able to share concerns with governmental authorities about technical, environmental and economical aspects of the projects
    3. TSO convinces central authorities of the idea, and ask them for commitment.
- **Negotiate long term master plans or development guidelines with the authorities:** commitment of the central authorities reinforces chances to end the process with a negotiated and accepted master plan or guidelines for the overall network development for a long period ahead. A negotiated overall restructuring strategy requires planners to accept and respect a working process which is more open than before. Projects are not considered one by one but on a long term / large area basis. For governmental organization, potential benefits are found in an overall coordination of society interests. Environmental issues are generally tackled in a "more controlled way" and less time-consuming efforts are needed to get permissions. This also brings a deeper credibility for public / authorities and finally a better chance of succeeding a longer term network development work.

An example of the strategy process resulting in an overall restructuring plan is given in Appendix 2.

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APPENDIX 1 – Questions Always Asked by Planners to Designers

As previously discussed, understanding the interaction and needs of both planners and designers during their joint work in assessing the options within the improvement study stage of the planner/designer relationship (see Figure 1 above in Section 1) was identified early on as being a key element in the work of JWG19. The consequence of planners, designers, operators and manufacturers sharing the same vocabulary, concerns, and vision will be convergence towards a range of optimal solutions for a more reliable and optimized network.

As part of this process of gaining this understanding, JWG 19 compiled a questionnaire outlining questions that will normally be required to always be answered by designers for planners as part of their option selection process. The questionnaire focussed on five different families of solutions: sag compensators, probability ampacity calculation, monitoring systems, voltage increase, and use of high temperature low sag conductors. Respondents were also asked to provide any further questions always asked but not contained within the questionnaire.

The questions and the answers provided by those respondents to the questionnaire are tabulated in two formats on the following pages. The first format shows the individual respondents and there responses in detail and provides useful reference for the individual needs of the respondents reflecting the international differences in working practices, legislation and local natural environment.

The second format is a summation of the responses sorted on their category and on those questions most frequently asked pro-rata by the international responses received. These provide an indication of the data which will need to be provided for a technology to suffice the needs of planners to gain their acceptance of that technology. This may prove useful to both manufacturers of these technologies in creation of their data sheets and also designers in their work in association with planners.

Questions to be answered by Designer Sag Compensators

Technology Characteristics	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Maximum predicted increase in normal line rating (%)	X	N	X	X	X	X		X	X	X	X	N		
Is the system fail safe		N	X	X	X	X		X		X	X	N		
Does system have inbuilt diagnostic capabilities	X	N			X	X		X			X	N		
Tolerance for error in predicted increase in normal line rating at point of measurement (+/- %)	X	N	X	X	X	X		X		X	X	N		
Tolerance for error in predicted increase in normal line rating along line length (+/- %)	X	N	X	X	X	X		X			X	N		

N = No response – is technology not in use in country?

Technology Profile	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Number of years available commercially (yrs)		N	X	X	X	X		X		X	X	N		
Longest period of service in a real transmission system (yrs)		N	X	X	X	X		X		X	X	N		
Longest period of service in clients transmission system (yrs)		N	X	X	X	X		X		X	X	N		
Expected asset life of the system (yrs)		N	X	X	X	X		X	X	X	X	N		
Expected completion time for scope of works (days)		N	X	X	X	X		X	X	X	X	N		
Expected outage time of the circuit to complete the scope of works (days)	X	N	X	X	X			X	X	X		N		
Expected routine maintenance period (yrs)	X	N	X	X	X			X	X	X		N		
Expected completion time for routine maintenance (days)	X	N	X	X	X			X	X	X		N		
Expected outage time of the circuit for routine maintenance (days)	X	N	X	X	X			X	X	X		N		
Revised EMF level (V/m over freq range in Hz)		N	X	X	X			X				N		
Impact to maintenance method statements (as applicable)		N	X	X	X			X				N		
List of component parts of the line construction that can be effected by introduction of new technology	X	N	X		X			X				N		

Permits/easements/Planning Permission	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Modifications and specification to support structures (as applicable)		N						X				N		
Permit/Easement/Planning Permission requirements (as applicable)		N						X	X	X		N		
Estimated lead time (in mths) to obtain Permit/Easement/Planning Permission (as applicable)	X	N						X	X	X		N		
Expected completion time for scope of works (days)	X	N		X				X	X	X		N		
Expected outage time of the circuit to complete the scope of works (days)	X	N		X				X	X	X		N		

Questions to be answered by Designer Probability Ampacity Calculation

Technology Characteristics	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Maximum predicted increase in normal line rating (%)	X	X	X	X	X	X		X	X	X	X	N		
Does system have inbuilt diagnostic capabilities	X				X	X		X			X	N		
Method/type of calculation/measurement		X	X	X	X	X		X	X	X	X	N		
Input data requirements (historic and/or real time)		X	X	X	X			X	X	X	X	N		
Input data type (current data, ambient temperature, line temperature, etc)		X	X	X		X		X		X		N		
Input data frequency (real time, ¼ hourly, hourly, etc)		X	X	X				X				N		
Tolerance for error in predicted increase in normal line rating at point of measurement (+/- %)	X	X	X	X		X		X		X		N		
Tolerance for error in predicted increase in normal line rating along line length (+/- %)	X	X	X	X		X		X				N		
Prediction update time (Secs/Hrs)		X	X	X				X				N		

Technology Profile	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Number of years available commercially (yrs)			X	X	X	X		X		X	X	N		
Longest period of service in a real transmission system (yrs)		X	X	X	X	X		X		X	X	N		
Longest period of service in clients transmission system (yrs)		X	X	X	X	X		X		X	X	N		
Expected asset life of the system (yrs)		X	X	X	X	X		X	X	X	X	N		
Expected completion time for scope of works (days)		X	X	X	X	X		X	X	X	X	N		
Expected routine maintenance period (yrs)	X													
Expected completion time for routine maintenance (days)	X													

Financial	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Expected completion time for scope of works (days)	X	X						X	X	X		N		
Expected outage time of the circuit to complete the scope of works (days)	X	X						X	X	X		N		

Questions to be answered by Designer Monitoring systems and operational optimisation

Technology Characteristics	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Maximum predicted increase in normal line rating (%)	X	X		X	X	X		X	X	X		N		X
Is the system fail safe		X	X	X	X	X		X				N		X
Does system have inbuilt diagnostic capabilities	X	X	X	X	X	X		X				N		X
Maximum permissible distance for measurement from line conductor (m)			X	X	X	X		X				N		
Method/type of calculation/measurement		X	X	X	X	X		X	X	X		N	X	
Input data requirements (historic and/or real time)		X	X	X				X	X			N	X	
Input data type (current data, ambient temperature, line temperature, etc)		X	X	X	X			X		X		N	X	
Input data frequency (real time, ¼ hourly, hourly, etc)		X	X	X				X		X		N	X	
Tolerance for error in predicted increase in normal line rating at point of measurement (+/- %)	X	X	X	X	X			X		X		N		
Tolerance for error in predicted increase in normal line rating along line length (+/- %)	X	X	X	X	X			X		X		N		
Prediction update time (Secs/Hrs)		X	X	X				X		X		N		X

Technology Profile	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Number of years available commercially (yrs)		N[6]	X	X	X	X		X		X		N		
Longest period of service in a real transmission system (yrs)		X	X	X	X	X		X		X		N		
Longest period of service in clients transmission system (yrs)		X	X	X	X	X		X		X		N		
Expected asset life of the system (yrs)		X	X	X	X	X		X	X	X		N		X
Expected completion time for scope of works (days)		X	X	X	X	X		X	X	X		N		
Expected outage time of the circuit to complete the scope of works (days)	X	X	X	X	X			X	X	X		N		
Expected routine maintenance period (yrs)	X	X		X	X			X	X	X		N		X
Expected completion time for routine maintenance (days)	X	X	X	X	X			X	X	X		N		X
Expected outage time of the circuit for routine maintenance (days)	X	X	X	X	X			X	X	X		N		X
Revised EMF level (V/m over freq range in Hz)		X		X	X			X				N		
Impact to maintenance method statements (as applicable)		X	X	X	X			X				N		
List of component parts of the line construction that can be effected by introduction of new technology	X				X			X				N		

[6] Submission stated question not understood

Permits/easements/Planning Permission	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Modifications and specification to support structures (as applicable)								X				N		
Permit/Easement/Planning Permission requirements (as applicable)								X	X			N		
Estimated lead time (in mths) to obtain Permit/Easement/Planning Permission (as applicable)	X							X	X			N		
Expected completion time for scope of works (days)	X	X	X					X	X	X		N	X	X
Expected outage time of the circuit to complete the scope of works (days)	X	X	X					X	X	X		N		X

Questions to be answered by Designer Increasing the voltage of the overhead line

Technology Characteristics	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Resistance (R) per km (in ohms)	X	X	X[7]	X	X	X		X	X	X		N		
Reactance (X) per km (in mH)	X	X	X[8]	X	X	X		X	X	X		N		
Susceptance (B) per km	X	X	X[9]	X	X	X		X	X	X		N		
Maximum operating temperature (^{o}C)	X	X		X	X	X		X	X	X		N		
Maximum current at maximum temperature during emergency operation of line – ambient temperature 5^{o}C(A)	X	X		X	X	X		X	X			N		
Maximum current at maximum temperature during emergency operation of line – ambient temperature 15^{o}C(A)	X	X		X	X			X	X	X		N		
Maximum current at maximum temperature during emergency operation of line – ambient temperature 25^{o}C(A)	X	X		X	X			X	X	X		N		
Maximum period of time emergency operation can be sustained (hrs)	X	X		X	X			X	X	X		N		

Technology Profile	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna

[7] Planners do calculations
[8] Planners do calculations
[9] Planners do calculations

Number of years available commercially (yrs)		N[10]	X	X	X	X		X		X		N		
Longest period of service in a real transmission system (yrs)		X	X	X	X	X		X		X		N		
Longest period of service in clients transmission system (yrs)		X	X	X	X	X		X		X		N		
Expected asset life of the system (yrs)		X	X	X	X	X		X	X	X		N		
Expected completion time for scope of works (days)		X	X	X	X	X		X	X	X		N		
Expected outage time of the circuit to complete the scope of works (days)	X	X	X	X	X			X	X	X		N		
Expected routine maintenance period (yrs)	X	X	X	X	X			X	X	X		N		
Expected completion time for routine maintenance (days)	X	X	X	X	X			X	X	X		N		
Expected outage time of the circuit for routine maintenance (days)	X	X	X	X	X			X	X	X		N		
Revised maximum noise level (in db's)			X		X			X	X			N		
Revised EMF level (V/m over freq range in Hz)		X	X		X			X				N		
Impact to maintenance method statements (as applicable)		X	X		X			X				N		
List of component parts of the line construction that can be effected by introduction of new technology	X		X		X			X				N		

Permits/easements/Planning Permission	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Modifications and specification to support structures (as applicable)								X				N		

[10] Submission stated question not understood

Permit/Easement/Planning Permission requirements (as applicable)				X				X	X	X		N	X	
Estimated lead time (in mths) to obtain Permit/Easement/Planning Permission (as applicable)	X			X			X	X	X	X		N	X	
Expected completion time for scope of works (days)	X	X		X			X	X	X	X		N	X	
Expected outage time of the circuit to complete the scope of works (days)	X	X		X				X	X	X		N		

Questions to be answered by Designer High Temperature Low Sag Conductors

Technology Characteristics	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Resistance (R) per km (in ohms)	X	X	X		X	X		X	X	X		N		X
Reactance (X) per km (in mH)	X	X	X [11]	X	X	X		X	X	X		N		
Susceptance (B) per km	X	X	X [12]	X	X	X		X	X	X		N		
Maximum operating temperature (^{o}C)	X	X	X	X	X	X		X	X	X		N	X	X
Maximum current at maximum temperature during emergency operation of line – ambient temperature 5^{o}C(A)	X	X	X	X	X	X		X	X			N		
Maximum current at maximum temperature during emergency operation of line – ambient temperature 15^{o}C(A)	X	X	X		X			X	X	X		N		
Maximum current at maximum temperature during emergency operation of line – ambient temperature 25^{o}C(A)	X	X	X		X			X	X	X		N		X
Maximum period of time emergency operation can be sustained (hrs)	X	X	X		X			X	X	X		N		X
Thermal parameters of conductors			X											

All answers in bold font are new questions added as part of the survey by respective companies

[11] Planners do calculations
[12] Planners do calculations

Technology Profile	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Conductor type	X	X	X		X		X		X	X		N	X	X
Number of years available commercially (yrs)		N	X		X	X		X		X		N		
Longest period of service in a real transmission system (yrs)		X	X	X	X	X		X		X		N		X
Longest period of service in clients transmission system (yrs)		X	X	X	X	X		X		X		N		
Expected asset life of the system (yrs)		X	X	X	X	X		X	X	X		N		X
Expected completion time for scope of works (days)		X	X	X	X	X		X	X	X		N		
Expected outage time of the circuit to complete the scope of works (days)	X	X	X		X			X	X	X		N		X
Expected routine maintenance period (yrs)	X	X	X		X			X	X	X		N		
Expected completion time for routine maintenance (days)	X	X	X		X			X	X	X		N		
Expected outage time of the circuit for routine maintenance (days)	X	X	X		X			X	X	X		N		
Revised maximum noise level (in db’s)			X		X			X				N		
Revised EMF level (V/m over freq range in Hz)		X	X		X			X				N		X
Impact to maintenance method statements (as applicable)		X	X		X							N		
List of component parts of the line construction that can be effected by introduction of new technology	X		X		X			X				N		X

Permits/easements/Planning Permission	Argentina - Distrocuyo S.A.	Australia – company 1	Australia – TransGrid - company 2	Australia – company 3	Belgium - Elia	Germany – Vattenfall Europe Transmission	Hungary - Kitöltött	Ireland - EirGrid	South Africa – Eskom 2 RS	South Africa – Eskom	United Kingdom	United States - SERC	United States - Ameren	Italy - Terna
Modifications and specification to support structures (as applicable)								X				N		X
Permit/Easement/Planning Permission requirements (as applicable)				X				X	X	X		N		X
Estimated lead time (in mths) to obtain Permit/Easement/Planning Permission (as applicable)	X			X			X	X	X	X		N		X
Expected completion time for scope of works (days)	X	X		X			X	X	X	X		N	X	X
Expected outage time of the circuit to complete the scope of works (days)	X	X		X				X	X	X		N		X

APPENDIX 2 – An example of the strategy process resulting in an overall restructuring plan: the Danish case.

Denmark has more or less adopted a system development strategy as described in Section 6 of this Brochure. Three major drivers made this strategy necessary:

- Political aim of 50% electricity consumption covered from wind turbines by 2025
- Political aim of making an efficient market across borders
- Lack of political acceptance of overhead lines as future solutions

The political aims could only be achieved by a combination of development of system control and increasing of transmission capacity across the country and the borders. But this generated conflicts with the lack of willingness to accept overhead lines, so the political interference was triggered 2007 by introducing a new 400 kV overhead line meant for connecting one existing and 3-4 future coming offshore wind farms in the western part of Denmark.

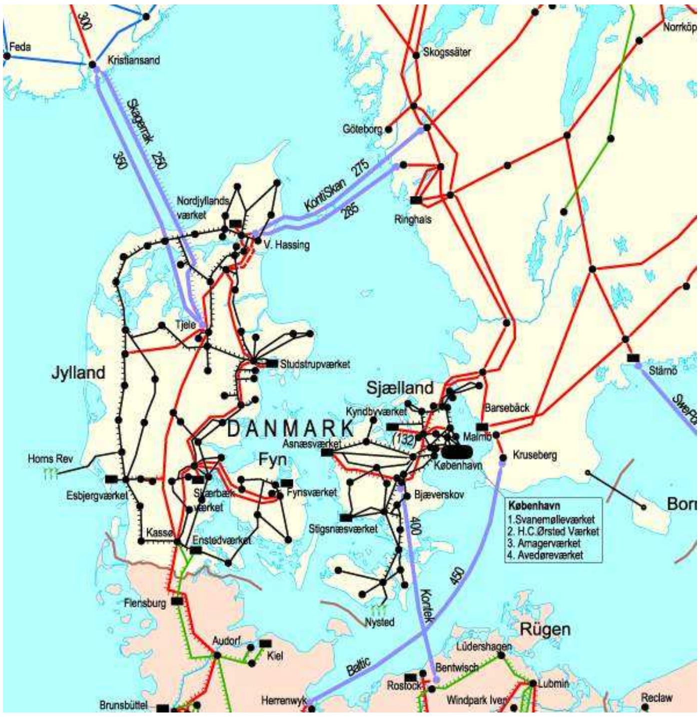


__Figure 26:__ The Danish power grid 132-400 kV including HVDC links to neighbouring countries. This grid consist of approx. 1000 km of 400 kV overhead lines, 70 km of 400 kV PEX Cables, 500 km HVDC cables/overhead lines and approximately 3000 km of 132-150 kV overhead lines.

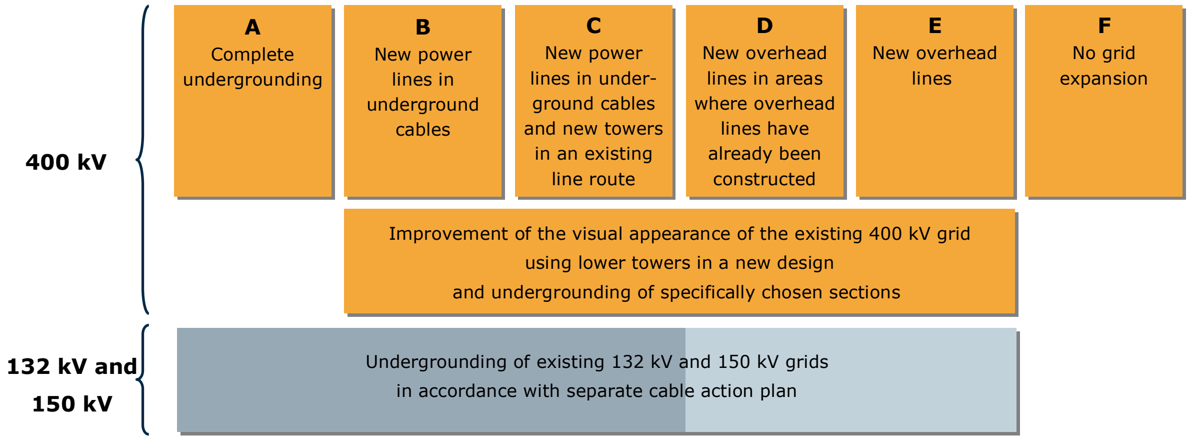
A committee was set up by the Danish Minister for Transport and Energy, in the summer of 2007 to prepare a technical report on the future expansion and undergrounding of the Danish electricity grid.

On 2 April 2008, the report [27] was presented to the Danish Minister for Climate and Environment, and to the political parties behind the energy agreement. It was aimed at forming the basis of political discussions and decisions on electricity grid expansion. The report outlined the environmental and landscape consequences of various expansion principles as well as the consequences for the security of supply, the functioning of the electricity market and socioeconomics.

The purpose of the report was also to ensure that politicians and the general public were made aware of the consequences of various expansion strategies, enabling the politicians to make decisions on the future expansion on a qualified basis. The report came to the main conclusions that:

- Electricity grid expansion should take place by means of controlled, coherent and long-term development, maintaining the security of supply and supporting the functioning of the electricity market in the best possible manner.
- Expansion should take place with due consideration to the continued technological development, the environment, including landscape considerations, and the socioeconomic framework.

The report presented six different principles for expanding and undergrounding the overall electricity grid. Two of these principles were considered to be inappropriate.

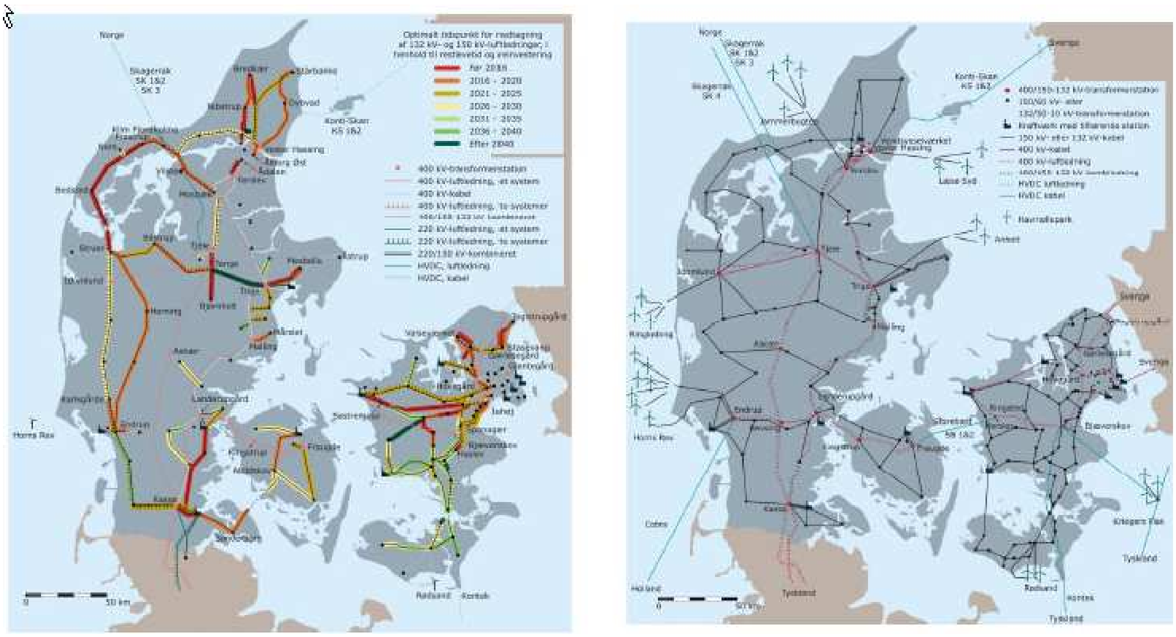


Political settlement on future guidelines

On 4 November 2008, a political decision was made on principle C with specified acceptance of upgrading/rebuilding three overhead line projects in or nearby existing routes. It was also decided that these would be the last overhead line projects in Denmark. Afterwards, the guidelines prefer B and the political aim on long term is A. In addition, the political settlement was based on a demand for a plan of undergrounding the 132 kV and 150 kV grid and a plan for the visual appearance of the existing 400 kV grid.

On March 2009, the TSO delivered the two plans in cooperation with environmental authorities and regional grid owners. On this background, the politicians decided to cable all of the 132-150 kV grid within 20 years (cost: approx. 2 billion Euros), and pointed out six places in Denmark for visual improvement of the 400 kV grid. (cost: approx 0,2 billion Euros) [28], [29]. A confidential cooperation between regional environmental authorities and the TSO played a key role in prioritising these localities.

The quickly specified plan for undergrounding the existing 132 and 150 kV grid allowed the design of a new grid structure, based on future demands rather than historical demands (see Figure 27). The plan for visual improvement, which concerned six localities in Denmark, involved solutions available for each place, all to be implemented within 5-6 years.



2009 **2029**

Figure 27 - Plan for undergrounding the existing 132 and 150 kV grid in Denmark