Invited Paper

Overhead line solutions for a changing Industry

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Synopsis

The challenges facing the Electricity Supply Industry are changing rapidly, utility owners are no longer engineers nor, in some cases, primarily in the electricity distribution business. Engineering skills are depleted due to re-engineering and "right sizing". Customers require an ever increasing level of reliability and weather conditions appear to be altering, increasing the chances of wide spread storms. In addition to this, environmental pressures forbid new construction in most cases. In order to operate in this environment, it is critical that engineers understand the options available to solve issues and problems relating to power transmission. This paper describes the changing environment as well as developments completed and underway in SC B2, "Overhead Lines", which can assist the engineer to meet these challenges.

Introduction

Since the late 1980's the Electricity Supply Industry has been undergoing various types of de-regulation. This normally implies the separation of Generation, Transmission and Distribution into independent companies, as well as privatization of utilities.

In addition customers can purchase directly from Generators who use the Transmission and Distribution wires to deliver the product. The route can be commercially determined and paid for in an open market trading environment.

Each of these changes affects the ability of the industry to deliver power as well as affects the loading on the assets, in particular the overhead lines. These changes and the effects on the assets will be dealt with the in proceeding sections.

Effect of changes on overhead lines

The effect of changes in the Industry is experienced in a number of areas:

Business priorities – focus on profit rather than budget management.

Engineering skills – outsourced skills with a reduction of in house skills.

Power flow requirements – the positioning of Independent Power Producers and trading affects power flow patterns on overhead lines.

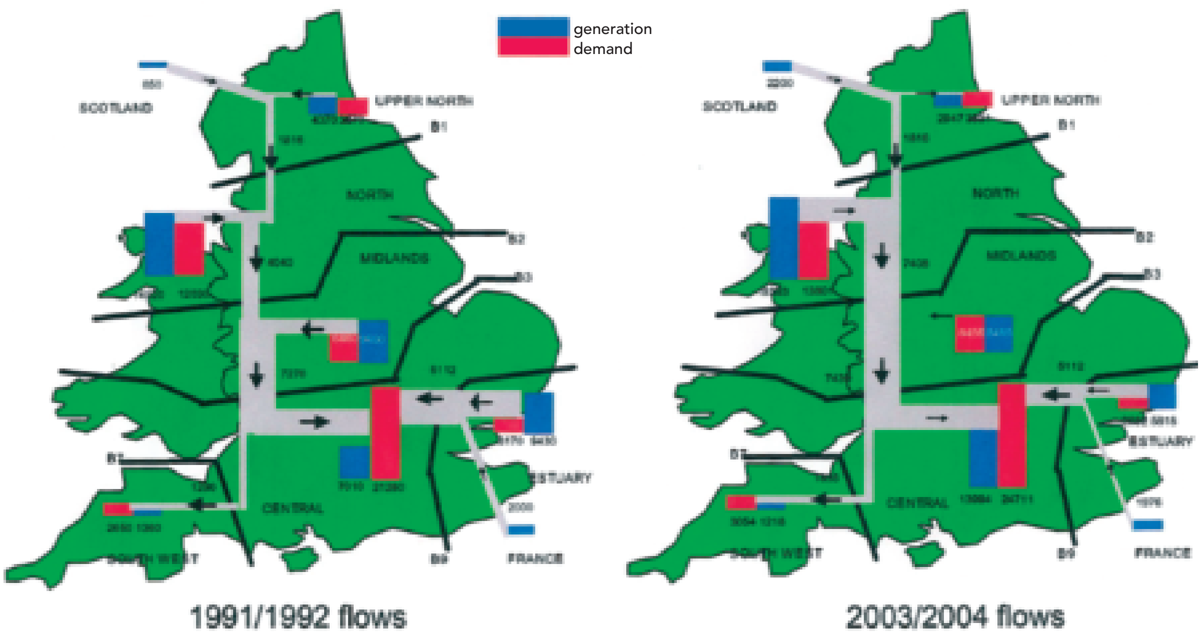
The impact on **overhead lines** is more than that experienced on other assets, the reason being that there is no one Original Equipment Manufacturer (OEM) for the line. The utility is responsible for the design, construction and maintenance of the line, where other devices such as breakers etc..., have experts on hand in the OEM to assist and advise on maintenance and loading practices... For overhead lines, this is not the case, the utility needs to rely on experts in the field to provide this service.

– The effect of trading and IPP's on lines is that the line loading is increased in ways never before envisaged. Lines built as radial lines with light conductors are required to carry heavy loads in a meshed network. This is shown in the Figure 1 where the power flow changed from East to West to North to South.

– The advent of storms extending over large areas as experienced in Canada and France in recent years has led to a re evaluation of the design loads applied to lines.

– The Environmental constraints and permissions required has resulted in permission taking from 4 years (developing countries) to 20 years (Europe). In addition legal costs can often prove to be the single largest cost component of the project.

Fig. 1: Changes in Power flows in the UK as a result of deregulation (Cigre Colloquium Scotland 2003)



– The maintenance is being further optimized thus requiring assets to operate for longer than previously between maintenance is carried out.

– The ability to strengthen the existing network or to construct new lines is limited due to the required return on assets as well as the normally lengthy and costly environmental permission process.

– Trading implies that the cost of constraints to power flow is prohibitive.

These impacts are not the only ones to be taken into account:

Possible solutions

Transmission line engineers need to understand the nature of the problem facing them as well as where to obtain information. This applies to consultants and utility engineers.

In this regard SC B2 carried out a work relating to mechanical aspects of overhead line conductors [1]. The resulting brochure covers the work of the past four decades in this field and allows the reader to rapidly assess the progress in this field as well as the references for the documents. ●●●

Increasing power transfer

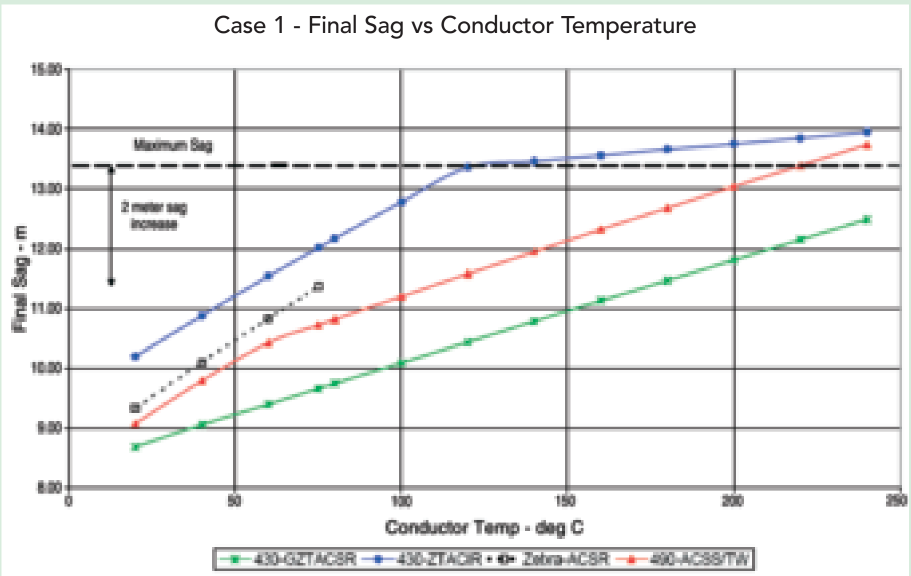
Due to the trading and inability to construct new lines, it is imperative that the utility engineer understands the various steps required to increase the power transfer of overhead lines. SC B2 spent the last 14 years studying various aspects of this topic. The first task was to determine equations whereby the temperature of the conductor could be determined in the steady state [2]. This enabled more accurate determination of the steady state thermal rating of conductors to be realized. This information could be used by network planners and designers in determining optimum stages in which to increase the thermal rating of lines.

The evaluation of conductor temperature was extended to include the dynamic state [3] (used in real time monitoring and probabilistic determination of conductor current rating) as well as the adiabatic state [4] (for determining the conductor temperature under fault conditions).

The thermal rating of transmission lines is a function of the position of the conductor in space (clearance above ground) and is therefore a function of the safety to the public as well as the integrity of the conductor. The safety of the public is also a function of the presence of vehicles or activity in the vicinity of the line. Using these factors together, as well as voltage surges on the line and the load on the line, it is possible to determine the probability of an unsafe condition arising. Keeping this probability constant, it is possible to determine the rating of the line for different load profiles or traffic patterns. This enabled designers to increase the thermal rating of lines beyond that which was previously possible. This was described in [5] and [6].

The study continued including the Real time monitoring of the transmission line thermal rating. This allows for the system operators to utilize the thermal rating of the line to the maximum whilst ensuring the risk of exceeding the templating or design temperature is minimized. There are many different methods of Real time monitoring, these were covered in [7].

It was found that the changing environment also required that new or more appropriate conductors



Graph. 1: Sag Variation with Temperature for Original Zebra ACSR and ACSS/TW, TACIR, and GZTACSR Replacement Conductors [8]

should be chosen. These conductors had to ensure that the line power transfer capacity could be increased without the towers or foundations having to be altered. A brochure was prepared [8] which described the different conductor technologies as well as the application of these technologies regarding the uprating of lines. This was covered in various case studies. One of the examples is shown in Graph. 1.

pared to the ACSR conductors but less than the other options. The graph also indicates that each conductor needs to be chosen on the particular case. Different conductors will suit different sags and temperature requirements.

Due to the many types of uprating that can be used, a paper [9] was prepared and published in 2004. This included a table of the uprating methods discussed.

Table 1: Table showing the comparison between the uprating methods

Method	How to use	When best to use	Cost
Deterministic	Increase height above ground to increase templating temperature.	Templating temperatures below 80°C.	Medium
Probabilistic	• Increase templating temperature. • Make use of load profiles. • Make use of local weather data. • Assess and decide on appropriate risk levels.	• Templating temperatures below 80°C. • Peaky load profiles.	Low to Medium
Real time monitoring	Install real time monitoring systems.	• Any templating temperature but more effective at high temperatures. • In networks where trading of power is undertaken.	Medium – low (Less than re-tensioning)
Re-conductoring	Replace existing conductor with new conductor (preferably, without having to increase tower height or strengthen towers).	• When high level of up rating is required. • Short lines. • Any templating temperature but more effective with higher temperatures.	High

The Graph 1 indicates the present capability of the line (400mm² A1/S1 54/7 "Zebra") shown by the dotted line. Assuming that the line can allow for a 2m increase to 13,5m (case 1) the temperature at which the conductor can operate and hence increase the power transfer is shown for different types of conductors. The green line indicates the most efficient in this case which is the gapped zirconium alloy high temperature aluminium alloy conductor steel reinforced (GZTACSR). However, a more cost effective conductor is likely to be the aluminium conductor steel supported trapezoidal wire (ACSSTW) which is slightly more costly com-

The Table 1 shows the different methods and the relative cost that can be used in uprating of lines.

Lowering impedance of overhead lines

Another method to increase the power transfer of lines is to increase the Surge Impedance Loading or lower the overall impedance of the line. This can be achieved by varying the conductor bundle configuration.

In this regard, an ELECTRA article was prepared in 2004 (to be published in 2005) [10]. This indicated the different bundle configurations possible as well as the benefits. ●●●

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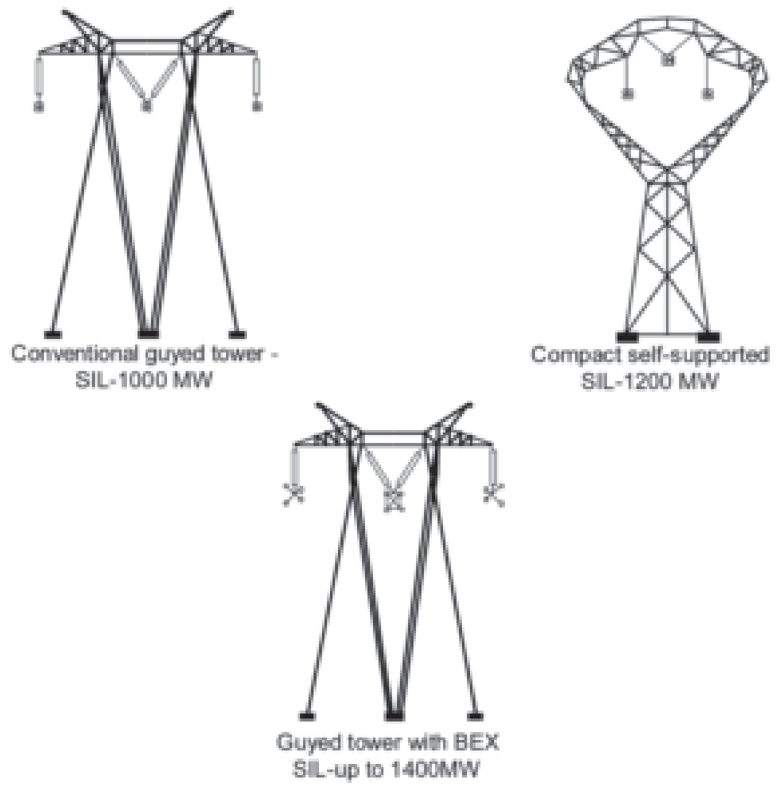
Fig. 2: Expanded bundle on right hand phase under construction [10]

The Figure 2 gives an indication of the existing and HSIL bundles. This configuration was used in Brazil.

The comparison of the different types of towers to increase the transfer capacity is shown in figure 3.

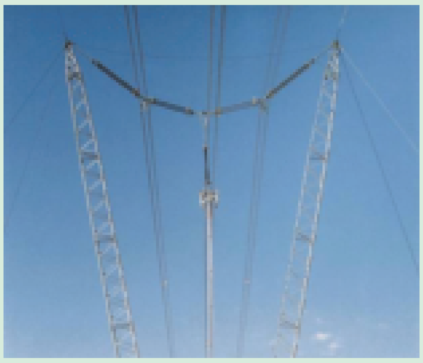
The below work indicates the ability to tailor make the line design to suit the needs of the network planners. This enables the overall cost of the networks to be reduced as it reduces the need for series compensation as well as reduces system losses.

Fig. 3: SIL values for different configurations



The compact self supported tower can be replaced by a cross rope compact design as shown in Figure 4. This allows for compaction with a lower cost tower.

Fig. 4: Compact cross rope configuration (note centre phase is slack in this case due to tap off (not shown))

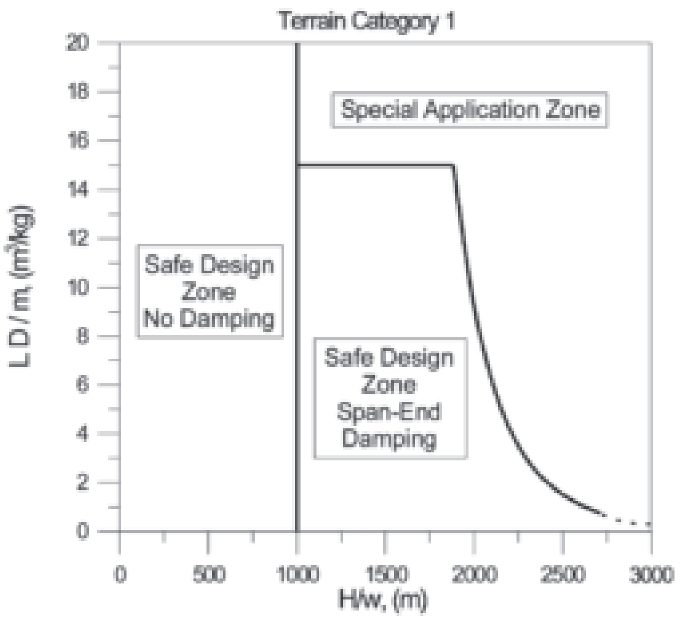


Retensioning – vibration considerations

The increase of thermal rating can be achieved by increasing the height of the conductor above the ground. This can be done by increasing the conductor tension. The drawback is that this could increase the vibration on the conductor and hence accelerate the deterioration of the conductor.

The determination of the safe tension for conductors is not a simple matter and has taken the best part of 4 decades to resolve. This is due to the complex make of the conductors and the determination of the energy input from the wind and the self damping characteristics of the conductor. The parameters that determine the vibration as well as the limits to set the parameters were determined theoretically and experimentally involving many experts over a number of years. These results have been published in a 2 part document with single conductor undamped [11] and damped [12]. Graphs have been produced indicating the safe tension for different terrains. An example of the graphs for flat terrain is reproduced here. The tension parameter H/w is the ratio of horizontal tension H in the span to conductor weight w per unit length, and LD/m, the ratio of actual span length times conductor diameter D to conductor mass •••

Graph. 2: Tension limitations for damped conductors



Terrain #1 : Open, flat, no trees, no obstruction, with snow cover, or near/across large bodies of water or flat desert.

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m per unit length. The tension H refers to initial horizontal tension before any significant wind and ice loading and before creep, at the average temperature of the coldest month on the site of the line. [12].

More recent results indicate that the bundled conductors can be tensioned at higher H/w ratios than single conductors. As most transmission lines consist of bundled conductors this implies that it will be possible to increase the tension further thereby increasing the thermal rating of the line.

Foundations

The uprating of lines affects all the aspects of transmission lines including foundations. For this reason a document covering the refurbishment and uprating of foundations was produced [14]. The document describes the best methods to review the condition and upgrading of existing foundations. It also describes the deterioration of foundations and the reasons for the deterioration such as damage by frost. Testing methods are also described.

Environmental requirements

The limitations of the environmental regulations dictate that certain work has to be completed before lines are constructed or upgraded or modified in any way. There is a maze of information that is required to be complied with. One of the most onerous of these is the compliance to ISO 14040 Environmental Management Life Cycle Assessment (LCA) series. The brochure produced explains these requirements and it reports on Scandinavian LCA studies and compares a number of LCA software packages. It presents an overview of the interaction of overhead line components with the environment. It contains the results of various LCA studies on overhead line components and overhead lines carried out by Working Group members which give a good exposition of LCA methodology. All of this is drawn together in conclusion and recommendations set in the broader context of LCA as one of many tools to assess and reduce the impact or interaction of overhead lines and the environment. The document therefore assists utilities in complying to the LCA requirements without having to go to extensive cost of first finding out and understanding the requirements as well as perform the LCA for a particular line.

The document is a follow up to another document [13] detailing the work of SC B2.14 dealing with standard practices relating to obtaining environmental permission for various activities relating to overhead lines.

Some other developments underway

In addition to the above developments, SC B2 is continually reviewing the changing environment and developing solutions to problems faced by utilities, manufacturers and other customer groups. Developments cover all the major components of lines.

Insulators: Work covers stress corrosion, effects of snow and ice, evaluation of old insulators and guides for naturally polluted research stations. In addition the research relating to uprating is continuing with effects on insulators of vibrations on hardware, high temperature operation of conductors and use of corona rings for composite insulators.

Overall design: Work covers research into mid span clearances (to enable more effective compaction), effect of large area storms (to determine lessons learnt) and comparison of probabilistic design methods (to use local weather conditions to maximize the mechanical loading on lines).

Foundations: The work includes the investigation and publication of case studies in refurbishment and upgrading. In addition probabilistic design of foundations is being finalized.

Towers: Work includes the assessment of variation of tower strengths, towers for new lines and new testing methods.

Electrical aspects: Work deals with the determination of AC resistance at high current densities (above 1A/mm^2) and the determination of sag tension relationships. The determination of weather parameters for determination of current rating is also being developed to guide utilities in the best practice relating to determination of current ratings and to prevent the practice in increasing wind speed without the determination of increased risk.

Mechanical Aspects: The work under consideration includes the fatigue endurance capability of the conductor/clamp system. This information is vital to uprating and refurbishment activities.

Management of lines: This work includes the development of management methods relating to the emergency restoration of lines. This includes the management of spares and the organizational requirements of the utility relating to effective management of emergency systems.

Weather parameters: This work includes the determination of weather parameters to use in the calculation of loads on the towers, conductors and foundation system. This includes high intensity winds as well as ice loading events.

Conclusion

The changing environment implies that CIGRE must continually be aware of needs of customers. This, in turn, means that the work of the Study committee must adapt to meet these needs. In the case of SC B2, as described here, my feeling is that the work of the SC has met and will continue to strive to meet the needs of customers.

The solutions refered to in this "invited paper"paper should allow for utilities to readily find the required solution to the most pressing of issues, that is uprating and refurbishment of lines as well as dealing with environmental issues.

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