NEW TOWER DESIGN FOR IMPROVEMENT OF ENVIRONMENTAL IMPACTS OF MV DISTRIBUTION OVERHEAD LINES.

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SUMMARY

In 1989 The Norwegian Electricity Federation (EnFO) initiated a project with the objective to assess the possibilities of improving the overhead lines impact on the environment. One part of the objective aimed at the integration of overhead lines in the landscape and the other focused on the aesthetic design of overhead lines with emphasis on the towers. For the last part of the project financial support was given by Norwegian power utilities, EnFO and the Norwegian Research Council. Professional industrial designers were engaged for the development and design of a new distribution 24 kV tower system. When the design progress was mature, a manufacturer was selected to contribute in the prototype and commercialisation process. The current objective is to construct two separate 24 kV overhead lines in the eastern part of Southern Norway with the new and environmental friendly tower system design within the early summer 1999. The paper gives a detailed description of the new tower system, and explains the design premises and addresses the technical aspects of the new system design.

BACKGROUND

Traditionally the evaluation of alternative solutions for expansion, reinforcements and maintenance within power supply systems has mainly been based on technical and economical optimisation including reliability assessments. During the last couple of decades the attention has gradually changed towards stronger concern about environmental issues including electromagnetic fields. During this period a growing resistance against the overhead lines gradually emerged. In conflict areas the trend is to replace sections of overhead lines by under ground cables and introduce transmission and distribution overhead lines with improved design and low emission of electromagnetic fields.

Up to 1991 the Norwegian authorities (i.e. Norwegian Water Resources and Energy Directorate, NVE) handled many problems related to licensing of hydropower developments. When the hydro power expansion nearly stopped after the introduction of the new Energy Act in 1991, focus turned to the overhead lines now being one of the main areas of conflict for NVE.

DESIGN OBJECTIVE

Around the world, several environmental friendly towers especially designed for certain specific situations or areas have been developed, but often with quite expensive solutions as a result. The objective in the project described in this paper has not only been to develop a system with aesthetic qualities that may fit into different surroundings, but also to restrict the design efforts to comprise MV distribution towers for ordinary projects with emphasis on the overall costs. These costs should be comparable with traditional design or even reduced [1].

The main reason for the focusing on the costs is the new regulatory regime following the Energy Act that has been operative since 1991. A summary of the new regime as it functions today and its estimated further development is described below.

MONOPOLY CONTROL

Efficiency requirements

Today all consumers are free to buy their electrical energy in an open competitive power market from any producer.

The producer is paid for the consumed energy and the power grid owners are paid according a transmission and distribution tariff (point tariff). The transmission and distribution system has been functioning and will continue as a natural monopoly. Due to this fact, the transmission and distribution tariffs are controlled by the authorities (NVE) that have defined a detailed framework for calculating individual maximum transmission and distribution tariffs for the power utilities.

In addition NVE has concluded that it is a substantial potential for increased efficiency in the transmission and distribution sector. Although comparisons between utilities in a country like Norway are extremely difficult to perform, it is obvious that the present efficiency varies from utility to utility, and that the largest potential for improvement is within the least efficient utilities.

Despite the difficulties, NVE has completed a classification project that should define the utilities current efficiency. NVE decided that from 1998 the point tariffs should be reduced in the range of 1,5% to 4,5% annually corresponding to their current efficiency status. The reduced income for transmission of power can only be compensated by improved efficiency within the utilities. After a test period of 4 years (1998-2001), NVE will evaluate the experiences and decide whether amendments or changes are necessary.

Compensation for customer interruption

A possibility for the utilities to compensate for diminishing income is to reduce their costs. This may be achieved by slowing down investments and maintenance in the transmission and distribution system. With time, however, this will affect the customer by reduced reliability caused by an increasing number of interruptions. To avoid the last scenario NVE decided that the customers from 1999 should have compensation for interruption of the supplied energy.

The utilities gave critical comments to the discussion documents that was circulated before the final approval of the new regulation, and that made NVE to postpone the requirement of compensation with one year. The final regulations are not specified yet, but so far NVE has indicated that all interruptions affecting the consumers for more than 3 minutes shall be compensated. The price of the customer interruption is estimated to 16 NOK/kWh (16 NOK ~ 1,9 Euro). This price approximately equals the average price for the socio-economic interruption costs for different categories of customers in Norway.

Compensation should even be given for planned interruptions when the customers are informed in advance of interruptions due to maintenance and repair. In this case the compensation should be 70% of the unplanned interruption cost. This is why a primary goal for the Norwegian utilities is enhanced efficiency without sacrificing the transmission and distribution reliability.

DESIGN CRITERIA

An overhead line is exposed to both electrical and mechanical stresses. The electrical stresses is handled by proper insulation co-ordination planning based on the knowledge of the frequency and amplitude occurrence of lightning, switching and temporary overvoltages and the presence of pollution due to sea salt and industrial emissions. The mechanical stresses are primarily related to wind forces and ice loads or a combination of the two. Both the electrical and the mechanical design have to meet the requirements of existing National Standards. The tower design is influenced by these Standards and other important factors like for example ergonomics for linesmen, the use of live line working and the use of new technology of XLPE covered lines.

DEVELOPEMENT OF PROTOTYPE

Among the Norwegian utilities that supported the project financially, were the utilities of Trøgstad and Østfold Energi Nett in the eastern part of Southern Norway. Early 1998 they decided to take active part in the prototype development and both build a 24 kV distribution line with the new design for testing in their own supply area.

Tower material

The design work has so far been focused on a 24 kV tower design with wood as tower material. For economical and environmental reasons wood poles are most frequently used in Norway. Wood poles are a cheap national resource and they are normally impregnated with creosote (or salt) ensuring a long economical lifetime. Both impregnation methods and the use of impregnated wood poles follow Norwegian National Regulations. Wood is a natural material for integration in the landscape and for environmental reasons the authorities (NVE) recommend use of wood poles for voltages up to 132 kV. A 300 kV overhead line with glued laminar wood towers has also recently been built by the Norwegian Power Grid Company.

XLPE - covered conductors

Both utilities wanted to utilise the concept with XLPE covered conductors[2]. This system consists of alloyed aluminium conductors with a thin insulation layer of cross linked polyethylene(XLPE). This insulation is sufficient to avoid earth faults or a short circuit for a considerable time when a tree falls on the lines or the phases clashes. Thus the phase-to-phase distance may be reduced considerably compared with the normal 1,5 m of conventional 24 kV overhead lines. In Norway the XLPE covered lines were introduced in 1985 and the clearance between the phases was reduced to 0,5m. The concept has many advantages. A thorough investigation of the fault statistics indicate that the average rate of faults are reduced from 4,5 faults pr 100 km for conventional 24 kV overhead lines to 1,0 faults pr 100 km for overhead lines with XLPE covered conductors. In addition other environmental advantages like improved visual qualities, reduced width of line route and reduced electromagnetic field with a factor of at least 1/3, were also taken into account.

Insulation co-ordination

Due to the insulation co-ordination strategy for handling over-voltages caused by direct lightning strokes to the phase conductors, a triangular design of the top of the tower was chosen as shown in figure 1. A separate shielding earth wire on the top of the tower is not economic and accordingly not used for 24 kV distribution systems in Norway. Thus the phases are exposed to direct lightning strokes.

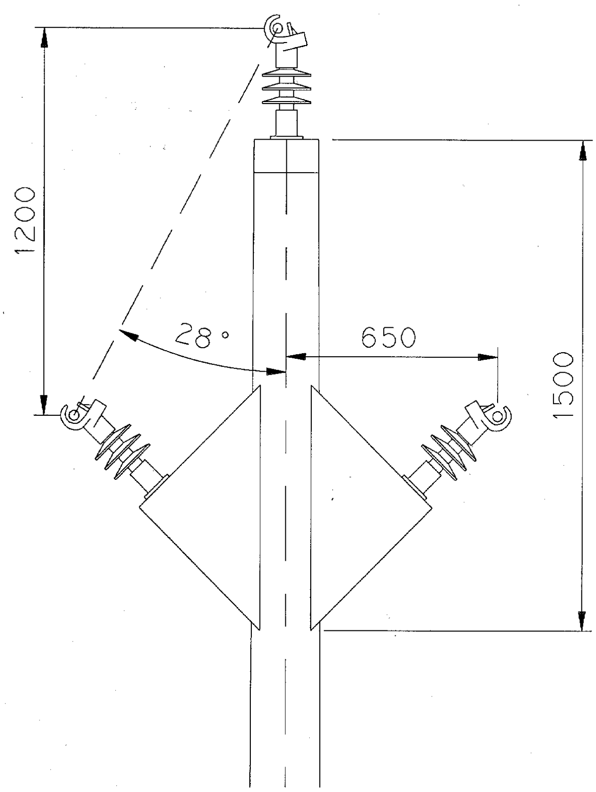

Figure 1. The triangular design of the top of the pole.

Due to the low clearances between phase-to-earth and phase-to-phase at the 24 kV level, a lightning stroke to one phase will normally develop to phase-to-phase and finally three-phase flashovers.

When phase-to-phase flashovers occur, the foot point of the arc is not allowed to move along the line as with bare conductors, because of the XLPE insulating coating on the conductor. The phase-to-phase lightning arc is followed by a short-circuit current with a duration given by the relay time for the closest circuit breaker. Even with momentary relay disconnection, the arcing time, with a high short-circuit current, is so long that the conductor normally will melt at the arcing foot points and fall to the ground. This is a serious and dangerous fault to the public, because the XLPE insulated conductor on the ground will not necessarily cause a phase-to-earth fault and then may remain energised on the ground.

This problem has been solved with rather primitive solutions involving phase-to-phase arcing horns that has to be replaced after some few flashovers due to their degradation. Thorough research involving laboratory tests and comprehensive computer simulations at SINTEF Energy Research [3,4] led to a recommendation for the protection against these stresses. The recommendations propose to use the phase on top as shielding wire, which is possible when a triangular or vertical conductor configuration is used. With these configurations almost all direct lightning strokes will hit the phase on top. This phase is to be protected with a spark gap to earth. The other two phases are protected with phase-to-earth arresters.

When a direct stroke hits the conductor at the top, the closest spark gap will ignite and lead the main part of the lightning charge to the ground. Depending on the product of lightning current and the earth impulse resistance, the phase-to-earth arresters at the two other phases will be activated and keep the voltages within acceptable limits (phase-to-earth and phase-to-phase) to avoid further flashovers. This course of events will contribute to reduce the thermal stresses of the arresters to a reasonable level and prevent damage of the arresters.

Today it is possible to integrate the metal oxide blocks of the arresters into the insulators, but for the first installation in Trøgstad conventional arresters will be used in parallel with the chosen commercial insulators that are shown in figure 1. The lightning intensity in the area and its vegetation are the key factors when deciding the distance between each set of spark gap and arresters. On plain terrain the typical distance is between 100 – 300 m depending on the lightning intensity alone, while the protection may be omitted if neighbouring trees in wooden surroundings shield the line.

Arrangement at the top of the pole

Figure 2 shows a review of the arrangement at the top of the wood pole. The prototype of the "cross bar" for the "wing insulators" as shown if figure 2 is developed in co-operation with a mechanical construction company. It is not decided whether the final solution will be a one piece self-supporting construction or an enclosed steel frame. The prototype applies the last approach. Further investigations are necessary before the final solution is found.

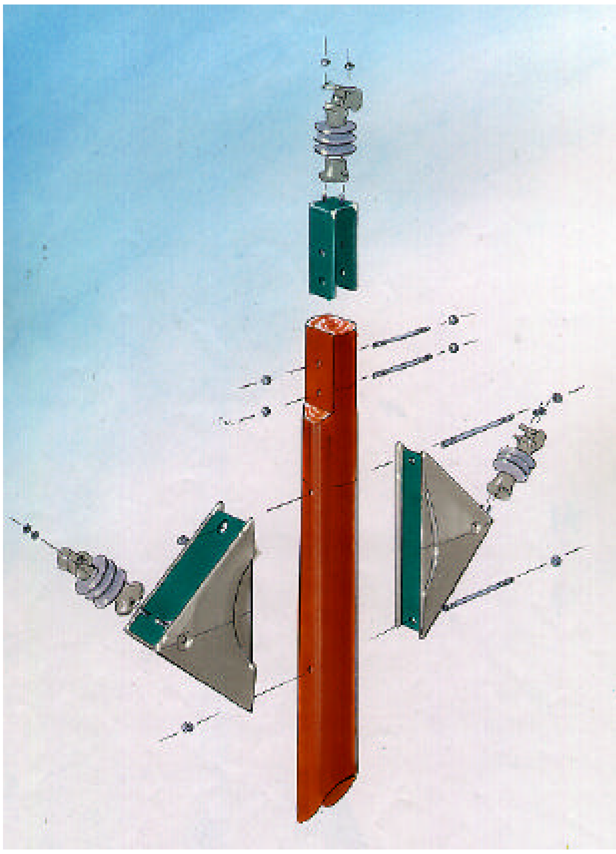

Figure 2. Arrangement at the top of the wood pole.

Live line working

The clearances indicated in figure 1 are results of the investigations on both the minimum approach distances with live line working (specified by IEC 61472) and ergonomic requirements. The new regulations defining the economic compensation for customer interruptions make live line working increasingly attractive. The staff at Trøgstad has decided to apply live line working and install both new equipment and equipment replaced during maintenance with components well adapted to this technique when it is economically advantageous. The utility plan to utilise live line working techniques including the bare hand method and offer the necessary education and training to their staff. Today the hot stick method is widely applied for internal and external projects.

Ergonomics

The ergonomic requirements depend on both the conditions when applying live line working, and the working requirements when the line is built and normal de-energised maintenance and repair is performed. It is important to protect the crew against unhealthy working positions and dangerous stresses especially when working at the top of a tower. Improvement of the efficiency at work is also important because the working cost is the dominating part of the overall cost of an overhead line.

The efficiency goals may be met by reducing the number of transport operations from ground to the top of the tower and by improving the availability of working operations at the top. This is achieved by optimising the distance from the centre of the tower to the outer phases as in this case by choosing a triangular XLPE covered conductor configuration instead of a horizontal suspension for conventional bare conductors.

The number of working operations could also be reduced by integrating different functions into one component and at the same time try to reduce weight and size to a minimum. One step in this direction is the development of a combined metal oxide arrester and insulator. In general inspection, maintenance and repair should be as simple as possible and the staff should feel safe when performing their work at the top of the tower.

Tower design family

The towers have different electrical and mechanical design according to their tasks:

- Anchor towers are primarily designed to withstand a broken phase line or ground conductor on one side of the tower at maximum ice load in order to preventing cascading of broken towers.
- Tangent towers are primarily designed to carry the weight of cross arms and lines with wind and ice loads.
- Angular towers are primarily designed to handle the specific forces introduced by an angle on the overhead line.
- Dead end towers are primarily designed to handle the forces at the end of an overhead line.

Due to the effect of different mechanical forces and of choice of different types of insulators (post, suspension, tension, etc.), these towers will have a different design. It is however important that the individual design is harmonised in such a way that they are identified to belong to the same "design family". This will improve the overall impression of the overhead line and reduce the disturbance on the environment. As a part of a complete unity each tower is designed to fit into the system. A strong visual connection between the different towers and well-formed shapes are important aesthetical factors improving the environmental impacts of overhead lines.

The figures 3-5 show the typical types of tower with the new design with XLPE covered conductors. Figure 6 shows an artistic view of the system.

Figure 3. Tangency tower

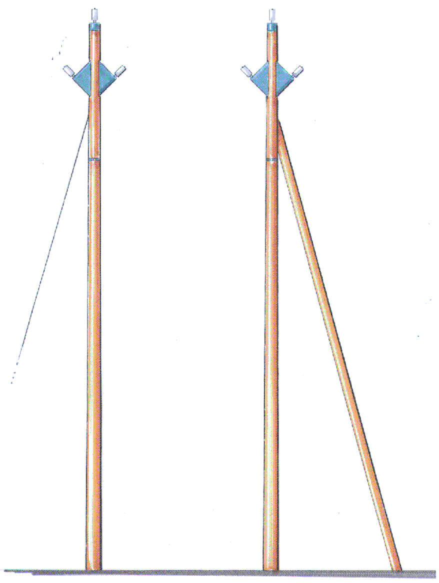

Figure 4. Angular towers

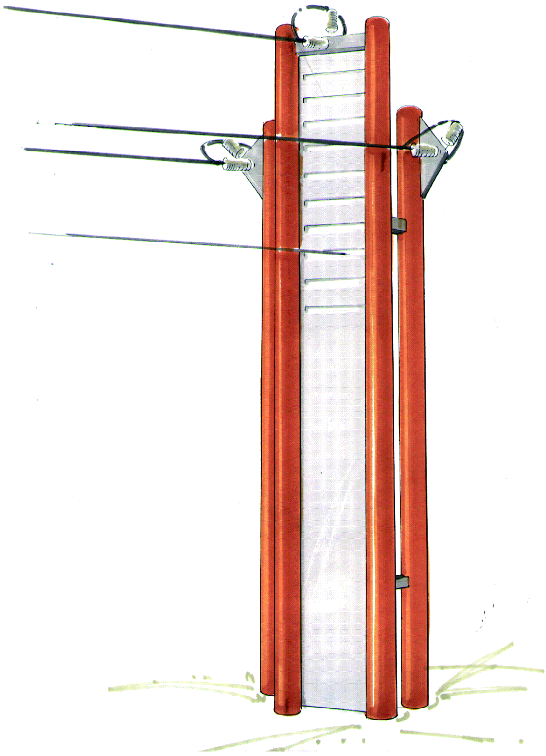

Figure 5. Dead end tower

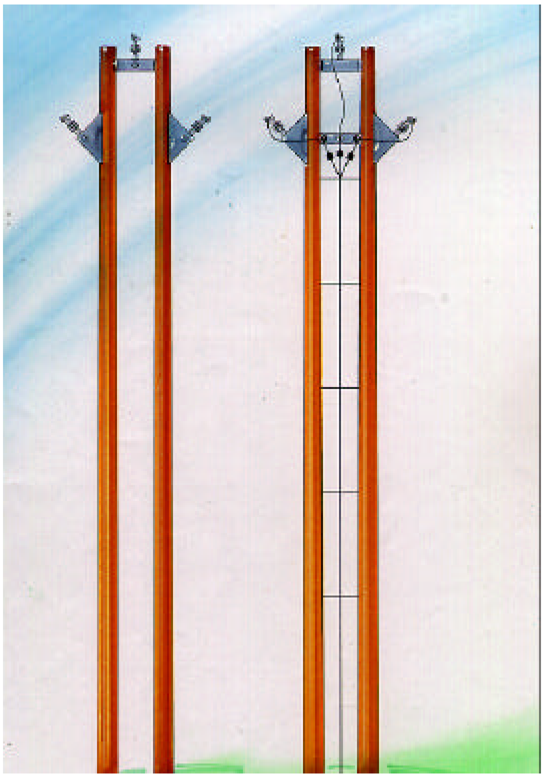

Figure 6. Tangency tower and a tower with cable termination

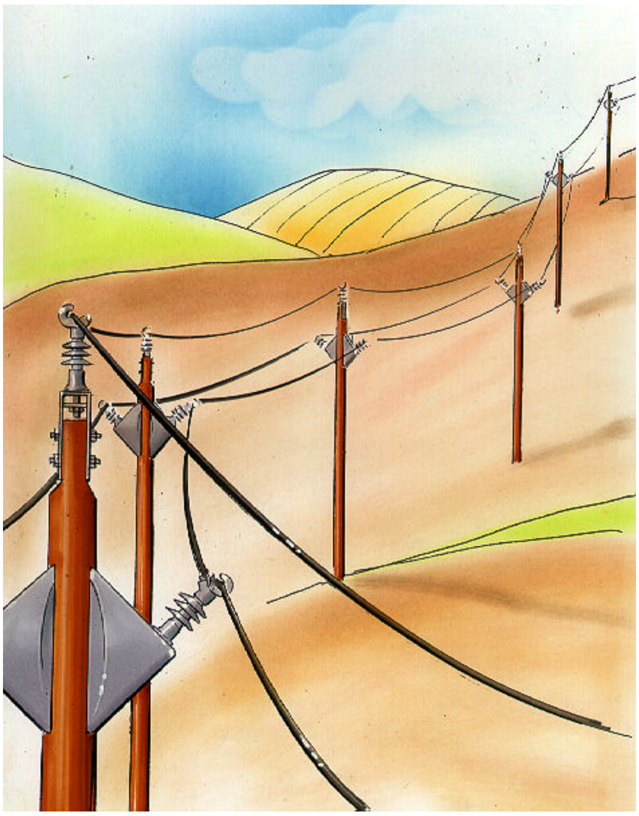

Figure 7. An artistic view of the system

Aesthetic design criteria

The basic aesthetic design criteria for the tower system design has been to ensure the possibility of a proper integration of the tower system into different types of landscape, and that this is valid where the overhead line finally is located. Through the design work the following factors that was found to be important are summarised:

- All different towers must possess a clear vertical orientation
- The different towers should be symmetrical
- All components should be well organised
- The different towers should possess equal shape and appearance
- The towers should individually and as a group be well proportioned
- The surfaces and colours of the system should be well harmonised

Applied standards and further work

The line at Trøgstad is electrically and mechanically designed according the requirements defined in NEK 391 (1989) "Norwegian electromechanical standard of insulation of overhead lines" and NEK 609 (1996) "Calculation of mechanical strength of overhead lines".

When the process with the prototype project at Trøgstad is finished, Østfold Energi Nett will commence their own process and build a similar overhead line based on the same tower design. This line will go along a road with quite heavy traffic and be easily visible to the public. It is then of great interest to gather information and evaluate the public opinion on the new tower design.

CONCLUSIONS

The co-operation between industrial designers, utilities, manufacturers and research institutions has in the end been fruitful, but scepticism some times hampered the progress. The progression with ideas, tower concepts and the evaluation of the necessary premises for the project has generally been very satisfactory and the process has been very interesting and useful for the involved parts. The manufacturers have in general been positive and interested, but they have so far had limited financial resources for contribution to the project. The last part with the prototype evaluation with Trøgstad and Østfold Energi Nett has been characterised by enthusiastic utility staff at all levels. This has been the key factor that has ensured a progress in accordance with the optimistic plans that was made for this part of the project.

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