1 SUMMARY

Lines for transmission and distribution network play a vital role for the reliability of the energy supply. The today’s needs consist of cost reduction for energy transport simultaneously with increased transmission capacity of existing lines, installation of conductors in spare systems, reconfiguration of conductors and installation of high-capacity lines on the routes of old lines, and new lines as well. This must be balanced with an increased insulation reliability and environmental aspects. The paper discusses solutions, which have been applied to transmission and distribution levels during the last years and have gained a raising interest among international utilities.

2 INTRODUCTION

Composite materials made of resins reinforced with glass or carbon play an important role for the substitution of conventional materials especially in cases of required weight reduction or negligible corrosion susceptibility. For electrical applications the principle of “composite insulators” incorporates glass fibre-reinforced resin cores meanwhile carbon fibres are suitable for components replacing steel structures.

Composite insulators are today in service for approximately 30 years and a comprehensive knowledge for insulator design and about selection criteria for reliable materials could be collected. With the introduced standards such as IEC 61109 for polymeric line insulators, IEC 61462 for polymeric hollow core insulators as well as IEC 61952 for polymeric line post insulators, there exist a technical basis for the definition of minimum requirements under consideration of in-situ stresses. Other standards such as IEC 62217 will harmonise the above mentioned standards and the IEC 60815 is under reconstruction to provide guidance for composite insulators as well. The paper shows the application of compact structures with composite insulators for 420kV arrangements, analogous construction principles mostly without bracing longrod insulator are applied to distribution levels. The enhanced reliability of compact solutions with polymeric posts is documented by the safe failure mode. The positive effect of the post versus pin construction superimposed by the effect of the hydrophobicity in the case of polymeric posts is discussed.

Steel pole structures in lines can suffer from corrosion damage after years in service depending on the environmental conditions after a service time well below the planned life time of the line. This requires expensive maintenance measures. Lattice steel pylons for electrical power transmission typically need to be treated with expensive protection coatings after 15–20 years, leading to considerable costs and pollution. Reinforced concrete elements – such as spun concrete pylons – are recognized to be corrosion-resistant. The corrosion protection can only be guaranteed, if the steel reinforcement is embedded in the concrete with a minimum protecting layer thickness of 30 mm to the atmosphere, which makes the poles quite heavy. However, if carbon-fibre reinforced plastic (CFRP) is used instead of steel, such protecting layer (cover) is not required. CFRP does not corrode and, when used in conjunction with high-strength concrete, allows a marked reduction in weight. In the paper the development and application state of a corresponding technique is discussed.

3 APPLICATIONS

3.1 High Voltage Compact Arrangements

Due to increased energy demand, the voltage up-grade of existing transmission lines has become a popular way for utilities to react on the situation. The increase of voltage is...
related to wider Right of Way (ROW) for conventional route designs, which causes problems in densely populated areas. As reported in /1/, a 125kV-line was up-graded to 420 kV in Switzerland operated by the Swiss utility Energie Ouest Suisse (EOS) nearby Lausanne. The solution consisted in the introduction of a compact line design for 3 towers employing horizontal vee insulating crossarms (figure 1). Extensively mechanical tests have been performed to investigate the static and dynamic behaviour of the arrangement for both, porcelain and composite solutions. Finally, the tested performance of the composite solution simultaneously with the known general advantages led to the choice of the composite solution under recognition of the first application for this voltage level. During testing as basis and reference, the static values have been determined to simulate the material limits of the individual components. Afterwards the complete crossarm was tested with simultaneous recording of specific stresses. All the time, the stresses have been in the elastic phase. Considering this result and the safety factor of at least 3.1, the utility became confident into the solution to use polymeric insulators. The post type insulator is made of a hollow core to provide sufficient mechanical resistance against buckling for the compression forces in axial post direction. The internal space of the hollow core has been filled with a permanent-elastic material to prevent condensation and internal partial discharges. The line (figure 2) is energized for approximately 4 years and withstood the heavy storm in December 1999 without any problems as well as pleases the community because of low radio interference disturbance.

For another 420kV project, the solution with solid core post insulators has been designed and comprehensively tested (figure 3). There exist no specific standard for this application, hence the utility defined a complex specification under the consideration of the specific stress factors. The tests consisted of electrical and mechanical procedures and can be summarized as follows:

- dielectric testing (BIL, SIL, RIV/corona, 50Hz wet)
- power arc testing with following mechanical diagnostic
- mechanical testing for light and heavy load cases

The dielectric tests have been passed without particularities. The test part under dry conditions was determined by the hardware design and the striking distance. In the test with simultaneous voltage and moisture stressing, the hydrophobic surface behaviour of the silicone rubber housing provided a significant safety margin in comparison to the specified values, which have been on the basis of conventional glass/porcelain insulators. In the power arc testing with 30kA, the performance of the complete arrangement with arcing horns was proven. The proper design of the horns guided the prolonging arc that the extinction length was achieved before the specified time of 1 second was passed. The following dielectric and mechanical tests showed unambiguously that the arrangement pre-tested with the arc did not suffer from any damage (housing tightness, mechanical strength). The mechanical testing of the light load case showed so high safety margins that the tests for heavy load cases have been applied to the light load arrangement. These additional and very stressing tests have been almost passed the only limitation was due to the test equipment in conjunction with the high but elastic deflexion of the arrangement. The results of this comprehensive test programme enhanced the utility’s confidence into the composite technology and initiated further optimization work for cost savings.

3.2 Cantilever Support Insulators

From 1979 to 1992, the Swiss railway company Bern Loetschberg Simplon (BLS) expanded their 240 km track system to be a double track /2/. Approximately 40 km of the
track length are within a tunnel. This tunnel has been equipped with porcelain insulators since 1913 and is characterized by very severe pollution conditions and required considerable maintenance of the network. The single phase to ground voltage is 15 kV at the railway-typical frequency of 162/3 Hz. The specific requirements for the substitution of the porcelain by polymeric posts have been:

- reduced weight for increased train speed
- high failing load
- maintenance-free insulator

The weight has been reduced by more than factor 2 and the mechanical strength (Maximum Design Cantilever Load) was specified to be 2.5 kN corresponding to the porcelain posts. The Specified Cantilever Load of the polymeric post is 25 kN, which provides a high safety margin, while the diameter of the load-bearing rod had to be selected for a limited deflexion. The request for maintenance-free insulation was a sophisticated challenge at this time – the hydrophobic behaviour of polymeric housing materials was initially known, but the lifetime of this property as well as appropriate artificial tests to evaluate the expected service performance were not available. So the use of Silicone Rubber housing was a visionary decision at this time. Due to the uncertainty about lifetime, the creepage length has been increased in comparison to the porcelain design (1115 mm instead of 700 mm). Using the terminology of IEC 60815, a specific creepage length of 43 mm/kV was designed, because the 27 mm/kV of the porcelain post has not been sufficient and required cleaning at least twice a year. A scientific test programme was launched to investigate the electrical and mechanical performance of the insulators after up to 20 years of service under these conditions. Initial measurements of the pollution layer provided ESDD-values up to 0.6 mg/cm² and NSDD-values up to 17 mg/cm², which gives an indication about the specific pollution containing dirt, brake dust and abraded particles from the catenary commutator. In-service measurements of hydrophobicity have been carried out by using a cable loop with SR-terminations placed as reference source in the tunnel. It shows that the hydrophobicity is still measurable after 20 years, despite the visual appearance that the surface is fully covered by a pollution layer /3/. Today there are more than 4000 post insulators installed in this tunnel (figure 4), they have never been cleaned and have shown neither a mechanical nor electrical failure. Part of the mentioned test programme was the comparing investigation of the cantilever performance after service. The following specimen were investigated:

- porcelain post for 13 years in service
- epoxy post for 2 years in service
- silicone post for 13 years in service

Increasing a cantilever bending force to an insulator in post type application, it will break at a certain level. This is valid for brittle materials such as porcelain or epoxy resin. This was confirmed by the tests, both insulators made of these materials broke at 20 kN (figure 5). The breakage took place above the base end fitting and was associated with a physical separation. The test of the polymeric post, which incorporates a glass-fibre reinforced resin rod, showed the failure at 40 kN. The failure mode was significantly different to the previously tested specimen: There was no physical breakage of the insulator, which indicates that the risk for line drop would be very low. This property was further investigated and could be confirmed by numerous tests /4/. This behaviour led to the introduction of the term “safe-failure-mode” for polymeric posts with glass fibre reinforced resin rod and appropriate design of the end fittings. The following conclusions were deduced from the investigations also under consideration of the test philosophy of IEC 61952:

In the case of an overload, a well-designed post insulator shows a safe failure mode. There is no physical breakage leading to a part separation. The failed insulator can be detected by visual maintenance inspection, due to its over-proportional deflexion.

Despite the over-proportional deflexion, the mechanical (bending) performance of the insulator remains on a certain
levels, which keeps the conductor in place, due to the high
residual strength capability of the post.

Hybrid solutions, incorporating porcelain or epoxy cores
might have an effect for pollution performance, but do not
have a safe failure mode.

3.3 Advantages of polymeric Posts for Covered and
Bare Conductor Systems

Pin/post type insulators are an appropriate way for compact
line designs, which can be in combination with covered
conductor systems. Covered conductor systems (CCS) are
recognized as an important improvement for compact line
arrangements, corrosion problems and against earth faults
induced by broken trees /5/. The application of polymeric
posts provides significant advantages over porcelain pin
and post insulators as follows:

A pin-type insulator (figure 6.1) provides a relatively high
creepage and striking distance for a certain insulators
height. This makes the design susceptible for puncture. In
the intact state, the short distance between thimble and
conductor can lead to high stresses to conductor insulation
of covered conductor systems resulting in high surface
leakage currents with possible insulation erosion and radio
interference disturbance.

A post type insulator is typically not puncturable but can
flash over. Due to the higher distance between bottom and
high voltage fitting, the dielectric stress to covered conduc-
tor systems is small.

A polymeric post (figure 6.2) versus a ceramic post shows
another important and additional feature: Due to the hydro-
phobicity the leakage currents across the insulator surface
are significantly lower, especially for posts with Silicone
Rubber housing also under severe pollution and without
maintenance. Another factor of leakage current limitation is
due to the smaller average diameter of the polymeric post
(it becomes only effective when the hydrophobicity is lost!). These aspects can solve problems with wood pole
fires as well in areas, where the fire is ignited by high leak-
age currents across the insulator surface.

Mechanically as briefly described in chapter 3.2, the safe
failure mode of polymeric posts with glass fibre reinforced
resin rods prevents line drops and cascade failures.

3.4 Spun Concrete Pole with Carbon Fibre
Reinforcement

The spun concrete element plant SACAC AG, in Lenzburg,
Switzerland, has participated since 1994 in a research pro-
ject for the Swiss Federal Laboratories for Material Testing
and Research (EMPA), supported by the Commission for
Technology and Innovation of the Swiss Confederation.
The aim of this four-year project was to study the feasibil-
ity of using light, corrosion-resistant high-strength spun
concrete pylons prestressed and fully reinforced with
CFRP.

In 1999, this project was awarded the European Innovation
Prize for Textile Technology at the Techtextil Fair in
Frankfurt, Germany. The basic research phase at the insti-
• puncturable
• hydrophilic
• brittle

\[ \begin{align*}
&\text{not puncturable} \\
&\text{hydrophobic} \\
&\text{safe failure mode in bending}
\end{align*} \]

Figure 6.1: principle consideration of porcelain pin type insulator

Figure 6.2: principle consideration of silicone post type insulator

Figure 7: CFRP reinforcement cage (‘skeleton’) of the pylon
In September 2000 the first CFRP prestressed spun concrete pylon for an electric power line was manufactured /6/. This 27 m pylon was used as a support mast in the renewed power line section from Beznau to Baden, which has been upgraded from 50 kV to 110 kV. The high corrosion resistance of the CFRP reinforcement cage allows the concrete cover to be reduced – in this case the wall thickness is only 45 mm, compared to about 100 mm with steel reinforcement. In addition, with a density of just 1600 kg/m³, a fifth that of steel, and a tensile strength of 3000 N/mm², twice that of a prestressing steel, using carbon-fibre leads to a 90% reduction in the weight of reinforcement. A high-strength spun concrete of strength class B120 is used, thereby permitting cross-sectional dimensions to be minimised. The predicted maintenance-free life is around 50 years. The total weight saving is 40% – six tonnes per pylon as against ten tonnes for traditional spun reinforced concrete pylons – and so transport and installation costs are lower. The 27 m high pylon is prestressed by 40 carbon-fibre plastic rods with a diameter of 5 mm at a prestressing level in concrete of $\sigma_{c,i} = 10$ N/mm² at the base and 15 N/mm² at the top.

The pylon’s taper is 1.175%, resulting in a variation of the outer diameter from 850 mm (base) to 530 mm (top) with a constant wall thickness of only 45 mm ± 5 mm. The passive shear reinforcement of the pylon consists of a 13 mm wide carbon-fibre tape spiral 0.5 mm thick in the central pole region and 1 mm thick in the prestress transfer zone at the ends, with a constant pitch of 45 mm. To validate the static calculation methods, several static tests were undertaken on the completed mast to a maximum of 70% of the designed bending resistance. The pylon met all expectations /6/. After installation in summer 2001, long-term in-situ monitoring has been carried out by direct electrical resistance strain measurements of the carbon-fibre pre-tensioning rods, along with conventional strain-gauge measurements.

The combination of carbon-fibre reinforced plastic and high-strength concrete has led to a new manufacturing process for components and structural element design. It will enable thin-walled, light, delicate and highly durable concrete elements with very low consumption of raw material to be produced. In particular, SACAC AG is also looking at the possibility of producing other standard structural elements, such as lighting poles, mobile phone antennae poles, poles for supporting wind turbines, and applications such as special structural elements for housing.

4 CONCLUSION

The paper discusses selected advantages of composite insulators and structures for lines with compact requirements. Beside the recognized properties of Silicone Rubber insulators in polluted areas, the mechanical performance offers with the safe failure mode a feature that improves the line reliability significantly and permits suitable arrangements for areas with limited right of ways. In respect to the principle performance, the shown examples for transmission level are applicable to distribution level as well. The substitution of steel as reinforcing material by carbon fibres is shown on the example of an 110kV pole for a line upgrade from 52 kV.

5 REFERENCES

/1/ Ammann, M. a. o.: A new 400 kV line with compact towers and composite insulated crossarms. CIGRE 1998, Paper 22/33/36-06

/2/ Kocher, M.: Experience with Silicone Composite Insulators in the Tunnels of BLS Lötschberg Railway

/3/ Schmuck, F. a. o.: Increased installation performance and applications using composite insulators – a manufacturer’s philosophy. World Insulator Congress 2001, Shanghai

/4/ Papailiou, K. O. a. o.: On the raising application of polymeric post insulators. CIGRE Meeting in Prague 2000

/5/ Proceedings of the 4th International Covered Conductor Conference Covered Conductor Electrical Systems 2000, Helsinki