Zur Weiterentwicklung von 420-kV-Kompaktleitungen mit Silikonverbundisolatoren und deren Vorteile in Notleitungssystemen

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Inhalt

Der Beitrag beschreibt das Prüfprogramm eines 420-kV-Kompaktarrangements aus Verbundisolatoren und die gewonnenen Ergebnisse. Im Vergleich zu früher eingesetzten Kompaktarrangements wurde eine technische Lösung mit Massivkern für den Stützer eingesetzt. Die Prüfergebnisse haben eindrücklich gezeigt, welche hohen Sicherheitsfaktoren mit glasfaserverstärkten Strukturen zu erzielen sind sowie das Potenzial für eine erhöhte Zuverlässigkeit von Kompaktleitungen. Weitere Vorteile werden am Beispiel eines Notleitungssystems diskutiert.

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FURTHER DEVELOPMENTS OF COMPACT LINES FOR 420 KV WITH SILICONE INSULATORS AND THEIR ADVANTAGES FOR APPLICATIONS IN EMERGENCY RESTORATION SYSTEMS

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ABSTRACT

The paper describes the test programme and results of a 420 kV braced line post arrangement manufactured from composite insulators. In comparison to a previously installed arrangement, a solution with solid core post has been introduced. The test results have shown impressively the high safety margins of glass-fibre reinforced structures and the technical potential for an increased reliability of compact lines. Further advantages are shown on the example of an Emergency Restoration System.

KEYWORDS

Compact – Line – Composite – Insulator – Solid Core – Post – Mechanical Strength – Electrical Performance – Emergency Restoration System

1 INTRODUCTION

Compact lines are considered as an accepted solution to solve infrastructural constrains in the cases of voltage upgrades of existing lines or for line routes passing through areas with high population or infrastructural density. Composite insulators offer many well-known advantages, which can be utilized for compact arrangements in an excellent way. Important criteria are for the design stage, the lower weight in comparison to porcelain/glass insulators and the flexibility/deflection of the glass-fibre reinforced structure in the case of cantilever loading. For basic mechanical performance, IEC 61952 provides guidance for product qualification. There are also CIGRE publications, which do consider the load performance under static /1/ and dynamic /2/ load conditions and deduce an average threshold for mechanical stresses under working load conditions for a particular design. However, there exists no standard, which defines the requirements and tests for compact arrangements consisting of composite post and bracing longrod insulators, also called braced line post arrangement. For this reason, data from calculations have to be confirmed by comprehensive tests for further developments of compact arrangements. This paper deals in the first part with the results of a re-

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cently tested solid core solution for the post. Basis for the design has been the experiences collected since 1996, when the performance of a composite insulator solution for a 420 kV compact line was comprehensively investigated /3/. At this time, the post insulator was manufactured from a hollow core insulator. In the second part of the paper and on the example of a compact 420 kV Emergency Restoration System (ERS), the savings for erection and transportation are shown in comparison to a conventional solution. With the use of composite insulators, the reliability and overall functionality of ERS were significantly improved.

2 DESIGN OF THE NEW 420 KV LINE WITH SOLID CORE INSULATORS
2. 1 REQUIREMENTS IN COMPARISON TO THE HOLLOW CORE DESIGN

A typical technique for designing braced line post assemblies includes the use of a pivoting attachment between the assembly and the tower that optimizes the performance of the installation. In the case of an unbalanced situation caused by conductor breakage or uneven ice loading, the assembly would move in the direction of the applied force and be finally subjected to tensile loading conditions. This reduces the bending force requirements in comparison to a non-pivoted attachment and it is possible to reduce the diameter of the post rod, thus, lowering the assembly weight and cost. Early simulations and erections in the eighties have shown that the number of consecutive towers in a line section using pivoting attachments for the crossarms can be in the range of 14 /4/. In the design stage of the actual project, the forces have been superimposed (Figure 1). The equivalent situation to service load conditions of the design is achieved, if any pre-loading causes a (pre-) deflection that is representative for the in-situ loads. This is true for the design and later proven by testing, because the applied compression component is out of the axis of the post. This causes a bending to the post insulator towards the brace side. Any buckling would follow this pre-stressing and would result in a deformation upwards in the middle of the post (P-Δ model). The mechanical requirements were part of the specifications and submitted by the utilities (Figure 2). For Arrangement 1, the normal load case was tested in a (quasi-static) load test with high compression component and the broken wire was simulated by a fast release of a defined unbalanced load. In contrast to, Arrangement 2 and 3 required quasi-static load testing for normal load and broken wire cases.

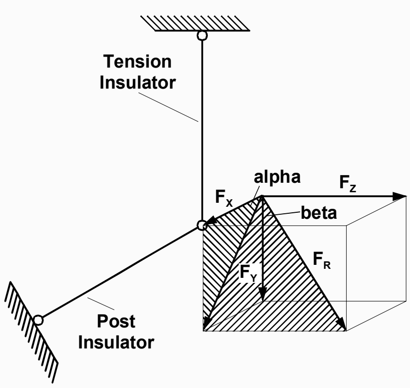

Figure 1: Superimposition of Forces

	Normalized Load Condition		Light Load Condition		Heavy Load Condition	
	normal load	broken wire	normal load I	broken wire I	normal load II	broken wire II
Vertical Force F_Y in kN	107.3	dynamic test performed /3/	70	34.3	77	38.3
Transversal Force F_X in kN	11.4		39.3	11.8	69.8	23.8
Longitudinal Force F_Z in kN	0		3.5	66.3	4.3	66.3
Resulting Force F_R in kN	107.9		80.4	75.6	104	80.2
alpha in °	84		60.7	71	47.8	58.2
beta in °	0		2.5	61.3	2.4	55.8

Installed Design	Hollow Core Post		
Drafted Design		Single Solid Core Post	Double Solid Core Post
Used Terminology	Arrangement 1	Arrangement 2	Arrangement 3

Figure 2: Comparison between installed and new 420 kV-Design

2. 2 PROPOSALS FOR NEW ARRANGEMENTS

The data of Figure 2 contain a safety factor to working loads of 3.1 and 2.5 respectively. Figure 3.1 shows the installed design of the Swiss line /3/, which was used as empirical basis for the design work of the solid core posts. The post is made of a hollow core insulator (E-

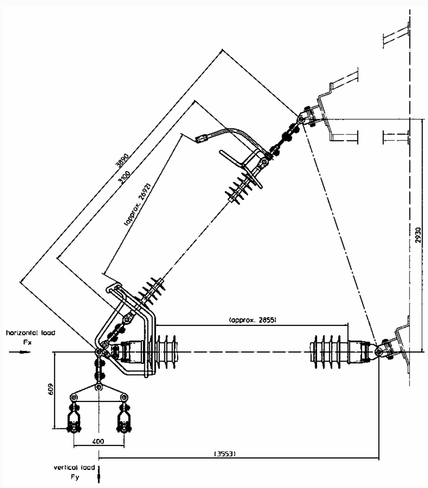

Figure 3.1: Installed Hollow Core Design –Arrangement 1

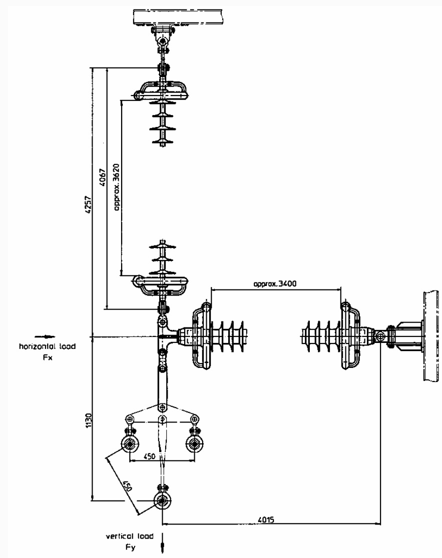

Figure 3.2: Draft for Light Load Condition-Arrangement 2

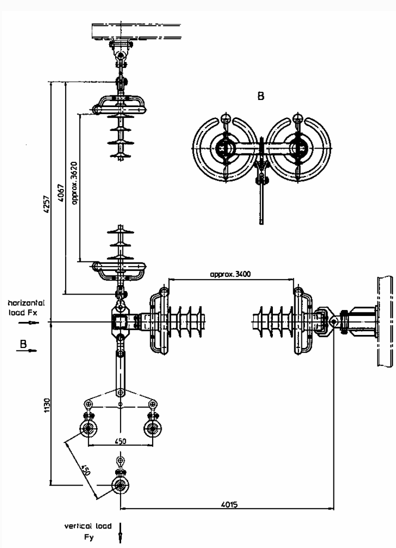

Figure 3.3: Draft for Heavy Load Condition-Arrangement 3

Modulus 21`000 N/mm^2). There is no steel cross-arm, thus an angle of ~50° is formed between post and brace. The internal space of the hollow core post is filled with an elastic compound to prevent internal discharges and condensation. The end fittings are attached to the tube by using the well introduced combination of gluing and heat-shrinking. The hardware was designed for low radio interference disturbance and power arc rating of 40kA/sec. The line operates with twin ACSR conductors with a diameter of 38 mm. The Light Load and Heavy Load Conditions for the new design led to different design proposals (Figures 3.2 and 3.3). In contrast to Arrangement 1, the angle between post and brace is 90°, which reduces the compression component to the post due to vertical loadings. The solid core post (E-Modulus 34`000 N/mm^2) does not require an internal filling and the end fittings are applied by using crimping technology. The hardware was more simplified and designed for a direct attachment to the end fittings. The striking distance across the post is adjusted to be smaller in comparison to the brace. The line will have triple bundle with AAAC conductor of 31.7 mm. Due to the high compression load of the Heavy Load Condition, a double post arrangement has been envisaged in this case following a conservative design approach. All three designs use a pivoted attachment to the pole.

3 TEST RESULTS WITH SINGLE SOLID CORE (ARRANGEMENT 2)

3. 1 MECHANICAL TESTING

The mechanical test should “judge” the calculated results and give an indication on the suitability of both arrangements to the forces requested by the specification. In a first step, it was agreed to test only Arrangement 2 with the single post. The insulators were tested without the Silicone Rubber housing to detect cracks and plastic deformations in an easier way. The set-up of the test arrangement is shown in Figure 4. The force was applied at the attachment point of the link to the conductor yoke. The axis between jack and post have been adjusted under consideration of the angles “alpha” and “beta” defined by the specification (Figure 2). The applied force was measured by a calibrated load cell in the jack and the displacement was measured of three positions and digitally recorded during measurement. A number of tests sequences had to be made to adapt the test equipment to the deflection of the test object. Figures 5.1 and 5.2 show representative curves for Light Load Conditions. All test cycles included a ramped load increase to 60% of the specified value followed by load release and an increase to the 100% value. This also takes into consideration the “creeping” of the complete arrangement due to adaptation to the first load exposure. Figure 5.1 shows that the 100% value was significantly exceeded without failure followed by the passed test of the broken wire in Figure 5.2. This high performance led to the decision to apply the Heavy Load Condition to the single post solution as well (Figures 6.1 and 6.2).

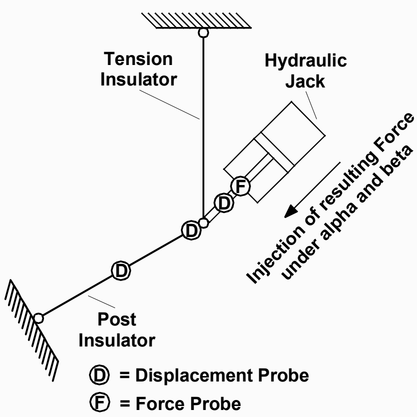

Figure 4: Diagnostic Measurements during Testing

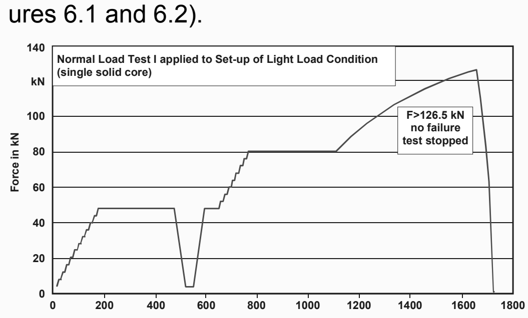

Figure 5.1: Normal Load I - Arrangement 2

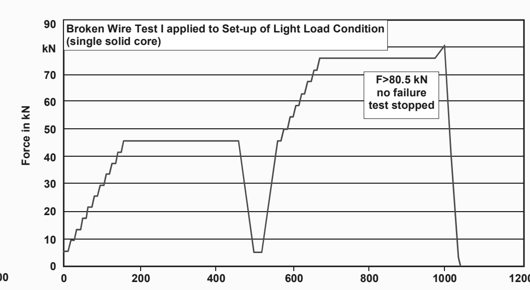

Figure 5.2: Broken Wire I - Arrangement 2

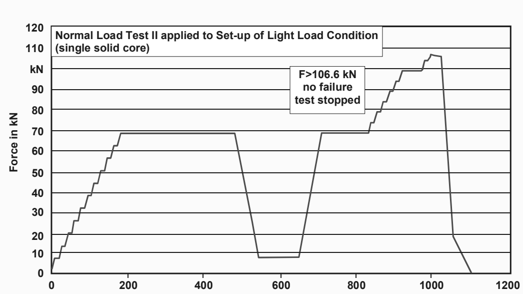

Figure 6.1: Normal Load II - Arrangement 2

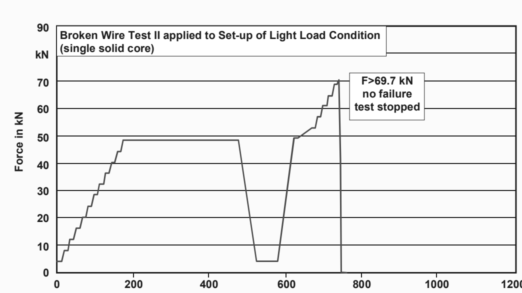

Figure 6.2: Broken Wire II - Arrangement 2

A summary of the test results of Arrangement 2 is shown in Figure 7. The %-values document the relation to the specified values, which already contain a safety factor of 2.5. It should be mentioned that all tests were performed with one specimen. An interesting option can be deduced from the results that Arrangement 2 could also cover the requirements of Arrangement 3. Both, the relatively small excess of the specified values for broken wire I and normal load II as well as the non-compliance of broken wire II have been caused by the limitations of the test equipment and not by the arrangement itself. For this reason, the failure of the arrangement could not be achieved, which would show the known safe failure mode /5/. Comparing the results of the Swiss test program with the actual procedure, the Arrangement 2 was subjected to higher loads, which was reflected by the higher deflection as well. The maximum measured deflection of Arrangement 1 (hollow core solution of Figure 3.1) was in the range of 38 mm; while Arrangement 2 (solid core solution of Figure 3. 2) showed more than 200 mm without any damage. The results do document the safety and design potential of fibre-reinforced structures. The preference is for the solid core solution, because there is no filler required inside and the attachment technology permits a higher utilisation of the intrinsic rod properties.

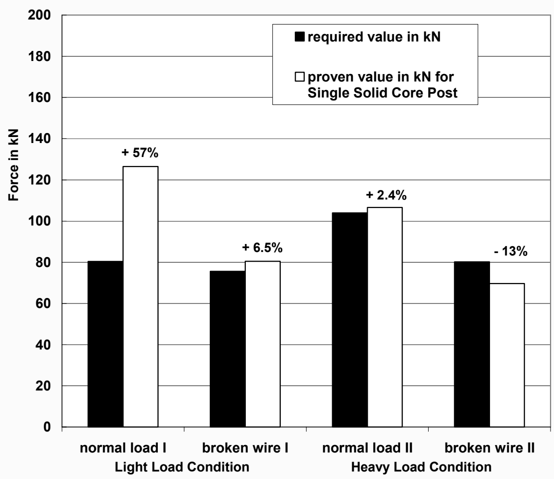

Figure 7: Summary of mechanical Test Results

3. 2 ELECTRICAL TESTING

The electrical withstand values were defined by the utilities to meet the local requirements for insulation co-ordination and are summarized with the corresponding standards in Figure 8. Figure 8 shows unambiguously that the electrical requirements are comprehensively covered in the corresponding standards. The requirement for the Radio Interference Voltage had to be fulfilled with a specially adapted combination of a corona/arc ring. After the power arc test, various electrical and mechanical tests were performed to prove the integrity of the arrangement.

Property	Arrangement 1	Arrangement 2 Arrangement 3	applied Standard
Corona Test (extinction voltage)	> 265 kV	> 265 kV	IEC 60383-2, IEC 60060-1
Radio Interference Test	not measured	< 100 μV (40 dB/ 1 μV) at 278 kV	IEC 60383-2, IEC 60437, CISPR 18-2
BIL 1.2/50	> 1425 kV	> 1425 kV	IEC 60383-2, IEC 60060-1
SIL Wet 250/2500	> 1050 kV	> 1050 kV	IEC 60383-2, IEC 60060-1
PF Wet Withstand Voltage	> 630 kV	> 520 kV	IEC 60383-2, IEC 60060-1
Power Arc Test	no test hardware designed for 40kA/sec	30kA for 1 second without destruction	IEC 61467, IEC 60383-2, IEC 60060-1

Figure 8: Required electrical Values

3. 2. 1 Results of High Voltage Testing

The high voltage tests were passed without particularities and showed high safety factors (Figure 9). In the tests under dry conditions, the results, depending on hardware design and

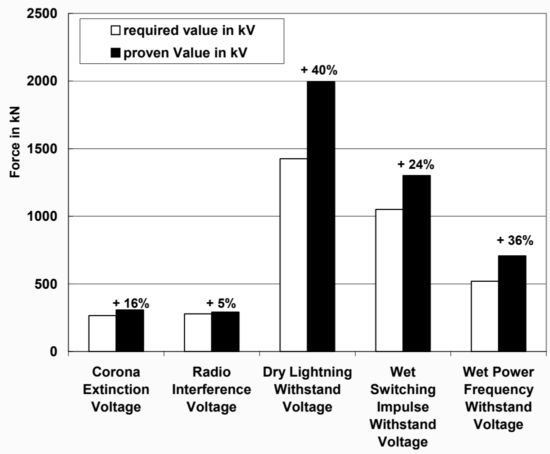

Figure 9: Summary of electrical Test Results

Figure 10: Wet Switching Impulse Testing

striking distance, are comparable to conventional solutions. During testing of the simultaneous voltage and rain performance, the composite arrangement provided significantly higher values in comparison to glass or porcelain. This can be attributed to the smaller diameter of the composite insulators and the hydrophobic (water-repellent) effect of the Silicone Rubber. Figure 10 shows the flashover during Wet Switching Impulse Testing. Despite the higher striking distance of the brace, most of the flashes appeared across this insulator influenced by the water direction of the artificial rain.

3. 2. 2 Results of High Power Testing – Power Arc

As required, 30 kA for 1 second has been given as test scenario. The short circuit was initiated across the post insulator, because of its shorter striking distance. The test scenario "D" of IEC 61467 was selected – unbalanced supply and return circuit. The calibration of the cir-

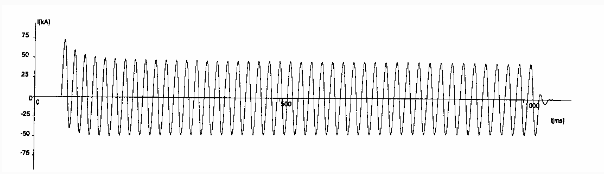

Figure 11.1: Calibration Shot

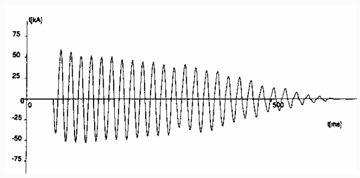

Figure 11.2: Power Arc Current

cuit was made with cage shunts and provided 33 kA for 0.98 sec (Figure 11.1). This calibration test does not take into account the dynamic behaviour of the power arc and its interaction to the test circuit. The arc current over time (Figure 11. 2) shows that the arc extinguished after 560 ms. This is attributed to the electromagnetic and thermal forces (dominating is the electromagnetic effect for this condition), which are used to guide the arc at the arcing horns. In the test case, these effects do superimpose and prolong the power arc until extinction under the selected test conditions and available electrical energy (Figure 12.1). The test specimen was still in position after the test, and the housing was blackened by the power arc (Figure 12. 2). No part of the housing was damaged by thermal stress. The end fittings were marked by the power arc roots but did not show a considerable loss of material. The aluminium end fittings of the post exhibited a certain colour change but the following mechanical tests showed no reduction of strength at all.

Figure 12.1: Arc Extension during Test

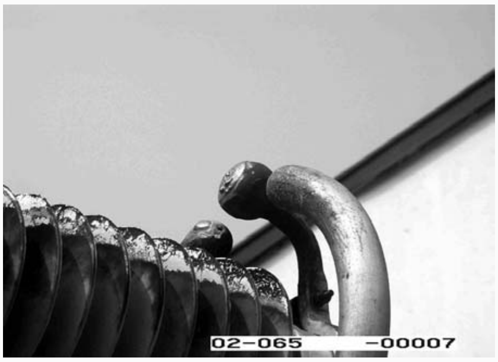

Figure 12.2: End Fitting after Power Arc Test

Although the actual arc front extinguished earlier that the specification requires, it was agreed in this particular case to consider the test as having been passed. This decision was based on the physical evidence to the limited damage at the arc ring component, the excellent guidance of the arc away from the insulator and calculations that determine a value limit of energy in the end fitting area to be well below acceptable limits. Hence, a safe operation also in a power arc case could be guaranteed. This extrapolation is only valid for the investigated materials and end fitting design.

4 APPLICATION OF HIGH STRENGTH POST FOR EMERGENCY RESTORATION SYSTEMS

The first designs of the ERS used V-shaped towers, hence the insulators were composite tension insulators. Glass cap and pin insulators have not been considered because of their higher weight. This design concept can be used for voltages up to 500kV /6/. A disadvantage is the area consumption of such structures. With the availability of composite high strength post insulators, compact designs such as braced line posts were developed and commissioned. The properties of the insulators of the ERS are derived from the main design criteria of the system, short erection time, light weight, endurance and limited number of parts.

The insulators of the ERS must therefore have the following properties: easy handling due to low weight, low susceptibility against damages due to multiple assembly/disassembly, limited number of individual parts, high insulating behaviour without any maintenance. These properties are met with solid core silicone insulators in an almost ideal way. The insulator arrangement is fully equipped with combined arc/corona protection. The ERS is containerised for easy transport to difficult areas, hence weight and volume consumption play a vital role. The low susceptibility of the composite insulators against fractures does not require spare parts in the container, which is a logistic advantage too. On the example of a typical 420 kV system, the savings for erection and transportation can be estimated as follows: 55 % for erection and 50 % for transportation. This saving could be demonstrated for a 420 kV ERS by-pass system, installed in year 2000. For the crossing of the high speed rail connection between Antwerp and Amsterdam, the clearance of the line Krimpen – Zoetermeer between tower #46 and #47 had to be increased by approximately 10 meters. For this, a new tower was built next to the existing tower. One of the essential project conditions was the limited outage time of the 420 kV system to be three days maximum. The construction of the new tower did not meet this requirement. As solution, the corresponding part of the 420 kV line was re-routed via three restoration towers (Figure 13). Due to the time constrains the conductors were pulled from the existing towers to the restoration towers. For this purpose special designed frames with rolling-out wheels and conductor clamping devices were installed. The 4-bundle conductors were released from the clamps in the existing towers and brought to the required length. The frames were positioned over the conductors and took over phase by phase from the existing towers to the restoration towers. Finally the conductors were clamped in the frames. The transfer time could be realized within five hours, which met the time requirements in an excellent way. The simple and time-efficient take-over of the conductor can only be applied with the braced line post arrangements and not with the previous V-shape design.

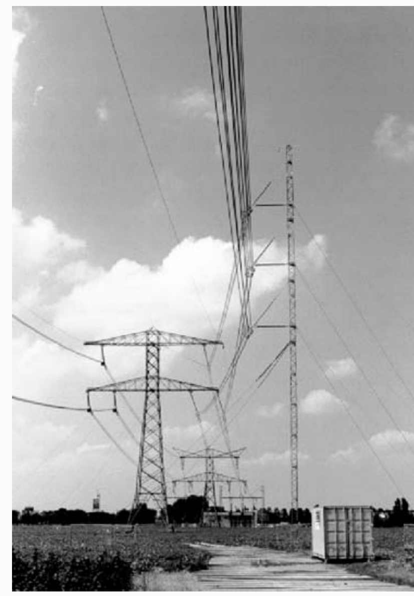

Figure 13: 420kV by pass with ERS

5 CONCLUSIONS

The known features of composite insulators can comprehensively be utilized for compact arrangements. In the case of permanently installed arrangements, the lower weight leads to saving for tower constructions and the overall performance and reliability takes benefit of their pollution behaviour and safe failure modes. Within a comprehensive test programme, the high safety factors of Silicone Rubber insulator components could be proven. For ERS, the features of composite insulators have led to lower system weight and installation time, which reduces costs in emergency cases. With the availability of high strength solid core post insulators, optimized solutions for even higher voltage levels are in the design stage under consideration of the presented test results.

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