Diagnostics of insulators Failures on Overhead Lines

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SUMMARY

At this part is desription of the diagnostic and ultrasonic method that provides inspection on the hanging insulators of interrupted high-voltage transmission lines. It describes different localization and types of the defects under hanging metal armature. The method explains the causes which guided to the evaluating cracks on the end of ceramic insulators under hanging metal armature. The ultrasonic diagnostic helps to find the defective insulators and recommends to use them for another duty or exchange them..

KEYWORDS

Ceramic Insulator, Long Rod Type Insulator, Insulator String,, Ultrasonic inspection method, Fractographic analysis, Insulator feilures, Crack detection.

1. PROBLEMATICS OF BREAKING CERAMIC INSULATORS

Slovak high voltage transmittion lines 440 kV mainly use insulators (type LS 75/21(23) or LS 85/21(23)), made from ceramic material SiO_2 - Al_2O_3. Time operation some of these high voltage lines is more than 25 -30 years without exchange of insulators.

It happend several breakdowns of ceramic insulators at high-voltage transmission in a last five or six years . The detection of the reasons these accidents and efects that caused breaking of the isulator were solving by the team of specialists of mechanical ispection, metollography, electrotechnical laboratory, chemical ceramic research laboratory and specialists for nondestructive testing. They were asked to find and create complex inspection system - diagnostic to give information about present situation at hanging ceramic insulators, to establish systematic documentation of condition transmission lines . From the economical aspects was asking on this diagnostic important because it determine if is necessary to provide global insulating of selected transmission line or if is necessary to exchange only insulators on the some pillars of transmission lines. The asking was approximately to estimate residual lifetime of the hanging insulators and to protect high-voltage transmissions lines against unexpected damages and breakdowns.

4. THE SCOPE OF THE RESEARCH

The group of the specialists performed test on the broken and down hanging insulators and also directly on hanging insulators of interrupted high- voltage transmission lines. From the beginning the test were performed by IEC 383 in following range:

- Visual inspection
- Test of metallizing the arm (fixture)
- Test at thermal cycle
- Test of mechanical strenght
- Ultrasonic testing for laminated breakage
- Testing pigment absorbability of fragments
- Testing of geometry and cone appearance after arm removing

Chemical and physical testing :

- Chemical analysis
- Mineralogical and diffraction analysis
- Determination of bulk weight and density
- Determination of temperature dilatability

Fractographic analysis:

- makrofraktographic analysis
- mikrofraktographic analysis
- meassurement of porosity

Testing of electrical isolation properties.

- to estimate residual lifetime
- test of wet flashover voltage (salt fog) by standard ČSN IEC 507.

Testing of eletrical and physical values:

- Measurement of electrical surface conductivity

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- Measurement of breakdown voltage

2. RESULTS OF THE LABORATORY TESTS

Some of testing methods didn´t gave us any satisfactory results, except fractographis and ultrasonic analysis.

By detailed fractographic analysis, when was splitted the head, it was proved, that low tensile strenght of mechanically tested insulators was always associated with occurrence of local /bulk or surface/ stress raiser with surrounding region of slow crack growth. At the in-service breakdowns it was concluded that a stable crack growth off the perimeter precedes the final fracture taking part at the bulk of the insulator. The main breakdowns were result in destruction of the head of the insulator into slices with flat peripheral region and inded central part (Fig.5 and 6).

Figure 5. Transverse cuts and network of thin cracks in the head of the broken insulator

Figure 6. Broken insulator with destruction of the head

The transverse cuts of insulators revealed a dence network of thin cracks, combined with less frequent and thicker defects in the peripheral region of the insulator.

FEM numerical analysis of the stress field of the head of insulator was carried out to stress distribution leading to failure. The main results can be summarized as follows:

First crack initiate close the upper end of the head insulator mounted in metal armature.

With increasing tensile loading and development of the main crack initiating of the perimeter the stress field in the bulk change form tensile to pressure.

After critical growth of the peripheral crack the bulk of the ceramic fails under pressure. New crack initiates in the remain intact rest of the ceramic insulatorand the whole process repeats several-fold until the lower end of the reinforcement containing the head of the insulator is reached and a final breakdown occur.

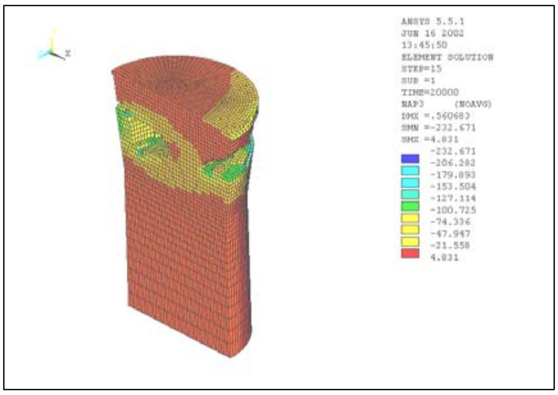

Figure 7. The critical growth of the peripheral crack the bulk by FEM numerical analysis.

Based on the FEM analysis it was concluded that the observed features of insulators failed under in-service conditions, i.e. the combination of different types of failure in the peripheral and central part of the insulators, is conatural and reflects the kinetics and distribution of stress field under external loading.

The fractographic analysis indicates a stable peripheral crack growth period proceding the final failure. In the central part of the insulator. According to literature data the analyzed ceramic material is so called static fatigue. It occurs under constant loading at fractions of tensile strenght meassured by short-term tensile tests. The micromechanism of stable crack growth is similar to the stress corrosion cracking in steel and resides in a chemical reaction between the stressed matrix and the aggressive enviromental compound. The stable crack growth rate can be as low as 10^{-9} msec^{-1}.

6. PRACTICAL ULTRASONIC TESTING OF THE INSULATORS

Concerning the results of the fractographic and FEM analysis it was very important to test several houndred hanging ceramic insulators of the transmissions lines to find all real failures at the end of head insulator or transversal cracks leading to breakdown.

As the diagnostic system was developed the ultrasonic meassurement methode. This methode is not new and is known for manufacturer who have to tested quality of produced insulators. That means the ultrasonic testing was used mainly for new insulators.

The main task of this ultrasonic methode was testing and localization all defects or peripheral cracks under hanging metal armature as is describe on the picture (Fig. 8).

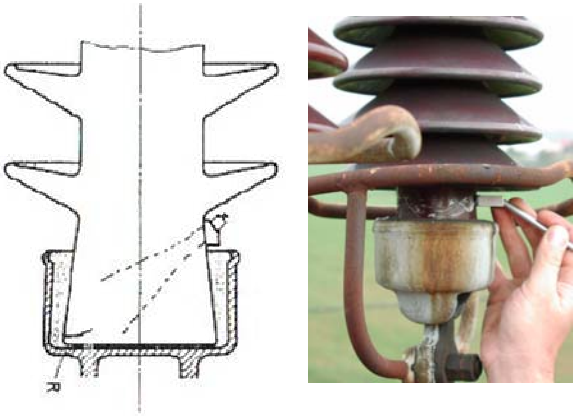

Figure 8. Schema of the using ultrasonic probe to detect transversal crack at head of the insulator and practical testing by angle beam probe

The diagnostic groups were equipped portable flow detectors and ultrasonic meassurement probes, including simple mechanical manipulator. Following the inspection procedure they were able to detect critical failures – especialy transversal cracks under armature. These cracks particulary can cause to the break of insulator during duty of the high-voltage transmission.

Figure 9. Ultrasonic testing on the hanging ceramic insulators of 440 kV transmission lines

The application of ultrasonic diagnostic helped to discover several important and critical defects, that were confirmed by splitting of the head of insulator in laboratory.

Typical discowered defects by ultrasonic testing were:

- springing-off the edge of insulator
- the separation of bulk inside head under metal armature
- the laminated/transversal cracks under hanging metal armature

Figure 10. Damages of the edge of insulator

Figure 11. Internal separation of the bulk

Figure 12. Starting crack growth

Figure 13. Critical crack growth – the tensile strenght of the insulator was less than 80 kN

The mechanical splitting help us to compare the results of ultrasonic inspection, real finded feilures and mechanical loading tests.

All insulators with feilures that were indikated by ultrasonic inspection were mechanical tested for tensile strenght. This testing confirm that most critical is cracks growth in the bulk more than 50% of the axial lenght the upper end of the head insulator mounted in metal armature.

All other insulators with the failures as the large springing-off the head edge, the separation of bulk inside head under metal armature, starting transversal cracks under hanging metal armature complied mechanical tensile strenght test 160 – 200 kN. But as was acknowledged by fractographic and FEM numerical analysis, these small feilures lead to initiating and to the development of the crack and after several periods a final breakdown of the insulator occurs.

CONCLUSION

Though ceramic materials are not supposed to be prone to ageing or time dependent degradation of material properties, the preliminary results suggest that certain long-term processes leading to in-service breakdowns after years of operation have to be taken into account. In the given case a combination of static fatigue stable crack growth off the perimeter and progressive fracture development gradually slicing the head of ceramic insulator towards the bottom of the reinforcement containing the insulator can most probably furnish an explanation of in-service breakdowns after up to 20 years of operation.

The way of ultrasonic inspection is most reliable and most efective method how to find all defective insulators on the high voltage transmission lines. It can gives global view to condition of existing transmission lines and the network managers can easily decide to use them for another duty or to exchange insulators immediately.