THE POLICY OF CONEL ROMANIA – STEE SIBIU ABOUT PROTECTION AGAINST SWITCHING AND LIGHTNING OVERRVOLTAGES

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The paper presents the policy of CONEL ROMANIA - STEE SIBIU about protection against switching and lightning overvoltages with particular references to:
1. Necessity of surge arresters  
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   3.1 Construction and operation principle of MOSA  
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5. The diagnose of MOSA

The conclusions of this paper shows the need of an operational procedure which shell treat, solve and unify the services problem on the maintenance (and their type) of metal oxide surge arresters.
THE POLICY OF ST SIBIU ABOUT PROTECTION AGAINST SWITCHING AND LIGHTNING OVERTOLVAGES

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1. NECESITY OF SURGE ARRESTERS

1.1 Lightning overvoltages due to direct stroke to the overhead lines

Lightning overvoltages due to direct stroke represent one of the main reasons of outages on overhead lines. For the purpose of improving the lightning performance of overhead lines is important to determine these overvoltages and to establish the best performances of the protective devices. The protective devices improve the lightning performances of the lines. It is difficult to select the protective devices on economic calculations and their results are inconclusive since the outages and their costs are very different dependently by the characteristics of consumers. So, the results of the calculations can not been comparing because of their inaccurate criteria used for this.

1.2 Methods of calculus of the overvoltages due to the direct stroke on the overhead lines

The main methods for the calculus of the overvoltages, used in Romania, are:

a. The method of the “travelling waves”, which take in account also the induce overvoltage on the phase conductor For the analytic determinations are used Dragan (2) and the routine DECLA.

b. The R. Lundholm’s method. This method uses the following hypothesis: the tower (their section and consoles) is represented by vertical and cylindrical conductors, respectively horizontally; the conductors are cylindrical, horizontally on the ground and perpendicularly on the tower; the insulator strings are equivalent with air spark gaps; the channel of the stroke is presented as a horizontal conductor by infinite impedance; the ground is plane and has an infinite conductance.

c. The C. F. Wagner’s method. The evaluation of the overvoltage due to the lightning on the top of the tower consists in two stages: the currents distribution on the tower and on the ground wires and the calculation of the overvoltage on the insulator string are established in the first stage and the voltage on the phase conductor due to the electric load of the lightning channel and the induce voltages are calculated in the second stage.

d. The D. V. Razevig’s method. Razevig (7) presents an integrated method for the evaluation of the lightning overvoltages due to the direct stroke on the electric line or near the electric line.

1.3 The flashover of the insulator string. The probability of the outage of the overhead line

The most dangerous overvoltages are caused by the lightning stroke on the phase conductor or on the tower. An outage of an overhead line due to lightning may arise when the overvoltage is so highly as it causes the flashover of the insulator string and this flashover turns into a flaming arc. Is important to assess the number of outages of the overhead line due to direct stroke, shows the field experience. For a year, this indicator has been evaluated by Dragan (3).

1.4 The propagation of lightning overvoltage waves to the substation

The causes of a flashover or of a sparkover on a substation may be: an atmospheric discharge in substation due to a shielding failure; a backflashover in the substation due to the rising of the potential on the grounding plug socket; the propagation of the lightning overvoltage waves which may be the cause of the rising of the potential in the substation. The parameters, which are significant for the waves image and amplitude are: the lightning current characteristics; the place where the lightning stroke the overhead line; wave deformation due to Corona discharge and stripping effect.

Important overvoltages on the 110-750 kV overhead lines with shield wires arise for a shielding failure of the shield wire or for a lightning stroke on the top of a tower. The stochastic number of overvoltages, for the last case, has been evaluated by (3). Bazutkin (2) shows that the number of the propagated overvoltage waves to the substation depend on the footing towers resistance; the majority of the atmospheric overvoltage waves to the 110 kV and 220 kV overhead lines are due to the direct stroke to the top of the tower; the number of the overvoltage due to the direct stroke on the phase conductor increases for the 400 kV overhead lines due to the shielding failures; the propagated overvoltage waves for 110 kV and 220 kV overhead lines are with short tail for 95-99% of cases. For 400 kV overhead lines this percent is 80%.

1.5 The protection of ST’s Sibiu substations against atmospheric overvoltages

The protective devices use at ST Sibiu against overvoltages are: gapped silicon carbide (SiC) arresters
and metal oxide surge arresters (MOSA). These arresters are connected to the leading-in of the ST’s Sibiu substations.

The following parameters are used at the picking of the arresters:

- For the gapped silicon carbide (SiC) arresters: the cut-off voltage, the flashover voltage, the attendant current.
- For the MOSA: the rated voltage, the continuous rating voltage, the persistent current of the arrester, the reference current, the reference voltage.

SiC arresters and also MOSA must have the following properties: they shall suppress the overvoltage across the substation insulation and prevent its flashover, under normal conditions they shall act as insulators, in case of their overloading they shall not constitute a permanent short-circuit phase-to-ground and they shall not cause severe risk for other equipment or personnel nearby.

The features for these arresters are: long life, proof against natural environment, easy to install, enough clearance, free from Corona interference and easy for maintenance and inspection.

When an overvoltage wave has been propagated from the line to the substation, for the analysis of the substation protection against this is tackled in account the overvoltages on the substation’s equipment terminals. Lungu (5) analyses the stresses of a substation’s insulation equipments by applying a method of calculus for the atmospheric overvoltage waves attenuation and strain during their propagation across an overhead line. For the evaluation of overvoltage waves form and amplitude has been used Dommel’s method.

Fig.1 shows the variation of the atmospheric overvoltages on the substation’s bus bars for a lightning stroke at 100 m distance by substation, with out considering the Corona discharge. The amplitude of the 1,2/50 µs overvoltage wave is 750 kV.

Fig.2 shows the variation of the atmospheric overvoltages on the substation’s bus bars for a lightning stroke at 100 m distance by substation, with out considering the Corona discharge. The amplitude of the 0,5/10 µs overvoltage wave is 750 kV.

Fig.3 shows the variation of the atmospheric overvoltage on the substation’s bus bars and on the transformer’s end-connection for a lightning stroke at 1000 m distance by substation (curve 1 and 2) and for a lightning stroke at 500 m by substation (curve 3 and 4), considering the Corona discharge. The amplitude of the 1,2/50 µs overvoltage wave is 750 kV.

The conclusion of this evaluation is that the atmospheric overvoltage wave is a non-periodic and a single pole one, with many wiping on their tail.

Fig.1 and Fig.2 show also the increasing of the voltage on the equipments terminals when there are not arresters installed in substation. The arresters, which have been applied in a substation, for 750 kV amplitude of an atmospheric overvoltage wave due to a lightning stroke at 100 m distance by this, reduce the voltage on the substation’s bus bars from 756 kV to 429 kV (for MOSA) and to 423 kV (for SiC arresters). Therefore, the absence of the arresters is the cause of a 75% overvoltage increase on the substation’s bus bars. The arresters type does not affect the value of this voltage.

Fig.1: 1 – the incident wave; 2 – the variation of the overvoltage, when there isn’t any arresters in substation; 3 - the variation of the overvoltage, when there is a MOSA in substation; 4 - the variation of the overvoltage, when there is a SiC arrester in substation.

Fig.2: 1 – the incident wave; 2 – the variation of the overvoltage, when there isn’t any arresters in substation; 3 - the variation of the overvoltage, when there is a MOSA in substation; 4 - the variation of the overvoltage, when there is a SiC arrester in substation.
discharges of ZnO resistances and other advantages which are due to the insulating material of the housing (porcelain or polymer).

Fig.3: The variation of the atmospheric overvoltage on the substation’s bus bars and on the transformer’s end-connection

The policy of CONEL-Romania – ST Sibiu protection against overvoltages, after 1990, is based on the use of the MOSA, first for the replacement of the SiC arresters and now the MOSA are the only arresters used for the new substations.

Around 1990 in the 110, 220 and 400 kV networks of CONEL Romania has installed more than 1000 ZnO arresters phases mounting between phase and ground, for the protection of the bus bars, transformers, autotransformers and lines and they represent 38% for 110 kV MOSA, 37% for 220 kV MOSA and 30% for 400 kV MOSA.

ST Sibiu utilizes the routine PAS for testing the protective diagrams against overvoltages. ISPE Buchuresti has projected the routine PAS and it is used for the modeling of the arresters and for the modeling of the waves deformation and attenuation due to the flexible conductor resistance, to the return path in the ground and to the effect of the Corona impulse. Also the routine PAS determines the fluctuation of the voltage in all substations’ nodes and it identifies the unprotected equipments against overvoltages.

The routine PAS is based on the Bewley Lattice Diagram for the analysis of the overvoltage waves propagation.

2. STANDARDS AND RULES USED IN CONEL ROMANIA FOR CHOOSING AND TESTING SURGE ARRESTERS

In Romania has been elaborated, within the European integration, national standards equivalent with the CEI or EN normative. For this purpose, for the protection against switching and lighting overvoltages have been assimilated the CEI 71-1/ 1993, CEI 60071-2/1997, CEI 71-3/1982, CEI 99-1/1991, CEI 60099-3/1990, EN 60099-4/1993 and EN 60099-5. Except the national standards in CONEL have been elaborated normativs and internal instructions for the mounting, the exploitation and the testing of the equipments. For the sphere of protection against overvoltages exist the normative PE 109 “Normative for the selection/choosing of the insulation for insulation coordinate and for the protection against overvoltages”, normative PE 116 “Normative for tests and measurements at electric equipments and installations”, 3.2 RE-I 71-2000 “Instruction for the mounting, exploitation and testing the arresters”.

The arresters selection/choosing is based on the stipulations of CEI 71-1, CEI 71-2 and EN 60099-5 and the utilization guides supplied by the main producers from witch CONEL Romania acquired till now arresters (ABB, Tridelta and SIMENS for the 110-750 kV systems and RAYCHEM, ABB and SOULE for 20 kV systems).

3. THE CONSTRUCTION AND OPERATION PRINCIPLE OF MOSA. THE MODELING OF MOSA

3.1 Construction and operation principle of MOSA

Two types of arrester have been developed: externally gapped arrester and gapless arrester.

The gapless arresters are installed in the substations of CONEL Romania.

This arrester comprises one ore more ZnO element in a weatherproof housing, which may be made of porcelain, polymer or other insulating material to contain and support the elements. The dimensions of the containment must make allowance for the effects of pollution and cooling. The construction generally provides gasket seals to frequent ingress of moisture and pressure relief vents, in case of failure. Suitable contacts between the blocks and the external connections of the equipment are provided. The ZnO elements have excellent nonlinear voltage current (V-I) characteristics. When an applied voltage is low, only very small current can flow through the element due to its high resistance. With an increased applied voltage, the arrester element conducts a large current due to its reduce resistance. As the result, the voltage across the arrester does not reach the breakdown voltage of the arrester and no flashover will occur. The essential element of the surge arrester is the highly non-linear voltage dependent resistor called varistor. Varistors elements are connected together in series so they have high impedance at the rated system voltage, but much lower impedance to overvoltages.

3.2 The numerical modeling of MOSA

During the past years the research on the MOSA by the Technique University of Bucharest has been directed for
the discovery of an equivalent circuit, which by modeling to deliver comparable results with the results of the laboratory tests.

The varistors with metal oxide constitute a ceramic material based on the zinc oxide with semiconductor properties. Due to its microstructure/ (microcrystalline structure) it has special electrical properties. Microscopically its structure contains small crystals of ZnO, smaller than 20 µm, a very conductive material A constitutes their interior by electrical resistivity \( \delta < 10^{-2} \Omega \) a very non-conductive stratum constitutes surface and its thickness is smaller than 0.2 µm.

The value of the electric conductivity of the slug has been revision by addition of the n doping elements: Bi, Co, Mn or Sh. Every superficial stratum between two adjacent crystals represents a small varistor with a nonlinear voltage-current characteristic and with a 3.5 V flashover voltage.

The n doping elements B lies on the network corners. These elements provide \( \approx 10^{18} \) free electrons on each cm\(^3\) which contribute to the electrical conduction.

The equivalent circuits, after Haddad (4), represent the ZnO varistor as follows:

1. For the calculation of the material granular resistance the ZnO crystals have been represented by a low resistance \( R_g \), and its effect is considerable only for the impulse discharge currents.
2. By simulation the properties of the intergranular stratus: a circuit has represented these by \( R_g \) resistance with excellent nonlinear voltage current characteristic, and a parallel capacity \( C_{lg} \).

For kA impulse currents, the resistive component is greater and the capacitive one is negligible.

The latest researches have been concentrated on the MOSA behavior to the very fast front overvoltages. Due to the difficulties in obtaining the experimental dates the efforts have been aimed to the modeling of the non-less than 0.5 µs stresses impulse.

Fig.4 shows the equivalent circuit, as two series circuits: the first is represented by the ZnO crystals resistance \( R_g \) (1Ω) and the proper inductivity \( L \) due to the dimensions of the arrester material and the second, in series with the first, is a parallel circuit, which represent the properties of the granular material.

The high discharge currents cover one of the circuit branches and so a very non-linear resistance \( R_{lg} \) and a less inductivity \( L_{c1} \) characterize the branch. The second branch includes a nonlinear resistor \( R_c \) and a high inductance \( L_{c2} \). The condenser \( C_{lg} \) models the shunt capacity of the arrester.

3.3 The thermic behavior of the arresters

The parameters of a thermic model used for the study of the arrester at the Technique University of Bucharest are: the heat quantity, the temperature, the thermic resistance and the capacity.

Hurdubețiu (5) proposes a thermic model, which allows the simulation of the MOSA and their components performances. This model takes in account the heat transfer on two directions (axial and radial) and also the dependence between specific heat and temperature.

Fig.4: The equivalent circuit of MOSA

4. FIELD EXPERIENCE AND SOME OUTAGE EXAMPLES OF MOSA IN ROMANIA

Romania has a reach experience for the SiC arresters field, which represent 85% from all the arresters of the CONEL. SiC arresters have been produced, in Romania, for the 20 kV networks and 33 kV magnetic blowing arresters for the railway traction.

MOSA have been designed and produced, in Romania, in 1994, for the 20 kV networks. The ZnO resistors have been secured from imports.

Romania has also a reach experience in the testing field by performing testing in laboratory and in operating. Our specialists participated at the receiving of the MOSA and also they tacked part at the tests in the producers’ laboratories.

The application of MOSA to power lines started in Romania, around 1994, in the line of 6, 20, 110, 220, 400 and 750 kV classes.

Only some arresters faults have been produced in this short period and two of them are significantly. The first take place in a 110 kV hydro-substation. During a storm some trees failed dawn on the electric line and produced its outage. Due to the loss of charge and to the malfunctioning of the protection has been produced the generator racing. The voltage on the arresters has been higher than the rating voltage for a longer time (due to the resistive characteristic on temporary overvoltages).

As result of this incident three MOSA have been damaged.

Other incident has been produced on a 20 kV derivation line, with 24 kV maximum voltages, which supplies a television relay, at 1500 m altitude, in a mountainous region. Very much incidents have been produced on this line, for all type of arresters. These incidents have been
produced only in wintertime. The first set of damaged arresters had a 24 kV rating voltage. The damaged arresters have been replaced with other arresters with 27 kV rating voltage. These new arresters yielded also after a year, apparently unjustified. This case needs a program for the investigation of the exploitation conditions in detail through measure the harmonics and overvoltages for the analysis. An electric overstressing is the cause of these damages. A partial breakdown of the resistors column has been found, followed by an external flashover due to the breakdown of the polymeric insulation. The sealing of the polymeric insulation has been testing in laboratory, by variation in temperature between -45° C and 60°C and any damage has not been found.

5. THE DIAGNOSE OF MOSA

CONEL-ST Sibiu uses a program for the MOSA prophylaxis. In accordance with this program MOSA from the 110-400 kV systems are testing yearly in the first two years after mounting and than once at every five years. Although the producers declare the MOSA as “free maintenance”, to avoid the electrical faults there is necessary preventing prophylaxis. Even the producers have been confirmed this aspect and they advise for the periodical testing of the parameters and also they show tolerance limits for these. As we know, CEI 60099-4, amendment no1, studies the indicators for the evaluation of MOSA in use. For example, an electric fault has produced in a CONEL substation due to a fault on a 198 kV MOSA installed on the transformers terminals. The MOSA has generated a monophase short-circuit on the transformer terminals, during a rain, after three days from mounting. The electric fault has produced due to a significant mounting error of the sealing system of the arrester, which hasn’t been seized by the producer. If the arrester has been tested immediately after operation, the damage made was avoided.

The methods used at CONEL-ST Sibiu for the diagnose of the arresters are: the testing of the reference voltage and of the partial discharges level, in the testing laboratory; the testing of the resistive component of the current, on-line; the testing of the total earth leakage current, of the top value of their third harmonic, on-line. The last two methods are selectively used, depending by the type of the arrester, by the values of the reference parameters and by the testing instruments delivered suddenly with the arrester by the producers.

The resistive component of the current is indirect measuring with monitors, by the harmonic analysis of the earth leakage current using the network’s three harmonic compensation. This is the most efficient and the most conclusive method used until now.

The total current, the top value and their third harmonic are measured by using portable testers. This method offers insufficient and inconclusive informations for the assessment of the MOSA. The measured values are intensely affected by the weather including sunlight, rain, contaminant and strong wind, by the insulation state, by the third harmonic in the network voltage, by the manner of tuning the third harmonic filters and by the spatial fitting of the arresters, etc. We consider this method only as an informative one.

However, a remarkable phenomenon has found for a very small number of arresters by using this type of tester. A four time higher value of the total current has picked-up in the first eight hours after MOS putting into exploit. This is an untypical behaviour taking into account other arresters on the same type. The metered values are very high. Testing, in the same time, the resistive component of the current, hasn’t determined any of its increase, and more, its values have been normally. The increase of the total current is due only to the increase of the capacitive component in the earth leakage current. An identical increase has determined for the third harmonic. The respective arresters will be tested in laboratory and in operating, for clearing up the cause of this behaviour and for avoiding the future faults.

REFERENCES

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