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Tischer, Gg. "Stand der technik des ubersoannungsschutzes von fermelde-anlagen mit uberspannungsableitern." NTZ Nachrictentechnische Zeitschrift. Vol. 17 No. 9 478-483 (September 1964)

NL

STATE OF THE TECHNIQUE ON SURGE PROTECTION OF TELECOMMUNICATION INSTALLATIONS WITH SURGE DIVERTERS

Protection against atmospheric voltage surge (lightning, static charge) and protection against the influence of power plants (direct overvoltage, capacitive and inductive coupling) must be differentiated with respect to cause. The surges which must be rendered harmless differ by orders if magnitude, height and duration. In accordance with this, there exists a number of safety devices which, because of technological and economic reasons, can only be used against one kind ofsurge or another. In connection with this, the state of the usage technique of surge diverters permits their satisfactory and extremely economical use for operation and protection against all dangerous surges occuring in telecommunication installations, as long as they do not deal with permanent potentials such, for example, as those caused by traction currents of electric trains.

1. Protection against atmospheric surges.

In protection against atmospheric surges through proportional voltage methods, in which the outlay corresponds directly to the expected surge, for example, exclusively through

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appropriate insulation, nonatter how extensive and costly an outlay would be needed, there could always be found a residual probability failure becaase of the statistical behavior of these surges, according to place, duration, and volume. Therefore, it has always been necessary to use, for protection against atmospheric surges voltage-independent safety elements, i.e. those not restricted in their effectiveness by the high voltage of the surges, namely, surge limiters of various types, radio air links, carbon diverters, various semiconductive components, and surge diverters. Here preference is more and more often given to surge diverters (cold cathodes, gas discharge tubes) for example as in /1/. They alone make it possible to obtain, from the environmental influences (air pressure, air humidity, temperature and contamination), independent close-tolerance ignition voltages and other properties which show only minimal changes even after repeated, strong loads. Thus, disturbances originating in surge-limiter defects are avoided.

Protection through efficiently operating surge diverters has shown excellent results everywhere. The remaining low number of failures can be further diminished, if enough attention is also paid to devides working with the diverters, such as good grounding circuits, the avoidance of voltage overloads by means of reflections at nongrounded cable ends, etc.

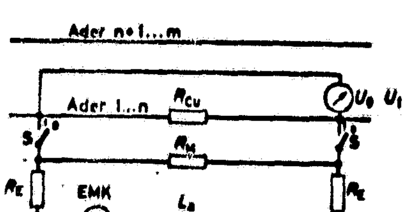
2. <u>Protection against the influence of power plants</u>.

The area of protection against sureges from power plants is distinguished by a constant increase in the number of affected telecommunication lines, as can be expected with the increase of the network density of telecommunication installations in the one hand, and of power supply lines and electric trains on the other. The construction of "energy roads", i.e. narrow, parallel-directed, diverse power supply lines, as well as possibly pipelines for the utilization of their reduction effect, and for the spatial compression and separation of telecommunication installations, is also of very little use. In the forseeable future, an affected telecommunication line will be an ordinary occurrence. The increasing energy consumption requires the simultaneous installation of efficiently operating units in power plants and transformer stations, and the conversion of transmission lines to higher voltages. Connected with this is also an increase of energy supply lines with solidly grounded operation. All this leads to the conclusion that, in rhe whole, surges induced into the telecommunication lines by single phase ground short-circuits of the energy supply lines must manifest a constantly growing tendency in number and volume, even if a substantial expenditure is invested for reduction by means of ground cables and insulation improvements. As the onset of short-circuits, with a few exceptions, is brought about by atmospheric processes with a statistical behavior, (lightning, sunrise flash-overs because of dew covered insulators with a simultaneous increase of air ionization), an economically still justifiable further increase in expenditure for protection against these initiating processes should scarcely have a further reducing effect. Furthermore, it must be concluded from the (as yet unpublished) studies sponsored by the VDE commission 0675/2, as well as from earlier investigations /2,3/, that the influence of the stress time upon the breakdown voltage of paper-insulated cables is only slight as long as the voltage is applied for longer than approximatley 10^{-6} sec. (sic). Therefore an improvement with regard to endangering of the insulation of the telecommunication line, even with a decrease up to now of switch-off periods to approximately 0.1 sec. in the speed degree of the energy supply lines in case of a breakdown, is scarcely to be expected.

In principle, it is possible to combat the disturbances and endangerment of telecommunication line and personnel, resulting from the influence of heavy current, by surge proportional methods. Aside from eht necessity of providing for the rising costs of these protection methods, which are at least proportional to the surges, an effective use of these methods would require a constant communication system between the influences and influenced, and exact knowledge concerning the expected surge in the telecommunication line in question. Aside from the lack of bidirectional mobility, this process could also require increased costs, since, for example, determination of the actual short-circuit current in interconnected networks through the many variables (location of short-circuit, direction and capacity of inputs and outputs, which change according to the time of day and year,etc.) requires an even higher research outlay. In such a case it is possible that the protection measures themselves cost less that the precise investigation of the expected excess voltage in every individual case. Furthermore, the fact must be considered that as the surge heretofore, cannot, for the most párt, be simply supplemented by an addition of further installations in proportion to the surge, but that new costs can arise in connection with the higher surge. Therefore there develops a need for protection system independent of surges which would permit bilateral mobility at least after the first and only installation of safety measures against danger. The present state of the technique on surge protection by means of diverters permits such a sure-independent and economic protection system wuth surge diverters. For this purpose, use is specially made of a long known effect, which in /5/ is named "copper protection", and which until now has been seldom used and often unknowingly, although it is precisely this effect that can give excellent protection to affected telecommunication cables at low cost. The theory is treated in greater detail in /6/.

Figure 1 shows an equivalent circuit diagram of an affected cable. Here, the following simplifications, among others, have been made: instead of continous grounding of the metal sheath, two concentrated earth-transition resistors (resulting from a precise calculation) have been entered. Furthermore, the capacity of the strands with respect to the sheath and its internal inductivity, and, parallel to L_a, a resistance, which takes into account the iron losses in the armor, are omitted. Switches S are entered instead of diverters, i.e. the diverter operating voltage of approsimately 10 v, i.e. 20 v per strand, is not taken into consideration. In Figures 2a,b, and c are entered the currents and voltages to be expected for a cable length of 5 km and an affecting voltage E_o of 500 v. The following practical conclusion can be immediately drawn:

Fig. 1



a= strand

EMF - induced electromotive force

L_a - external inductivity approximately 2 mHy/km-WL=0.628 Ω/km

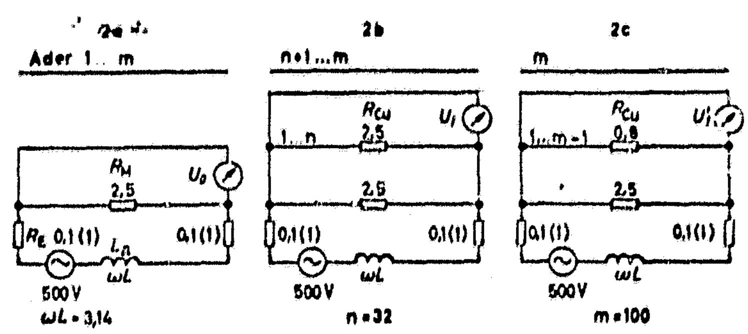
R_M - resistance of the cable sheath

R_E - resultant earth transition resistance, for example: 1.1 Ω or 1Ω.

(text cont'd next page)

R_{Cu} - resistance of parallel stands 1 to n; for example:
at 1.2 stand diameter 16/n Ω 1 km.

Figure 1. Equivalent circuit diagram for a telecommunication cable with a diverters for protection against surge with use of the latent reduction figure.



	Ω	R_E 0,1	1		R_E 0,1	1		R_E 0,1	1	
Kreisimpedanz	Z_0	4,16	5,48	Z_1	3,46	4,51	Z_1'	3,24	3,36	Ω
Strom	I_0	121	91,2	I_1	144 $1{,}19 \cdot I_0$	111 $1{,}21 \cdot I_0$	I_1'	154 $1{,}27 \cdot I_0$	126 $1{,}37 \cdot I_0$	A
Phasenverschiebung	$\Delta\varphi$	+49	+35	$\Delta\varphi$	+65	+44	$\Delta\varphi$	+75,5	+50,5	0
Induzierte Spannung Ader/Mantel	U_0	302	228	U_1	180	139	U_1'	92,5	75	V
$r_{lat.} = \frac{U_1}{U_0}$		—	—		0,6	0,61		0,31	0,33	
Erderspannung $I \cdot R_E$	U_{E0}	12,1	91,2	U_{E1}	14,4 $1{,}19 \cdot U_{E0}$	111 $1{,}21 \cdot U_{E0}$	U_{E1}'	15,4 $1{,}27 \cdot U_{E0}$	126 $1{,}37 \cdot U_{E0}$	V
Gesamtpotential Ader/Bezugserde $U_{E0} + \frac{U_0}{2}$		178,1	205,2		104,4	180,5		61,7	163,5	V

Fig. 2

b= strand

Kreisimpendanz- circuit inpendance

Strom - circuit

Phasenverschiebung - phase shift

Induzierte Spannung - induced voltage

Ader/Mantel - strand/ sheath

Erdspannung - earth excess voltage

Gesamtpotential - total potential

(Text cont'd next page)

Ader/ bezugserde - strand with respect to earth

Figure 2. Currents and voltages appearing in a cable according to Figure 1, 5 km long at 100 v/km of induced electromotive force without and with varied use of the latent reduction figure.

2.1. Latent reduction figure.

If, in the case of influences, switches S are closed (Figure 2a, b, c), i.e. in example 2b (e) 32 (100) diverters respond, then the resistance of the strand R_{Cu} must be switched parallel to R_m. The total resitance of the circuit changes from Z_o to $Z_1 (Z'_1)$. With this, the currents and voltages change as shown on the Figures. Thus paralle switching of stands through diverters effects a reduction of voltage in the remaining stands, the total C_u-diameter containing the "latent reduction figure" r_{lat} (which is not indispensably needed in its entirely, nor used. The process would in practice take place in sucah a manner that each time the diverter pairs with the lowest operating voltage respond, and furthermore, as many of them as needed, until the reduction effect becomes so great, that the operating voltage is not reached for the remaining diverters. This leads to 3 very essential conclusions for surge protection with use of the "latent reduction figure" by means of diverters.

2.1.1 Ungrounded protection for constantly operating strands.

Special strands, which may in no case be grounded, particularly when the surge takes place, may be left without individual protection if the surge is correspondingly reduced by diverters in the remaining strands of the cable. The response voltage of the diverters determines also the voltage in the unprotected strands. Therefore, it is very advantageious to use diverters with a low response voltage. Only when the surge is so high that the "latent reduction figure" is completely used up, i.e. when all the diverters have responded, will the voltage in the strands be without individual protection: $U_1=U_o x\ r_{lat.}$ The ungrounded protection for special strands is obtained in a diverter-protected cable of its own self, without any supplementary outlay.

2.1.2. Security of the protection.

From 2.1.1 it follows that there is no danger, if, in a cable with many pairs, which is completely protected by diverters, individual diverters are defective, so long as $U_1 = U_o\ s\ r_{lat}$ remains below the permissible maximum.

2.1.3. Monitoring expenses.

Becuase of 2.1.2 it is possible to assign considerably longer intervals than before for monitoring the installed diverters; this favorably affects operating economy.

2.2. Rises of potential.

It can be seen from the examples that inductivity L_a contributes substantially to the circuit impedance Z_o(or Z_1). Consequently, even in the most disadvantageous example (Figure 2c with $R_E = 1\Omega$) the total current rises only by a factor 1.37. When the diverters are switched on, it is therefore not so much that an additional diverted current is created, but rather that a shift of the current from the heat-sensitive sheath to the strands takes place. Thus, with the use of diverters in ground cables no significant supplementary rise of potential is to be expected, as is likewise to be inferred from the exact calculations in /6/. The potential of particular importance to the case of influence --strand-reference--ground-- is, on the other had, substantially decreased.

In case of the use of cables with an insulated external sheath and bad ground conductivities, it is of course, conceivable that for a smaller intermediate intensification unit an adequate grounding installation cannot be built with economically justifiable expenditures. The formation of inadmissible potential differences is, however, avoidable through a construction of a "total protection" by means of diverters. Only in the case of cables which are not at all only slightly affected, and therefore are not provided with diverters, can, under special conditions, an inadmissible potential difference be picked up, because such cables take over the potential of remote points. If all these cables("total protection") or else a specially determined, sufficient number of them are provided on both sides with diverters, i.e. to admissible values. (Figure 3).

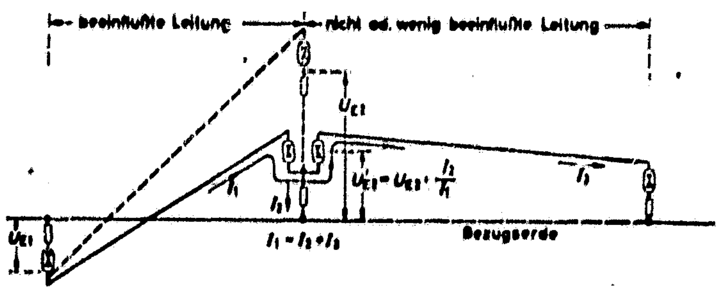


Fig. 3

Beeinflusste Leitung - affected cable

Nicht oder wenig beeinflusste Leitung - not or lightly affected cable;

Bezugserde - reference ground

Figure 3. Potentials with partial protection - - - - - -

Potentialc with a total protection - - - - - -

If we are dealing with cables, in which only low service voltage (peak value under 130 v) are directed to the ground it would be even possible, by the use of diverters with operating voltages between the highest service voltage and the maximum of 175 v = (highest tolerance value: 125 V 2), to attain the result that no higher voltages than 125 V_{eff} can be directed to the ground.

2.3. Residual voltages and cross voltage. (External and noise voltages).

Furthermore it can be seen from the equivalent circuit (Figures 1 and 2) through the inductivity L_a, that the current and the voltage are out of phase with respect to one another. These inductive phase shifts are also presented in /6/. However, diverters activated in such current circuits show an extremely advantageous effect. The cut-off pause (i.e. the time interval during which no current flows) becomes shorter than in a current circuit with only ohmic resistances.

As a result this secondary operating voltage (i.e. the operating voltage in the 2-nd, 3-d, etc. half-waves), becomes smaller. In the extreme case the diverter no longer cuts off at all through the entire duration of the surge. Rather it reverses the operating voltage into the other polarity, when the current changes sign in next half-wave, since with the zero passage of the current at voltage E, which is higher than the necessary secondary operating voltage, is again already available. The current is more sinusoidal, and avoids sudden changes which occur in current circuits with only ohmic resistances. Figure 4 shows oscillograms of this effect made in laboratory test, and those for short-circuit experiments are shown in Figure 5.

On the whole it can be seen that the residual voltage at the diverter becomes smaller than is to be expected from the observation of diverter behavior in purely ohmic current circuits.

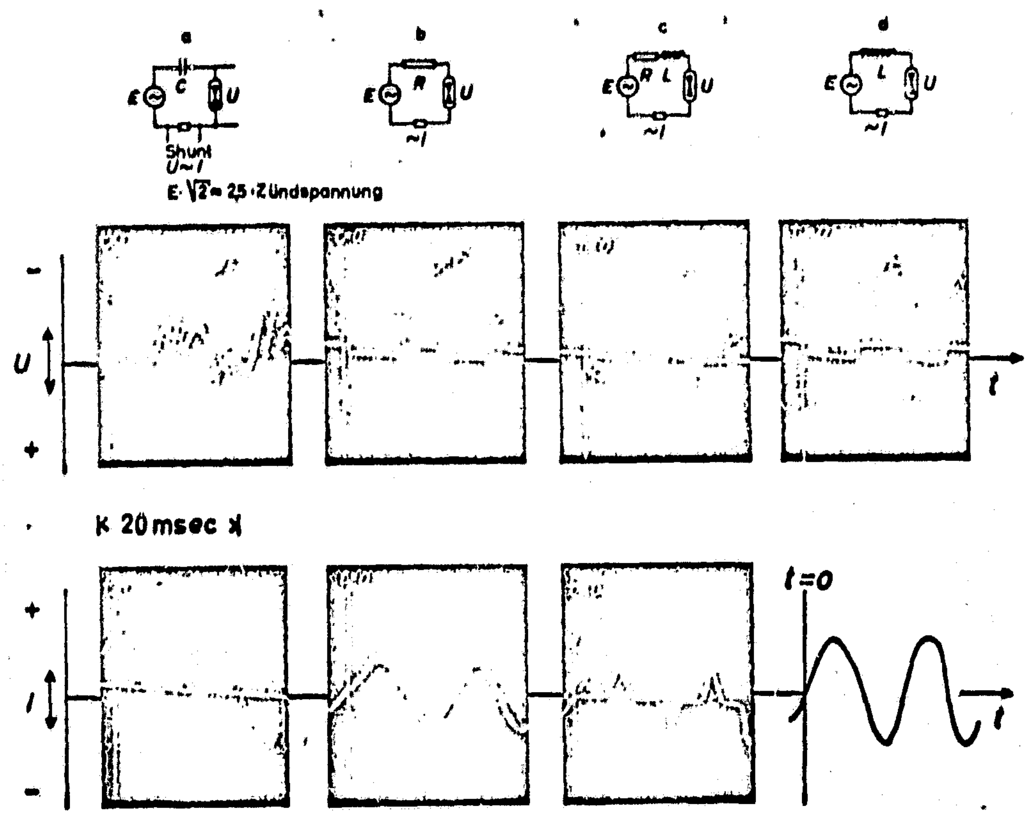


Fig.4

Zundspannung - ignition voltage

Current ------- advances --------- voltage

Higher -------- residual voltage ------- lower

Figure 4. Behavior of a gas discharge section in current circuits of various impendances. Due to connection to the oscillograph, ths sign in the voltage recording is reversed.

e)

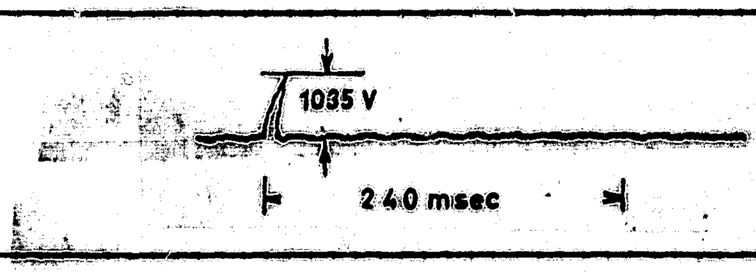


Figure 5. Residual voltage at a diverter at 1035 v operating voltage.

The residual voltage at a single diverter (voltage between strand and ground) affects also the transverse voltage, i.e. the voltage between 2 strands. The smaller the residual voltage of the individual strand, the lower is also the possible transverse voltage, the difference between the residual voltages of 2 strands provided with diverters. Figure 6 shows an example of such a transverse voltage. In cables which are terminated by transformers, this transverse voltage is avoided simply by connecting the diverters between the center of the transformer winding and the ground. Unfortunately, this connection system has, up to now, been much too little used.
* In cables which are not terminated by transformers, it is possible to obtain the same result with a single coupling coil (installation in one end of the cable is sufficient), because all 4 diverters of a DA/ double strand/ are actuated simultaneously.

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*) According to information given by Bayernwerk A.G. (Bavarian Plant) of the Bavarian State Electric Power Supply, this connection system has operated successfully and without any interferences against atmospheric voltage influence in, for example, the telecommunication installations of the Niedernach power plant and at Rissbachwehr for approximately 10 years. The same protection measure is also used against interferences originated by ground short-circuits.

f)

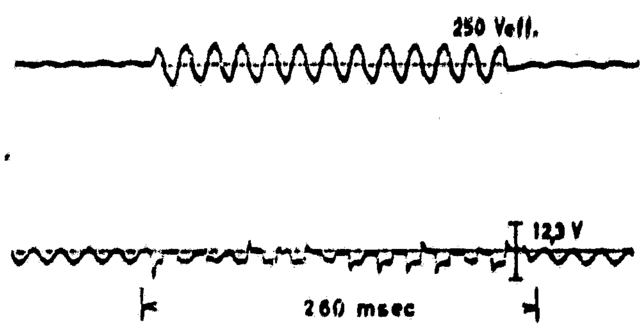


Fig. 6

Figure 6. Voltage between 2 strand orivuded with diverters (lower curve). (Upper curve U_1 of Figure 8 with a hump in the second half-wave due to a building-up process.

A transverse voltage also occurs even without the use of diverters in the investigated cable at all, or only in the investigated couble strand. The value of this transverse voltage is determined by the asymmetry of the two strands with respect to the ground and the longitudinal asymmentry and by the voltages occurring in the cable. Low longitudinal voltages produce lower transverse voltages. When no value has been assigned to it, this transverse voltage, which consists of a frequency mixture, will be names external voltage and, when appropriately evaluated for audio frequency, is called noise voltage. /72,7b/. The basic frequency of the leakage processes is that of the interfering power-line frequency (50 cps or 16 2/3 cps. However, these are frequencies which make only a small contribution to the noise voltage. Oscillograms of external voltages obtained in shor-circuit tests for varied termination of strands are shown in Figure 7. It is to be noticed that the registered low voltages appear only for the duration of the short-circuit (=0.1 sec.). Without appropriate equipment the DA could not always be cut off reflection-free. There can nevertheless, be made a comparative deduction to the effect that no substantial deterioration of noise and voltage has taken place with the use of diverter protection. tection. Particularly favorable for the continued smallness of all transverse voltages except for the highest possible inductive phase shift, is when diverters of the lowest possible ignition voltage and of the lowest possible minimum current are used for the build-up of an arc discharge.

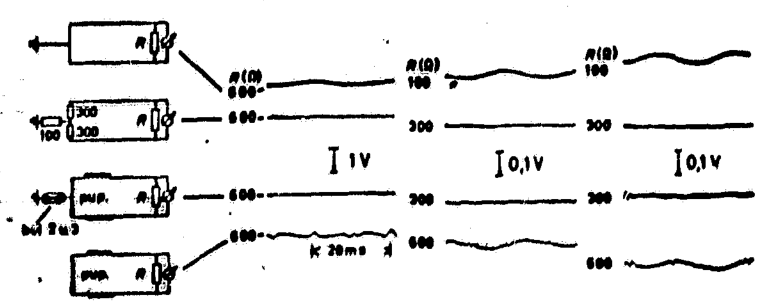


Fig. 7

g)

1. All other strands are ungrounded, without Voltage strand sheath: U_o=271 v	2. 25 DA / / are grounded from both ends U_1 = 116 v	3. Diverters respond at 16 DA / / U_1= 149 v

Figure 7. Oscillogram of external voltages is diversely connected strands. (Measurement sensitivity was increased by a factor of 10 between test 1 and tests 2 and 3.)

2.4 Frequency dependence.

The latent reduction factor for the examples of Figure 2 is :

$$r_{lat} = \frac{R_{Cu}}{R_M + R_{Cu}} \cdot \frac{\sqrt{(R_M + 2\,R_E)^2 + \omega^2 L_k^2}}{\sqrt{\left(\frac{R_M \cdot R_{Cu}}{R_M + R_{Cu}} + 2\,R_E\right)^2 + \omega^2 L_k^2}}.$$

For direct current this would result in

$$r_{lat} = \frac{R_{Cu}}{R_M + R_{Cu}} \cdot \left(1 + \frac{R_M^2}{R_M R_{Cu} + 2\,R_M R_E + 2\,R_{Cu} R_E}\right).$$

This would yield in the example instead

$$r_{lat\,(50\,Hz)} = 0{,}33 : r_{lat\,(0\,Hz)} = 0{,}417,$$

but this means that r_{lat} is also effective for very low frequency processes.

On the other hand effectiveness of the protection installation against inductive surge, as, for examples, in the armoring of cables for the improvement of the r_k- factor, decreases approximately in proportion to the frequency. The inductive appliances are installed for a defined frequency. Of particular importance is the not greatly frequency-dependent effect of r_{lat} in the case of protection against the hump surge factor of induced surges during the first half-waves, brought about by a low-frequency transient (in an energy-supply line during a short-circuit(direct-current link) /8/.

A higher first half-wave, which can also be found in the experiment on diverter-protection (Figure 6 above), which remains, however, in the range of diverter's operating voltage, has, in addition to the above-indicated, insignificant frequency dependence of the diverter protection primarily the following cause: more diverter-pairs are actuated during the first higher half-wave than would be needed for reduction of the operating voltage in the following half-waves. All these diverters continue nevertheless to be activated at a lower surge due to the secondary operating voltage already reduced after the first half-wave, thus reducing the surge to a level, which is lower than the operating voltage.

3. Measurement results of diverter protection with application of the latent reduction factor in practical short-circuit tests.

In course of the past year the author was given several opportunites*) personally to mae measurements on telecommunication cables, or to take part in such measurements during which short-circuits were applied to power lines running parallel to these cables. Switching operations and measurements values of tests, performed in Weisweiler on November 22 and 23,1963, are shown in Figure 8. These values have been published in /9/. The result of $r_{lat} \simeq 0.3$ was obtained in the investigated "Nordkabel" (Northern cable) (52 strands 1.2 mm in diameter.

*) Special appreciation is due to the REW, the Bayernwerk (Bavarian Plant) and the Schlushsee Plant. The author thanks also the Federal Post Office for putting the measuring equipment at his disposal.

By application of the approximation equation

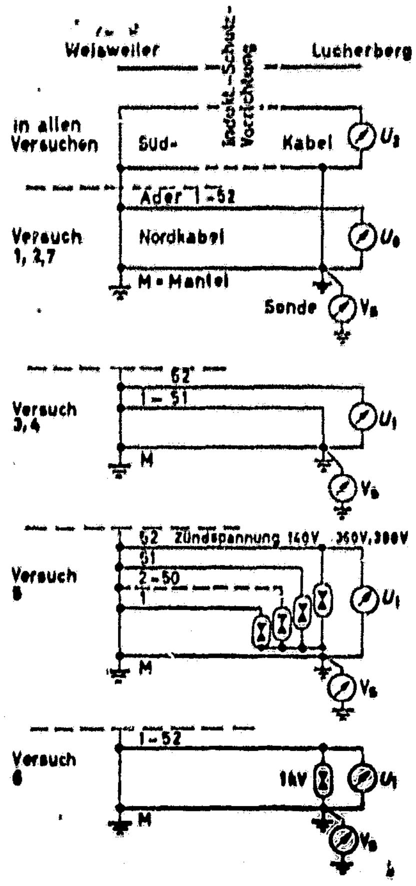
$$r_{lat} \simeq \frac{R_{Cu}}{R_M + R_{Cu}} \quad \text{with } R_{Cu} = 1.8\ \Omega$$

we obtain an R_M of 4.2 Ω whivh is to be understood as the resultant resistance by the cable sheath and other parallel-lying cables in the ground. From tis it can be concluded that, in correlation with similar in the tests performed on the "Sudkabel" (Southern Cable), which was provided with inductive protection, approximately an

$$r_{lat} \simeq \frac{0.9}{4.2 + 0.9} = 0.176$$

is to be expected in the diverter protection.
Of interest is the overlap of the reduction effect of r_{lat} from the nothern cable to the southern cable, while in the opposit case no effect could take place except for the fact that the parallel connection of the sheath of the southern cable decreased in effectiveness. The consideration described in 2.1.1., concerning the fact that only such a number of diverters will be activated that the voltage is lowered to the value of the operating voltage of the next-to-highest activated diverters, has been proven in Test 5 by the use of diverters with a staggered operating voltage. The last diverter with an operating voltage of 390 v was not actuated. An attempt was made to determine the potential raise of the grounding installation at Lucherberg, by means of a long probe approximately 300 meters, inserted perpendicularly to the tested section. Extremely

favorable grounding conditions yielded the values in Figure 8. The residual voltage of a diverter, already shown on Figure 5, was registered in Test 6, and in Test 5 the transverse voltage shown in Figure 6 was registered. Thus,is sum, the tests show with the theory presented in /6/, and with the considerations expressed in 2.1 and 2.4.



Versuch	Kurzschluß-strom I_K kA	U_0 V	U_1 V	U_2 V	U_3 V	Nordkabel U_1/U_0 $r_{tat.}$
1, 2, 7	2,8	520	-	140	0,25	-
3, 4	2,8	(520)	150	65	2	0,288
5	4,2	(780)	250	110	3,6	0,32
6	4,4	(820)	-	120	3,5	-

Fig. 8

k) Values in ( ) are calculation values. All values are rounded-off average values of various tests, observers and equipment.

U_o - unprotected voltage U_1 - voltage with a diverter protection.

Figure 8. Switching results and measurement values of tests with latent reduction factor.

Further tests /10/ on a telecommunication cable with 78 couble strands, with only 17 double strands used for protection yielded a value already of $r_{lat} \approx 0.46$

Tests carried out in the power plant of Walchensee on February 13 and 14, 1964 /11/ yielded a value of $r_{lat} \approx 0.23$ with the use of 38 strands of a cable with 20 double strands 1.4 mm in diameter, for the diverter protection. During this test it was also possible to prove the complete effectiveness of r_{lat} with respect to voltage humps due to transients, which were described above in 2.4. In other, only recently conducted tests with short-circuit currents of approximately 2.6 kilo-amperes, the following values for r_{lat} were obtained in a cable with 114 DA (0.9 and 1.i mm in diameter):

Grounding of 25 DA	$r_{lat} = 0.40$ (measurement)
Diverters are actuated in 16 Da	$r_{lat} = 0.55$ (measurement)
Grounding of all 114 DA	$r_{lat} = 0.157$ (approximate calculated value).

The measurement results of these tests are also in agreement with the above points 2.2 to 2.4. The oscillograms in Figure 7 originate from these tests.

4. Conclusions.

It has been possible to demonstrate that in addition to the already known advantages, that surge protection by diverters is shown by deailed investigations to have still other very substantial advantages. For example, it is also possible, by means of diverters, to decrease surges in strands which should be on no account grounded. In cables with a large number of strands it is not dangerous if individual diverters are defective. Furthermore, the safety of individual lines can be increased by means of an economically justifiable parallel connection of two diverters. Therefore, it is possible to improve the operating economy of the extremely useful diverters by rare expenditures for monitoring operations. Moreover, it is possible to increase the efficiency of testing expenditures by using such mounting and control equipment for the diverters, which permit the simultaneous handling and automatic control of a larger number of diverters (for example 10), instead of using the older type of mounting and control equipment which requires the removal and testing of each individual diverter.

The rises of potential due to diverted currents are low, because the current increases only slightly with the introduction of diverters: there takes place rather only a shift of the currents from the cable sheaths to the strands. In places where the pick-up of inadmissibly high voltage is possible because of special reasons, the method of the total protection removes this possibility by protecting all lines, even the unaffected or slightly affected ones, (see Figure 3). In addition, this method brings out the protective value of the diverters, which is independent of the surge. The surges can therefore also have high values, without oossibly somewhere picking up higher potential differences than those which correspond to the operating voltage of the diverters, i.e. to the admissible values. In the general use of this method, which is partly covered, or harmonically supplemented by the existing protection against atmospheric surges, it would thus be possible to attain an important measure of mobility in the switch-system of the telecommunication and power plants, whereby the economy would be indicated by this comparatively extremely low, one-time prime cost, which is independent of the height of voltage surges.

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