INVESTIGATION OF SINGLE-PHASE RECLOSURE USING A TRANSIENT NETWORK ANALYZER

By

G. BÁN

Institute of Heavy Current Engineering,
Department of Electric Power Plants and Networks
Technical University, Budapest

Received September 27, 1979
Presented by Prof. Dr. O. P. GESZTI

1. Importance of the problem

In the operation of extra high-voltage (EHV) transmission lines the use of single-phase reclosing is of high interest, because such automation can increase in a substantial measure the reliability of the line. The insertion of single-phase reclosure will be to the purpose, if it is ensured that the phase-to-ground arc is extinguished within the longest permissible dead time value, determined by the stability conditions.

Owing to the large capacity between the phases, with long lines the phase-to-ground arc is not immediately extinguished after breaking on both ends of the faulty phase. Owing to the capacitive and inductive coupling between the phases, the magnitude of the arc current is even then still 50—100 A. For the extinction of the arc a time of an order of second is needed, until the lengthening of the arc because of air movement and magnetic action becomes sufficiently large. In view of the fact that the reliability of the line increases with decreasing dead time, it is a natural aim to attempt the shortening of the arcing time of the so-called secondary arc forming after breaking. The importance of this is emphasized by the circumstance that after the extinction of the arc, time must be provided also for the regeneration of insulation at the site of the arc channel, because in a substantial part of the cases reclosing is accompanied by overvoltages, involving the danger of reignition of the arc. Methods for the reduction of the magnitude of the secondary arc current or of the recovery voltage after the extinction of the arc, i.e. for the shortening of arcing time, are:

a. Compensation of the capacitance between the phases by the insertion of so-called neutral reactors, between the neutral point of the shunt reactors and the ground.

b. Compensation of the capacitance between the phases with a capacitor connected in parallel with the breaker of the faulty phase.

c. Earthing one or both ends of the line for the shunting of the arc.

Of the afore-mentioned methods the solution according to a. seems to be the most advantageous, if the neutral point voltages for the shunt reactor insulation arising from the insertion of the neutral reactor are tolerable. This method requires substantial surplus investment, causes operational problems, and increases at a certain degree the probability of a failure of the shunt reactor insulation. It seemed therefore appropriate to investigate in detail the phenomena proceeding in the line—arc system from the formation of the phase-to-ground arc to the extinction of the secondary arc, and to establish on the basis of these findings the degree of arc time shortening, which can be expected with neutral reactors.

2. Method of investigation

The main device of the investigations was the transient network analyzer (TNA) developed at the Institute of Heavy Current Engineering of the Technical University Budapest. TNA, coordinated with a computer, has been used since several decades for the solving of HV and particularly EHV network problems. These physical models facilitate the elucidation of the processes, give information on the effect of the change of network parameters, and are suitable for the control of the results of computer calculations of increased accuracy, possibly becoming necessary. TNA developed at the Institute of Heavy Current Engineering for educational and research work has been complemented for the purposes of the investigations reported in the present communication with a dynamical arc model. The arc model parameters have been determined partly under utilization of data available in the literature, and partly on the basis of field test results obtained on the transmission line Zapadnoukrainskaja—Albertirsa. Experimental results obtained on the TNA have been controlled by a similar method.

3. Course of the phase-to-ground arc current

Figure 1 shows the oscillogram of the current of the phase-to-ground arc, recorded in field test. The primary arc current (section I.) contains a substantial d.c. component, which occurs at random: it depends on the moment of the ensuing of the fault. In view of the fact that the flashover of insulators of EHV transmission lines occurs at high probability as a consequence of lightning stroke or surface pollution, there is no distinguished value in the moment of the development of phase-to-ground arc. Following the breaking on both sides of the faulty phase, the primary arc develops into a secondary arc. The transition process (section II) is characterized by a damped transient oscillation of higher frequency and by a d.c. component. Next, the secondary arc current becomes a current of operating frequency, containing relatively few harmonics (section

III). In the last phase before extinction (section IV) the arc current becomes irregular, and is characterised by asymmetry, outstanding peak values, and intermissions lasting over times of several half-periods.

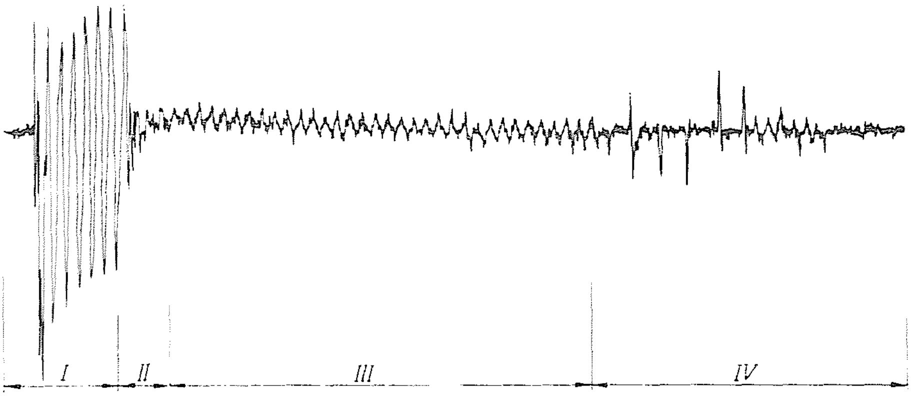

Fig. 1. Current of the phase-to-ground arc

It can be seen from Fig. 1 that the primary and then the secondary arc current are of transient character almost over the whole duration of the process, actually comparising a series of transient phenomena. Their investigation at an accuracy meeting practical demands can be undertaken most advantageously with TNA. Our present work reports on the analysis of section II and IV of the process.

3.1 Current components of section II

The physics of the development of current components can be understood on the basis of Fig. 2. One of the components is developed as a result of the capacitive and inductive coupling with respect to the two unfaulted phases, its amplitude being mainly determined by the voltage of the unfaulted phases and the capacitance between the phases. (Owing to the high ionization of the plasma residue from the primary arc, in this section arc resistance can be neglected as compared to the capacitive reactance of $\frac{1}{2\omega C_{ab}}$.)

The high-frequency component of section II results from the wave reflection series developed on opening the breakers of the faulty phase. Since the average value of arc resistance in the high-current section I of the arc is of an order of magnitude of 1 ohm, arc resistance at the beginning of section II is still considerably lower than the wave impedance of the line. Thus, the switching-off current wave is reflected at the site of the arc with a positive, at the open end of the line with a negative reflection coefficient, which gives the wave process an oscillating character. Frequency and amplitude of the oscillation depend for a short circuit current of given magnitude on the location of the phase-to-ground arc: amplitude is highest and frequency lowest when the fault occurs at the center of the line, or in the case of a line open only at one end, near to the non-open end. Oscillation becomes more complicated, if the breakers do not switch off at the same moment on the two ends of the line.

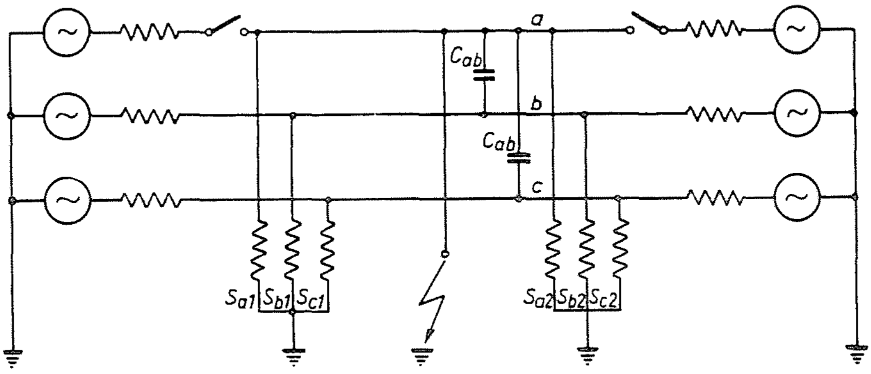

Fig. 2

The point of time of the formation of the d.c. component coincides with the moment of occurrance of phase-to-ground arc. If the shunt reactor current of the faulty phase is just maximal at the moment of the development of short-circuiting, then this momentaneous current value approaches zero value at a high time constant, corresponding to the high inductance of the shunt reactor, to the low impedance of the line and to the low resistance of the arc. If the shunt reactor current is just in zero transition at the moment of shorting, there will be no d.c. component.

If several shunt reactors are connected to the line, it follows from the abovesaid that a higher d.c. component will flow trough the arc. The resultant d.c. is affected also somewhat by the power transmitted through the line, because it shifts in time the current maxima at the two ends of the line with respect to one another. After opening the faulty phase, the shunt reactor current continues to flow through the secondary arc, therefore, the higher d.c. component will be added to the component of operational frequency, arising from coupling, and to the breaking transient, the shorter is the period between the occurrence of shorting and breaking the faulty phase.

It can be seen from the oscillograms of Fig. 3 that the current of the shunt reactors contains in section I of arcing also a considerable component of operational frequency. This is due to the fact that when the fault is located at a greater distance from the endpoints of the line, voltage does not drop to zero value at the terminal of the shunt reactor (see curve 1 in Fig. 3), so that also current of operational frequency must flow through the reactor. However, this component has no effect on the d.c. component of section II. The circumstance namely that the line breakers break the practically inductive short-circuit current in zero transition, provides for the ceasing in zero transition of the reactor current of operational frequency.

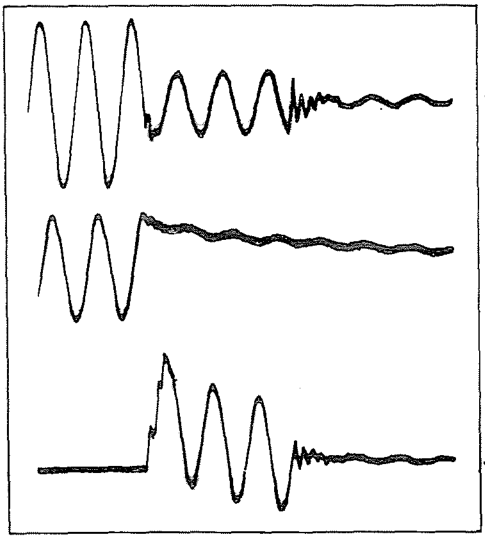

Fig. 3. Sections I and II (TNA). 1. Voltage at the end point of the faulty phase conductor; 2. Current of the shunt reactor; 3. Arc current

The development of the current components of section II is of importance, because the first zero transition of the secondary arc current may be retarded by the presence of d.c. component. This circumstance attains particular importance, when neutral reactors are inserted, because here the operational frequency component of the secondary arc current is of low amplitude.

In the development of the current of section II an important role is played by the increase in arc resistance, due to a considerable decrease of about two orders of magnitude of the arc current. The characteristics of the increase in arc resistance have been simulated in our TNA arc model under the justifiable assumption that in the period of 60—80 ms following the decrease in arc current, the cooling of the arc channel is not influenced by the secondary arc current, and arc resistance is dependent only on the current of the preceeding high-current arc. This is supported also by speed-films recorded on the forming of phase-to-ground arc during test fields.

Under the above assumption, network configuration, and switching moments corresponding to the field tests have been adjusted on the TNA, and the speed of the increase of arc resistance has been changed on the arc model, until section II of the current oscillogram obtained in the field test was exactly obtained on the TNA. With the arc model calibrated in this way, those network configurations could be also investigated (e.g. the insertion of neutral reactors), for which no field tests have been performed. With this method e.g. the longest secondary arcing time can be established, during which the extinction of the arc is not to be expected, even when using neutral reactors.

For the true simulation of the d.c. component on the TNA the arc resistance of the real primary current must be known. This is determined by simulating on the TNA the configuration of the field tests and changing the arc resistance characteristics of the model of the primary arc, until the curve of the reactor current obtained on the TNA becomes completely identical with that of the reactor current in the field tests.

3.2 Transients of section IV

In section 3 of the process the length of the arc still makes possible the continuous burning of the arc. The beginning of section IV is represented by that state, in which the considerable removal of the arc plasma from the insulator surface forces the arc to such measure of elongation that the arc becomes unstable because of the large arc length. The resistance of certain zones of the arc channel considerably increases, and on these parts even the relatively low arc current produces substantial voltage drop. Thus, along the arc channel, generally containing many curvatures, sparkover occurs, the current of which is not determined anymore by the supply voltage and the capacitance between the phases, but by the earth capacity of the faulty phase and the sparkover voltage of the gaps in the arc channel. This explains, that the arc current is pulse-like in this section, and of larger amplitude, than the current of the preceding section.

A detailed investigation of arc-reignition processes was thought to be expedient, because certain reignitions seem to increase substantially the time of the arc (those which considerably change the thermal state of the arc), while others scarcely.

From the point of view of the consequences of reignition that wave process is of great importance, which is produced by reignition on the line. The reignition-current wave reflected on the open end of the line, on reaching the arc channel, cancels the current of the arc and causes at high probability the extinction of the arc. This is indicated in Fig. 4 (fault at the centre of the line). Moreover, the voltage oscillogram of the figure shows, that following the extinction of the reignited arc, the recovery voltage attains only during the next period of operational frequency a substantial value because of the series of wave reflections. This is the reason why in section IV of the process arc current interruptions lasting for a half period systematically occur, and these interruptions further the regeneration of the insulation.

It follows from the abovesaid that the regeneration of the insulation depends on the location of short-circuit, because the point of time at which the cancelling current wave arrives at the arc channel is a function of travelling time. Fig. 5 shows the oscillograms of a reignition, where fault is located at one end of the line. The length of the reigniting current pulse is twice of that shown in Fig. 4, so that evidently it represents a greater danger from the point of view of the lengthening of arcing time.

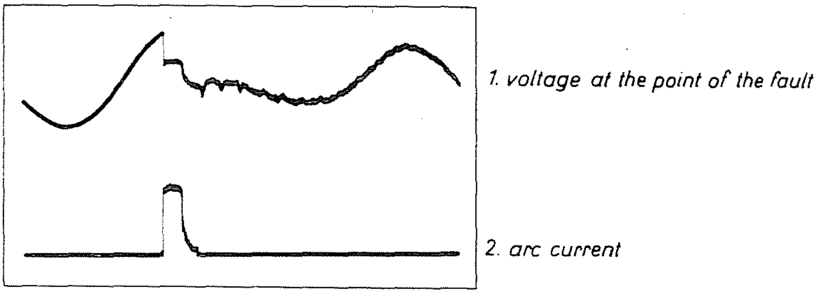

Fig. 4. Reignition at the centre of the line (TNA). 1. Voltage at the location of the arc; 2. Arc current

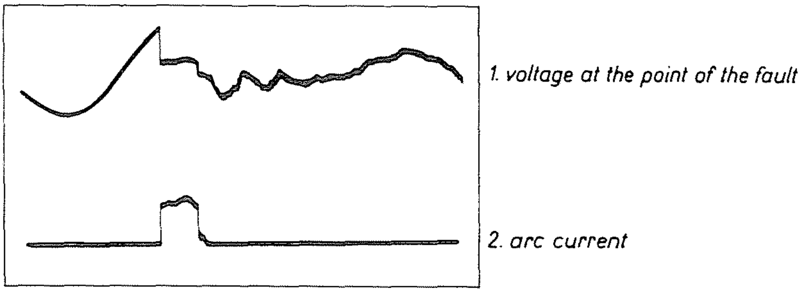

Fig. 5. Reignition at the end-point of the line (TNA). 1. Voltage at the location of short circuit; 2. Arc current

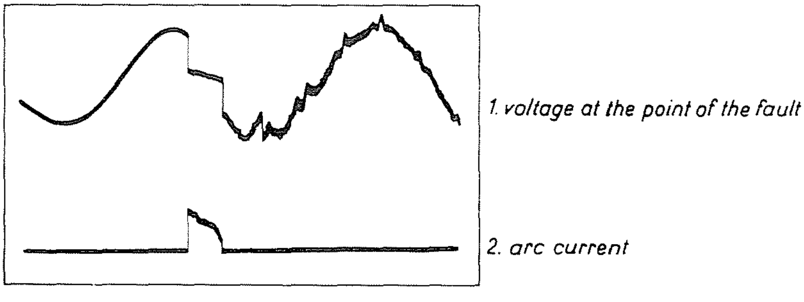

Fig. 6. Reignition at the end-point of the line (TNA). 1. Voltage at the location of the arc; 2. Arc current

In the wave process the moment of the reignition is also of importance. It can be seen from Fig. 6 that in the case of reignition occurring at or after the peak of recovery voltage, the transient recovery voltage following reignition pulse is very steep for the 480 km line length investigated. This generally results immediate in a new reignition, which lengthens arcing time.

Results obtained in the analysis of the transients of section IV are used for the solving of the following problems:

a. In field tests for the determination of the dead time of single phase reclosure, which point of the line will be suitably faulted to obtain the longest arcing time?

b. How to develop a synthetic laboratory circuit for the true simulation of the secondary arc extinguishing process?

c. What possibility exists for the sensing of the moment of arc extinction in the interest of preventing a reclosure to short-circuit?

Summary

The possibility of single-phase reclosure in EHV systems is a function of the extinction time of the secondary arc. A detailed analysis of the phase-to-ground arc is needed to reduce dead time. Dividing the complete arcing process into four sections, physical processes proceeding in the single sections are analyzed. Analysis is based on the oscillograms of field tests and a TNA is used.

Dr. Gábor BÁN, H-1521 Budapest