EQUIPMENT FOR D.C. NETWORKS PROTECTION AGAINST REMOTE SHORT-CIRCUITS

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Abstract

The short-circuits occuring in d.c. networks at long distances relative to the distribution sources result in the apparition of some fault currents with values comparable with the load normal currents. Consequently the over-current protection lose their efficiency and special protection equipment are required. The paper presents the structure, the operation principle and the calibration principle for an equipment for protection against remote short-circuit used for urban railway transport by trams.

1. INTRODUCTION

The d.c. networks which supply the urban railway transport (underground, tram) raise special problems during the exploitation as a consequence of submitting the contact cables to considerable mechanical stresses. The cables break leads to the apparition of some faults whose detection difficulty increases with the distance to the distribution station. Owing to the line electric resistance a remote fault results in the apparition of a deffect current comparable to the currents of normal overload. Such currents occur at trains start and during the connection of some auxiliary installations: conditioning equipment, electric motocompressors and are not detected by the maximal current protection.

Yet the remote fault currents differ from the currents of normal overload through the pair of parameters: increasing slope in the origine $(di/dt)_{t=0}$ and the total jump ΔI as time origine considering the moment of the apparition of the transient regime in circuit. The protection equipment role is to select the short-circuit regime based on these parameters and to control the supplying disconnection of the network where the deffect occured. The transient regimes estimated characteristics in a driving network are presented in table 1.

Table 1

Type of transient process	ΔI *[A]*	$(di/dt)_{t=0}$ *[A/ms]*
Trains start	50 - 300	5 -15
Connection of some auxiliary circuits	40 - 200	100 - 300
Remote faults	200 - 500	45 - 80

A significant dispersion of these parameters can be noticed. This can increase the difficulties in calibrating an efficient protection equipment without a rigurous study of its operation.

A protection equipment against the remote fault have been proposed ever since 1960 by AEG. This is still used nowadays both in its original version and in improved variants, but its efficiency is yet not satisfactory and its calibration remains an actual concern.

Through calibration it is intended to obtain a control curve which divides the plane $\left(\Delta I,(di/dt)_{t=0}\right)$ into two areas: a zone corresponding to a reliable operation of the protection (I) and another one corresponding to the non-operating regime of protection (II), according to fig. 1. The shaded area corresponds to the cases when the current maximal protection acts.

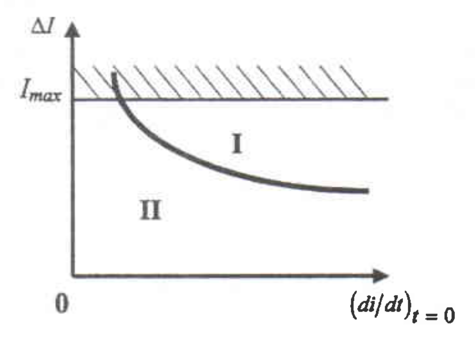

Figure 1

2. STRUCTURE OF A PROTECTION EQUIPMENT AGAINST REMOTE FAULT

A classic protection equipment against remote fault (fig .2) consists of two elements: a slope transformer (TP) and an electronic block - the electronic slope releaser (DEP). The input quantity is the line current *i(t)* whose variations are exponential waveforms due to the inductive character of the load. These variations can be fully characterised through the pair of parameters $(di/dt)_{t=0}$ and ΔI, according to the relation:

$$\Delta i(t) = i(t) - i(0) = \Delta I \cdot \left(1 - e^{-\frac{t}{T_L}}\right) \quad (1),$$

where $T_L = \frac{L_l}{R_l} = \frac{\Delta I}{(di/dt)_{t=0}}$ is the line time-constant.

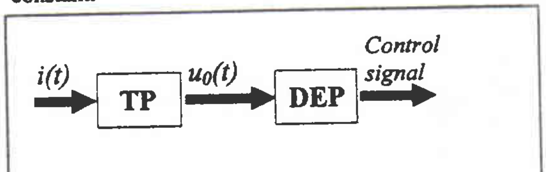

Figure 2

The slope transformer is a transformer with a special construction, whose primary winding consists of a bar carrying the protected line current and which in the secondary winding generates an idle-running voltage $u_0(t)$ which univokely depends on the primary current variations. This transformer also assures the galvanic separation between the force circuit and the one of protection and control.

The voltage across the transformer secondary winding is applied to the electronic slope releaser which generates at output a logic signal. This signal is used to release the ultrafast breaker through which the line is supplied

The used slope transformer is designed in the original variant occured in '60, the slope releaser have been improved but the operating principle remained the same.

The simplified electic schematic of an electronic slope releaser is depicted by figure 3.

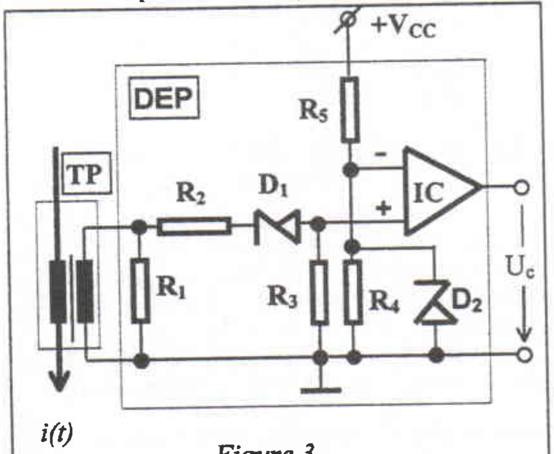

Figure 3

3. OPERATION OF PROTECTION EQUIPMENT AGAINST REMOTE FAULT

Across the transformer primary winding appears a voltage corresponding to a variation of the line current of the form (1) with the expression:

$$u_1(t) = L_{\mu 1} \cdot \left(\frac{di}{dt}\right)(t) = L_{\mu 1} \cdot \frac{\Delta I}{T_L} \cdot e^{-\frac{t}{T_L}} \quad (2)$$

This is valide assuming that the transformer core is not saturating, that is the inductance $L_{\mu 1}$ (the transformer magnetisation inductance reported to the primary winding) remains constant.

For a transformation ratio $K = 1/N_2$, the goal voltage across the secondary winding terminals is:

$$u_{20}(t) = N_2 \cdot u_1(t) = N_2 \cdot L_{\mu 1} \cdot \frac{\Delta I}{T_L} \cdot e^{-\frac{t}{T_L}} =$$

$$= A \cdot \Delta I \cdot e^{-\frac{t}{T_L}} = B \cdot \left(\frac{di}{dt}\right)_{t=0} \cdot e^{-\frac{t}{T_L}} \quad (3)$$

A and B are constants depending only on the line constructive characteristics (through T_L) and on those of the slope transformer (through N_2 and $L_{\mu 1}$). The voltage u_{20} is applied across the slope electronic releaser. There are three operating possibilities :

1) If this voltage does not exceed the voltage applied across the non-inverting input of the comparator IC remains nul and its output remains at a zero voltage level, so that the protection does not function;

2) If u_{20} exceeds the level determined by the stabilising diode D_1, but the voltage applied across the comparator non-inverting input remains lower than the predetermined reference voltage across the inverting input (imposed by the diode D_2), certainly the output remains at the zero voltage level;

3) If u_{20} overcomes the level determined by the diode D_1 and the voltage applied to the comparator non-inverting input becomes higher than the predetermined reference voltage across the inverting input, then the comparator output switches on a voltage level U_C. This level controls the driving of the protection against remote fault (through the release of the ultrafast breaker through which the line is supplied).

Through the performing of an optimal control one imposes the accurate determination of the dependence between the reference voltage U_{REF} and the line current. For this aim we use the equivalent schematic where we underlined the parameters of the slope transformer secondary winding: the resistance (R_{T2}), respectively the leakeage inductance with respect to the primary winding (L_σ); the schematic is supplied by the secondary voltage of ideal running and its output is the voltage applied to the comparator non-inverting input, according to fig. 4. We assume that all the elements from schematic are known.

The schematic operation can be studied in two steps:

Step I: D_1 is blocked and the current through the branch including it is zero; the equivalent schematic is simplified according to figure 5.

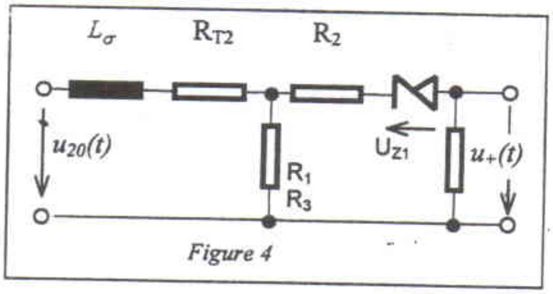

Figure 4

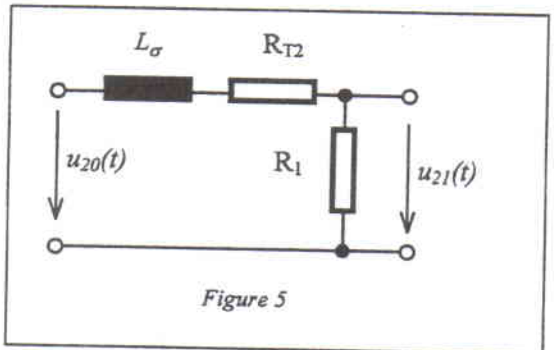

Figure 5

We calculate the expression of the voltage $u_{21}(t)$ across the resistance R_1. Because the circuit operates in a transient regime, we use the operational calculus and we get the Laplace image of the voltage u_{21}:

$$U_{21}(s)=\frac{R_1}{R_1+R_{T2}+L_\sigma}\cdot U_{20(s)}=\frac{R_1}{R_1+R_{T2}+sL_\sigma}\cdot\frac{A\cdot\Delta I\cdot T_L}{(1+s\cdot T_L)} \qquad (4)$$

Through the transformation into the time domain we get:

$$u_{21}(t)=\frac{A\cdot\Delta I}{\left(1+\frac{R_{T2}}{R_1}\right)\cdot\left(1-\frac{T_1}{T_L}\right)}\cdot\left(e^{-\frac{t}{T_L}}-e^{-\frac{t}{T_1}}\right) \qquad (5)$$

where $T_1=\frac{L_\sigma}{R_1+R_{T2}}$ is the circuit time constant.

The obtained expression indicates that the voltage $u_{21}(t)$ is obtained through the composition of two exponentials, the ascending slope being dominated by the time constant T_1 and the descending one by T_L. Actualy this phenomenon leasts only up to the t_1 when the voltage u_{21} equals the diode critical voltage D_1, then $u_{21}(t_1)=U_{Z1}$, when the diode is switches on. The value of t_1 can be easily determined through a numerical or graphical method.

Step II: The moment previous to phenomena developing during this step is t_1 . We are looking for the expression of the voltage applied across the non-inverting terminal u_- using the schematic from fig. 4. Because the circuit operated in a transient regime, using the operational calculus we get the Laplace image of the voltage u_- and consequently its instantaneous value for $t\geq t_1$:

$$u_+(t-t_1)=\frac{R_3}{(R_1+R_2+R_3)\cdot\left(R_{T2}+\frac{R_1\cdot(R_2+R_3)}{R_1+R_2+R_3}\right)}\cdot\left\{-(R_1+R_{T2})\cdot U_{z1}+\frac{R_1\cdot A\cdot\Delta I}{1-\frac{T_2}{T_L}}\cdot e^{-\frac{t-t_1}{T_L}}-\left[\frac{R_1\cdot A\cdot\Delta I}{1-\frac{T_2}{T_L}}-(R_1+R_{T2})\cdot U_{z1}\right]\cdot e^{-\frac{t-t_1}{T_2}}\right\} \qquad (6),$$

where: $T_2=\frac{L_\sigma}{R_T+\frac{R_1\cdot(R_2+R_3)}{R_1+R_2+R_3}}$ is the circuit time constant.

The expression indicates that the voltage u_- results through the composition of to exponential waveforms. The ascending zone is dominated by the time-constant T_2 and the descending one by T_L. The point of maximum U_{+MAX} is determined through the cancellation of the first order derivative:

$$U_{+MAX}=\frac{R_3}{(R_1+R_2+R_3)\cdot\left(R_{T2}+\frac{R_1\cdot(R_2+R_3)}{R_1+R_2+R_3}\right)}\cdot\left\{-(R_1+R_{T2})\cdot U_{z1}+\frac{R_1\cdot A\cdot\Delta I}{1-\frac{T_2}{T_L}}\cdot C^{\frac{1}{1-\frac{T_L}{T_2}}}-\left[\frac{R_1\cdot A\cdot\Delta I}{1-\frac{T_2}{T_L}}-(R_1+R_{T2})\cdot U_{z1}\right]\cdot C^{\frac{1}{1-\frac{T_2}{T_L}}}\right\} \qquad (7),$$

where: $C=\frac{T_L}{T_2}\cdot\left[1-\left(1+\frac{R_{T2}}{R_1}\right)\cdot\left(1-\frac{T_2}{T_L}\right)\cdot\frac{U_{Z1}}{A\cdot DI}\right]$

If the value U_{+MAX} is greater than the reference voltage across the inverting input determined by the critical value of the diode D_2 (U_{Z2}), then the comparator output switches to a voltage level U_C, providing the protection of the line.

The equation $U_{+MAX}=U_{Z2}$ is satisfied by the pair of values $\Delta I, (di/dt)_{t=0}$ which describes a control curve that divides the plane $\left(\Delta I,(di/dt)_{t=0}\right)$ into two zones according to figure 1. It is enough to adjust a value of a single element from schematic to determine the position and shape of the control waveforms. This element is the resistance R_1, whose control is accessible from outside. Through the modification of this resistance the constants T_1 and T_2 are modified.

3. CONCLUSIONS

This study can be useful for the optimal design of the protection equipment of the urban traction networks against remote faults and especialy helps in understanding the operation of this equipment, making possible their efficient calibration. Having in view this aim, only constructive and operational principles were presented, without other technical details.

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