

Transient Regime to Support Steady State Directional Function in Presence of Strong Capacitive Currents in Compensated MV Systems

W.-Y.Huang, R.Kaczmarek

Abstract—A Single Line to Ground (SLG) fault location task in systems grounded with Petersen Coil can be out of reach of steady state methods, based on detection of active component in faulted currents. Efficiency of these methods may not be assured when strong capacitive currents on faulted feeder squeeze the phase shift between the faulted and the sound zero sequence currents below actual acquisition limits.

Then the way to assure the directional decision is to exploit data recorded in transient regime, where an apparent phase difference is more important than actual phase difference in steady state. This is a consequence of the way the transient regime develops, beginning just after the fault inception with phase opposition between the faulted and the sound current residuals and finishing in steady state with a slight phase advance of the faulted residual over all the sound ones.

Keywords: fault detection, distribution systems, compensated systems

I. INTRODUCTION

PHASOR relationship between residual currents in systems with single line to ground fault points unambiguously to faulted feeder in ungrounded systems [1]. However, this may be less efficient in systems grounded with Petersen Coils where selective ground fault detection methods use the in-phase component of the zero-sequence current to discriminate the faulted feeder. The method known for a long time [2]-[3] has until recently been still developed under variant application options, either by comparing signs of projections of zero sequence currents [4]-[5] or looking for phase advance [6]-[7] of the faulted zero sequence current over the sound ones.

It has proved efficient in overhead line systems, confirming general consensus on these methods, which are abundantly cited in literature, but never critically discussed. However,

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with cable proliferation in distribution systems its re-evaluation seems relevant because strong capacitive currents diminish the phase advance between residuals, with possible inhibition of the discrimination capacities of relays.

We will see this phenomenon in steady state SLG fault regime in a radial compensated network (Fig. 1). It can be analyzed on equivalent residual circuit (Fig. 2), where V'' is the voltage over a SLG fault emplacement in absence of this fault [8]-[9], I_{0_f} - zero sequence current on faulted feeder, ΣI_{0_s} - the sum of zero sequence currents on all sound feeders and I_N is the neutral point current composed of active and inductive components.

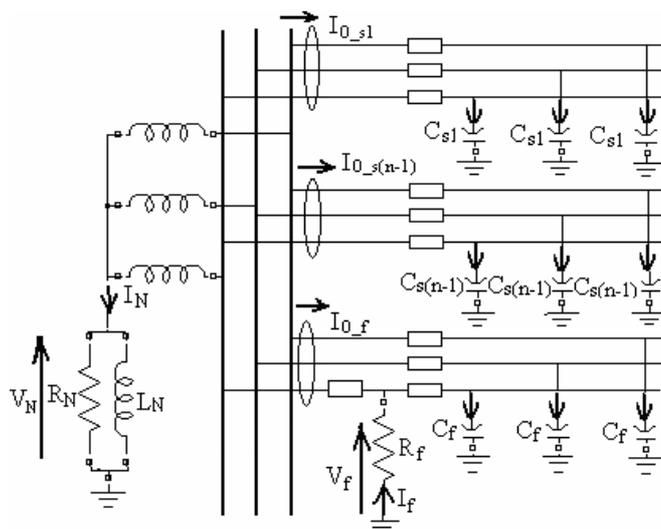


Fig. 1. A radial distribution network with an SLG fault.

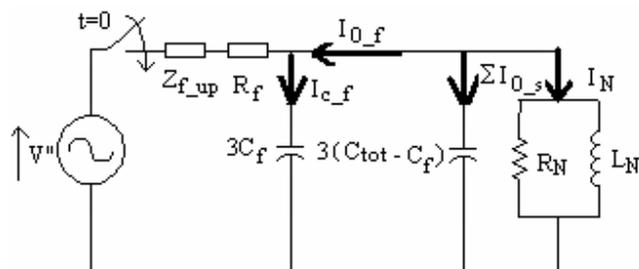


Fig. 2. An equivalent residual circuit of the distribution system from Fig. 1, with the up-stream line impedance Z_{f_up} from busbar to fault

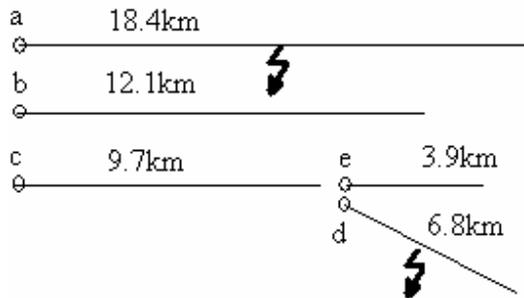


Fig. 5. Feeders disposition for study case

With fault on feeder “d” the zero sequence currents on all sound feeders (“a,” “b” and “e”) are almost in-phase whereas the phase difference ϕ_{ac} between currents on “a” and “c” is 7° , indicating the fault on one of the “c” feeder’s group, but this phase is certainly too low to be detected with 600Hz acquisition.

With sensors on all feeders’ departure we get more pronounced indication $\phi_{ad} = 23^\circ$, but this is still too low comparing to 30° limit.

When the fault occurs on “a” then residuals on “b,” “c,” “d,” and “e” are in-phase, whereas the faulted feeder is pointed by phase difference $\phi_{ab} = 8^\circ$.

With fault on cable feeder there can always be some problem with readability of the phase difference pointing to faulted feeder if its length reaches above certain well correlated length, here 4.5km.

D. Mixed radial system with laterals

To get the mixed system we replace cables on feeders “e” and “d” (of Fig. 5) by 30km overhead lines and place the fault on “d”. With in-phase residuals on “a,” “b” and “e”, the directional information in steady state is given by phase difference $\phi_{ac} = 14^\circ$ measured on busbar, or by $\phi_{ad} = 84^\circ$.

The fault signature becomes unreadable if the faulted feeder “d” is not “replaced by a line”, but “prolonged by a line” with fault occurring on it; in example of Fig. 5 the fault signature ϕ_{ad} will have value of 23° or less, depending on length of this prolongation.

In cases where the critical cable length is of conditional concern, for example with only one feeder approaching this length, there is no use in changing the installed relays, but their efficiency will be confirmed if some auxiliary procedures are available.

As far as static methods are concerned there can be two ways of dealing the limits of low frequency acquisition: either to raise the active current component I_{RN} or to look after an apparent phase difference in transient regime.

III. AN APPARENT PHASE ADVANCE IN TRANSIENT REGIME

As a matter of fact, an analogous parameter in transient regime can be much larger.

This is consequence of the way the transient regime develops, beginning with phase opposition between faulted and sound current residuals [8] and finishing in steady state

with the well known phase advance of the faulted residual over all the sound ones.

A. Homogenous radial system

We apply our diagnosis to 3 feeder radial cable system (18.4+12.1+9.7)km of 3*3.3MVA with fault on the longest feeder and inception angle 90° . With $R_f = 1k\Omega$ the phase difference between faulted and sound zero sequence currents is 8° in steady state and 73° in transient regime (Fig. 6). Unfortunately, the latter depends on fault resistance value. In the study case the phase difference falls down to 8° for $R_f = 1\Omega$.

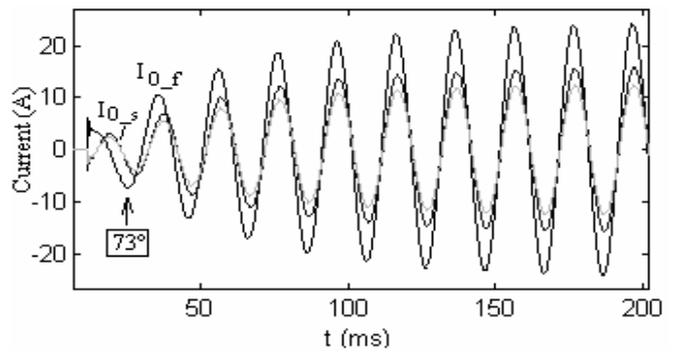


Fig.6 Phase difference between zero sequence currents in transient regime is much greater than in steady state ($R_f = 1k\Omega$)

Still there is a parameter in transient regime, which can be associated with notion of “apparent phase difference”, and points undoubtedly to faulted feeder. The matter goes about the way the residuals cross zero level immediately after fault inception.

The development of current residuals is correlated with evolution of the neutral point current I_N smoothly growing from zero to its permanent value. During the first millisecond after fault inception it can grow very slowly, particularly with resistive faults, because of high values of the neutral point elements L_N and R_N .

On the contrary, the feeders’ line-to-ground capacitors C_f and C_s charge and discharge vigorously. During a short time interval after fault inception the neutral point current I_N is negligible comparing to capacitive zero sequence currents.

Then the faulted zero sequence current is initially in phase opposition to the sound feeders zero sequence currents, see (3):

$$I_{0_f} = -\left(\sum I_{0_s}\right) \quad (3)$$

and proceeds toward zero level with different polarities (Fig. 7). The capacitive zero sequence currents having transients with time constants very short before the fundamental periods they take rapidly form of sinusoids leading the zero sequence voltage V_0 by 90° . Being all under the same charging conditions, the sound residuals cross the zero level in the same moment, whereas the faulted one develops opposite polarity possibly with an exponential component.

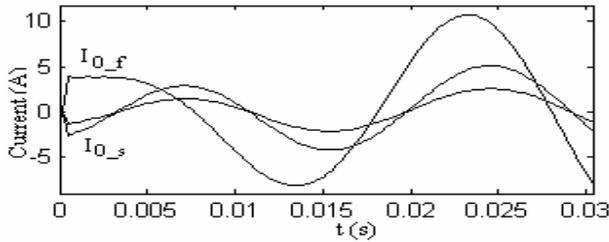


Fig. 7 Zoom on initial transient regime from the Fig. 6

In case of radial system the procedure to point to the faulted feeder is:

We detect slopes of filtered current residuals at their first zero crossing after fault inception. If all but one witness the same slope sign in the same time instant, then we can declare the latter as the faulted one:

$$\text{IF } I_k(t_0) = 0 \text{ for } k = 1 \dots n-1$$

$$\text{AND } \text{sgn}\left(\frac{dI_1}{dt}\right) = \text{sgn}\left(\frac{dI_2}{dt}\right) = \dots = \text{sgn}\left(\frac{dI_{n-1}}{dt}\right) \text{ at } t = t_0 \quad (4)$$

THEN the n^{th} feeder is the faulty one.

This is a one shoot procedure, without possibility of verification. On the other hand it is a conclusive test, as the matter goes about unambiguous identification of slopes' signs.

B. System with laterals

The same occurrence of zero crossing for sound residuals is also valid in systems with laterals (Fig. 8), like the one of Fig. 5 with cable feeders "d" and "e" prolonged with 30km of overhead lines. The fault location on the feeder "d" is pointed by residuals "c" and "d" which cross the zero level elsewhere than three other residuals crossing zero at the same instant.

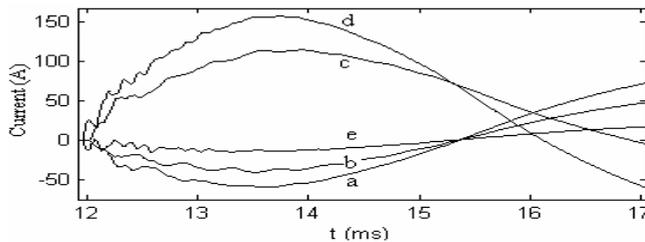


Fig. 8 Faulted ("c" and "d") and sound current residuals in radial five feeders system of Fig. 5, with 30km overhead lines prolonging cables on feeders "d" and "e", an SLG fault on "d". $R_f = 1\Omega$, $\theta = 90^\circ$

IV. CONCLUSION

In distribution systems grounded with Petersen Coils the faulted zero sequence current is initially in phase opposition to the sound feeders zero sequence currents and proceeds toward zero level with different polarities. Examination of these polarities assumes the directional function no matter what is the weight of capacitive currents in the monitored system. It is a robust procedure but it can be applied only once in the transient zone, so it can serve as a subsidiary way to the well known steady-state methods whenever their efficiency may not

be assured because of low frequency of acquisition of zero sequence currents.

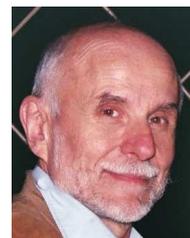
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VI. BIOGRAPHIES



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