# Wave Propagation Regime to Point to Faulty Feeder in a Mixed Cable-and-Lines Distribution Systems with an SLG Fault

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# Wave Propagation Regime to Point to Faulty Feeder in a Mixed Cable-and-Lines Distribution Systems with an SLG Fault

W.-Y. Huang, R. Kaczmarek

**Abstract--In radial distribution network with no discontinuities in feeders' impedances the shape of traveling wave induced by an SLG fault inception will be modeled by multiple refractions and reflections from busbar, fault and loads. The initial propagation zone presents a rigorous polarity disposition of residual currents, with sound residuals having the same polarity. We can determine the minimal sampling frequency necessary to get in that zone the current data indicating faulty feeder. The initial polarity length does not depend on the fault position, its resistance value or on the soil resistivity, and if scrutinized on all feeders it can point out from busbar to fault in systems with laterals.**

**The propagating waves can thus be involved in directional procedures in lines or in cables. Under certain conditions the directional function can be assumed also in mixed networks, with feeders partly in cables and partly in lines.**

**Keywords: Traveling waves, fault detection, distribution systems**

## I. INTRODUCTION

LARGELY used in transmission lines, the traveling waves haven't as yet found confirmation in distribution systems, where feeders are short and impedance mismatches frequent. First approaches have been tempted to fault localization tasks, but researches of characteristic frequencies have proved as yet inefficient [1]. The coordination by GPS of traveling wave's data has been reported efficient in calculation of fault position [2]. The robustness of procedures applied in simple cases, the insensibility of traveling wave regime of grounding, as well as the rising frequency of industrial data acquisition will certainly inspire more research of algorithms based on traveling waves.

In this area the rapidly proliferating cable installations are of special concern. The velocity in cables may be less than half the velocity in overhead lines, somewhat relieving the HF stress on acquisition, and on the other hand for an underground cable the characteristic impedance is several times lesser comparing to overhead lines what means higher discharging currents in cables. Finally the SLG faults are low resistive ones, often solid faults [3] what results for traveling waves in high voltage amplitudes.

It should be also noted that necessity of extremely rapid fault detection has been reported, in less than 1ms [4], when equipment is to be protected against excessive currents.

In our opinion, as far as the traveling waves in distribution systems are concerned [5], the directional function may be more realistic challenge than fault distance calculation.

## II. DIRECTIONAL FUNCTION IN SIMPLE RADIAL SYSTEM

The profiles of discharging currents becoming rapidly inextricable because of multiple reflections and refractions of traveling waves, and on the other hand being overshadowed by rapidly developing charging currents, we think it useful to isolate a very short initial interval of clear waveform profiles where the critical condition is with frequency of acquisition rather than with heavy analysis of frequencies. Hence the duration of this interval in several topological cases will be here our concern.

The following has been modeled in EMTP code with frequency dependent parameters.

### A. *Overhead system*

We consider a simple overhead line network with three radial feeders a,b,c with an SLG fault occurring on feeder a. The analyzed data are residual current waves as recorded by sensors on the busbar side of each feeder.

During the traveling waves' regime the residual currents are dominated by the zero sequence mode of wave currents. The residuals arriving on busbar present rigorous disposition of polarities: the sound feeders have the same polarity which is opposed to the one on faulty feeder. This disposition can be perturbed when a current wave returns from the shortest sound feeder after reflection on its load. The time it takes to travel to and fro along the shortest feeder determines the initial polarity zone $\delta_{ip}$ and gives the minimal frequency of acquisition necessary to get data pointing to faulty feeder (1)

$$f_{\min} = \frac{1}{\delta_{ip}} = \frac{v}{2l_{\min}} \qquad (1)$$

with $v$ – the zero sequence mode velocity and $l_{minn}$ – the length of the shortest feeder.

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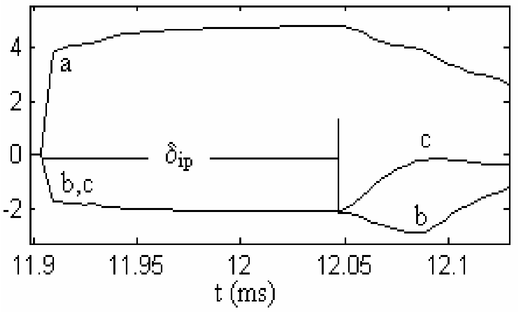

Fig. 1. Three feeder system a+b+c = 36.8+24.2+19.4km , residual currents recorded on busbar side with a resistive SLG fault of $R_f$= 1kΩ on feeder a at 1/10 of feeder length from busbar. At t=12.05ms the wave returning from the shortest feeder c may change the initial polarity on this feeder. The initial polarity period $\delta_{ip}$=0.144ms

With the shortest feeder's length of 19.4km the smallest frequency required is 7kHz (Fig. 1) and for robustness reasons – rather several times greater.

### *B. Underground cable system*

After the fault inception cables are siege of waves traveling both in cores and sheaths, a core – to – sheath SLG fault giving almost the same waveforms as a core – to – ground one. Fig. 2 presents an after-fault regime in a system of three feeder a,b,c with fault on the phase 3 of the feeder a, all sheaths being grounded on both ends.

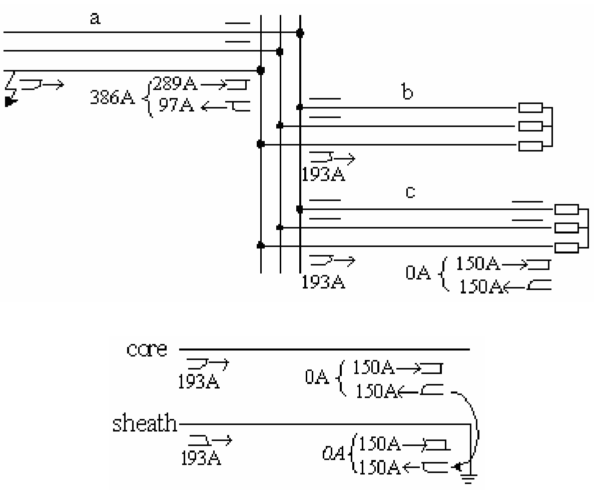

Fig. 2 Current waves disposition along cable in a three feeder system a+b+c = 18.4+12.1+9.7km, fault on feeder a. Upper: only cores are shown, bottom: core and sheath wave disposition on a sound feeder.

In the cable's core the current wave of -289A, accompanied in its sheath by magnetically induced synchronous wave of opposite polarity, arrives at busbar without exciting other phases because of mutual cancelling of external core and sheath fluxes (Fig. 2 upper part). There it superposes with its own reflection: -289A(1+1/3)=-386A. At busbar refraction the 386A wave is equally distributed between faulty phases on feeders b and c: -386A/2=-193A.

The residual currents are the sum on three cores currents. They are dominated by the faulty phase waves. Fig. 3 shows the simulated currents with paramount initial polarity zone, which for the shortest cable feeder of 9.7km lasts 0.123ms, giving a theoretical value for minimal frequency of acquisition of 8kHz.

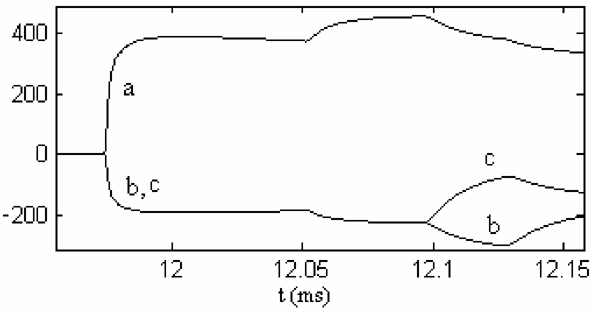

Fig. 3 After-fault residual current waves in a three feeder cable system 18.4+12.1+9.7km, a solid fault of $R_f$=1Ω resulting in important amplitudes. δip=0.123ms

### *C. Mixed cable and line system*

On of application of directional function based on analysis of the initial polarity zone may be with fault occurring on an overhead line in mixed systems, with cables on busbar side and overhead lines leading to loads. We present an analysis of a three feeder (a,b,c) system with 1:2 ratio of cable length to line length and an SLG fault on phase 3 of the feeder a. With the fault occurring on cable (Fig. 4) the HF amplitudes are several times higher comparing to the case of faulty line (Fig. 5) and may affect more seriously equipment isolation.

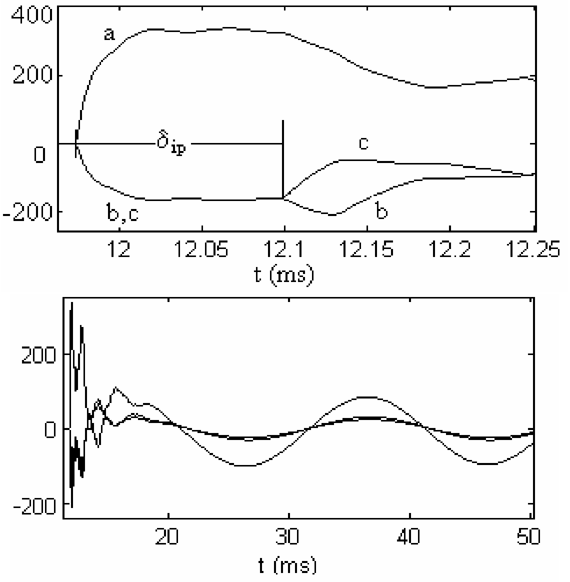

Fig.4 Residual currents with an SLG fault of $R_f$=1Ω in mixed feeder system (55.2+36.3+29.1km ), with cable to line length ratio ½, the fault occurring on cable at 9/10 of the cable length, bottom – zoom on the traveling wane zone. δip=0.123ms, the reflexion wave returning from load arriving theoretically on busbar at t=12.24ms

When the fault occurs on overhead line near loads, the travelling wave from fault position to busbar refracts when meeting impedance discontinuity at the line-and-cable joint. In this case, the amplitude of arriving wave on busbar is smaller than the one induced by a fault occurring on cable. With characteristic impedance of lines about 800Ω and that of cables 20Ω the ratio of initial amplitudes of the discharging currents is lower (12~14) than the impedance ratio mainly because of very low refraction on line-to-cable joint (here ~ 0.07).

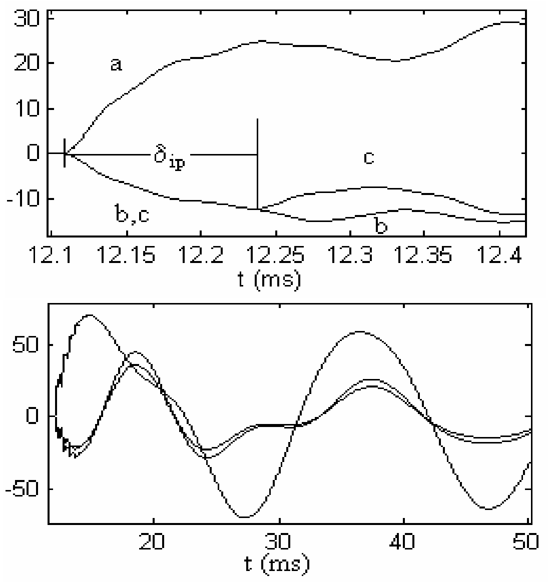

Fig.5 *idem*, the fault occurring on line at 9/10 of the line length. Bottom – zoom on the traveling wane zone. δip=0.123ms, the reflexion wave returning from load arriving theoretically on busbar at t=12.376ms

Weather the fault occurs on cable in vicinity of the cable and line joint (Fig. 4) or on line near loads (Fig. 5) the initial polarity zone is the same $\delta_{ip}$=0.123ms, its duration corresponding to time the wave takes to go to and fro between busbar and cable-and-line joint on the shortest feeder "c". This is because due to very low refraction, and also attenuation on line and cable, we cannot detect on the feeder "c" any action of the wave returning from load, when it arrives at busbar.

## III. DIRECTIONAL FUNCTION IN SYSTEMS WITH LATERALS

We consider a five feeders "a-d" network with a ramification on feeder "c" (Fig. 6) and cable sheaths grounded on both sides. Current sensors should be present at the beginning of each feeder, including laterals.

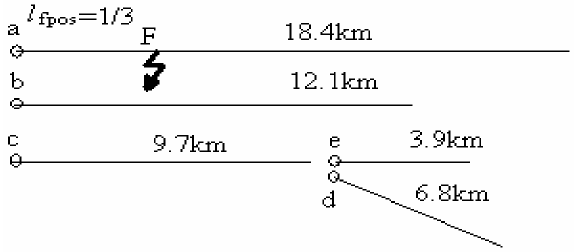

Fig. 6. Five feeders(A - E) network with one ramification and an SLG fault on feeder "d".

### A. Cable feeders

With fault on feeder "a" the current waves along feeders (Fig 7) develop partly as in radial network.

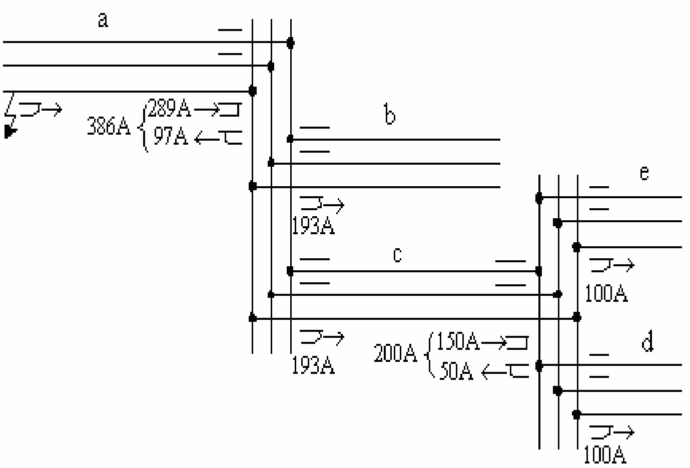

Fig. 7 Current waves disposition along cable in a five feeder system with ramifications, and SLG fault on the feeder "a" at 1/3 from busbar. Only cores are shown

The unique polarity of current waveforms at busbar points to the faulty feeder "a" (Fig. 8)

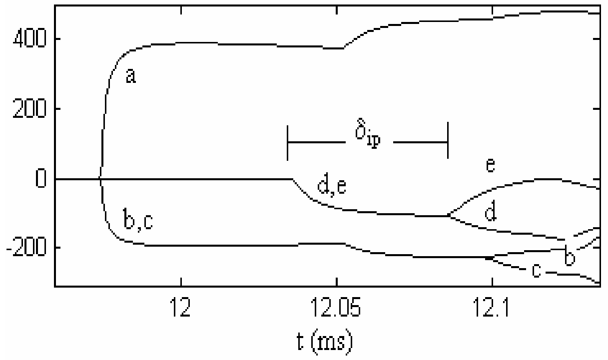

Fig. 8 The fault on feeder A pointed by current waves' polarity at busbar. δip=0.05ms

In general, the faulty feeder can be traced starting with identification on busbar of a unique sign, that we call "witness" sign, which is different from others. If the fault occurs on one of ramification, e.g. on "d", then we follow all indications of the same polarity as the "witness" sign. The fault is at the end of the chain ("c" and ""d" on the Fig. 9). In case presented on the Figure 8 the polarity of "e" locally conform to that of "a" (the witness sign) cannot point to fault because the intermediary feeder "c" is out of the supposed faulty chain.

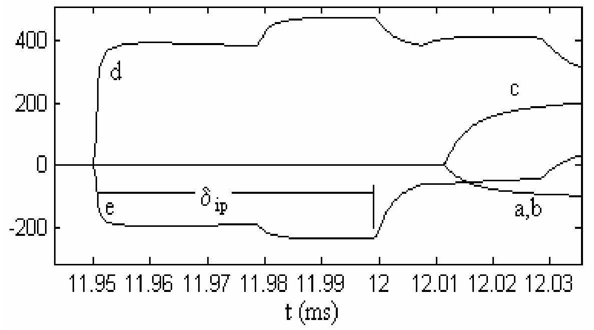

Fig. 9 The fault on feeder d, δip=0.05ms, same as in the of the Fig. 8.

### B. *Mixed feeders*

The laterals “e” and “d” of the Fig. 6 are now prolonged with overhead lines of respectively, 11.7 and 20.4km. We analyze two cases: first, with the fault occurring on cable segment of the feeder “d” (Fig. 10) at one third from busbar, and second one with fault occurring on overhead segment of “d” (Fig. 11) at one tenth from loads. The waveform disposition to take the directional decision is fundamentally the same in both cases with $\delta_{ip}$=0.05ms, what imposes an actual frequency of current acquisition at least 20kHz, and realistically of about 100kHz.

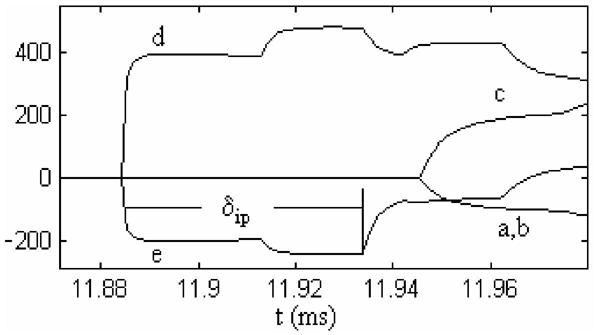

Fig. 10 The fault on cable part of the feeder “d”, δip=0.05ms.

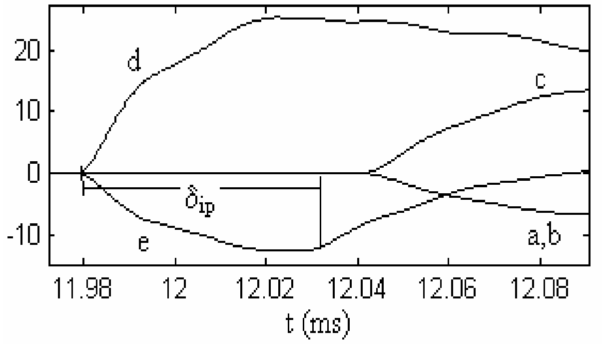

Fig. 11 The fault on overhead part of the feeder d, δip=0.05ms.

The similitude of waveform disposition with and without lines prolonging the cable feeders “e” and “d” (Figs 11 and 11 vs. Fig. 9) is another example of the decisive role played by cable feeders with the directional function based on analysis of traveling waves.

## IV. CONCLUSIONS

The rapid identification of faulty feeder using automatic analysis of residual currents recorded in traveling wave zone can be assured provided high acquisition frequency. We evaluate it on 100kHz in systems where the shortest cable feeder has length of several km. Impedance mismatch due to cable – and – line composition of feeders as well as some laterals on radial structure of the system are not an obstacle to the directional function if sensors can be installed on every feeder.

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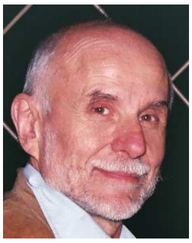
## VI. BIOGRAPHIES

**Wan-Ying HUANG** has graduated from Tsing Hua University in Taiwan with Master Degree in 2002 and in 2006 has got her PHD in the Ecole Supérieur d’Electricité SUPELEC and University Paris XI in France. She is now on a post doctoral research program in SUPELEC, working on protections in distribution systems and optimal design of electric machines.



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