Estimation of the Line-to-Line Voltage Phases in MV Distribution Faults using Transformer Inrush Currents

Antonio García, Félix Biscarri, Carlos León, *Member, IEEE,* and Enrique Personal

***Abstract*—This paper proposes an innovative and comprehensive method using transformer measured inrush current during the first breaker re-close to add usefull information as fault location problem input. It is divided into the main following sections: Introduction, Magnetizing Inrush Current- A Brief Analysis, Voltage Phase Estimation Method and Conclusion. The authors insist on the importance and the availability of the fault data recorded by the line protection relay (oscillogram, COMTRADE file), with the transformer impedances knowledge, to accurately estimate voltage phases.**

***Index Terms*—Inrush current, fault location methods, one-terminal lines.**

I. INTRODUCTION

DURING the last decade, these has been much research on the fault location problem. There are a lot of bibliographical references about main research topics regarding this paper: fault location methods for distribution systems (see [4]) and inrush current in power transformers([1], [2] and [3]). A classical research will be found in [5]. The IEEE offers a complete guide, [6]. Many new fault location algorithm are available [7], [8], but it authors usually assume that they knew of current and voltage values and also about its phases. The main contribution of this paper is to look for hidden information in a non linear event in lines: the inrush current, and its relation with phase voltages.

Both transmition and distribution networks, the usual methods can be classified into three groups: methods that use traveling waves, methods that use harmonics and methods based on the apparent impedance calculated from fundamental components of voltage and current. The last mentioned methods use, as available inputs from measurements, the phase voltages, the phase currents and all of the system characteristics except the fault resistance (R_F)

But there is a practical problem using these methods. With the means available to distribution companies, almost in Europe, the full aforementioned input information is not usually available. Sometimes, voltages and currents are measured but line impedances are partialy unknown. Sometimes, only the RMS voltages is known, but voltage phases are unknown.

The paper presents an innovative method to obtain the voltage phases from a set of registered current in three different conditions: pre-fault, fault and first breaker re-close.

This method might come in useful for complement a lack of information, in order to put into practice any of the fault location methods.

Medium voltage (MV) distribution feeders are normaly protected by overcurrent relays. Modern devices (IED), adding a microprocessor, not only measure the currents and trip the breaker switch when necessary, but also record the input currents. The stored oscillogram is reduced to a few tenth of seconds before and after a trip. The output oscillogram file is recorded in a standard file format (COMTRADE). These files are availables, usually few seconds after the fault, throught the utility communication system, in the Utility Dispatch Center.

Most protection strategies include an automatic re-close operation on the breaker switch, from a half to a few seconds after the fault detection. This operation allows to solve non-permanent faults. After the re closed operation, if there is still the fault, the relay switch-off the line permanently. As we has said, the relay records current's data in three different conditions: pre-fault, fault and first breaker re-close. Inrush current, due to re-energization of transformers, are shows in the last situation. Two real oscillograms from a medium voltage relay are shown in Figure 1 and Figure 2 (courtesy by Endesa Company). Note the short-circuit earth current is limited to $300A$. by the transformer neutral grounding resistor.

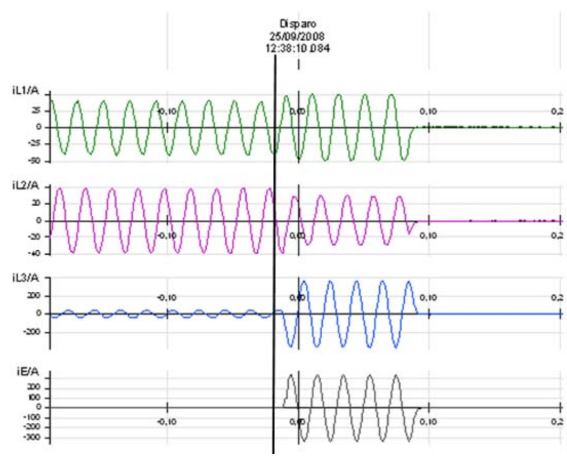

Fig. 1. Pre-Fault and Fault Currents in a Real System

This paper present a new method to accurately estimate, from recorded COMTRADE files, the voltage phases in trasnformers. This method is based in looking for the maximum value of the inrush current recorded, that accurate pointed the zero line input transformer voltage.

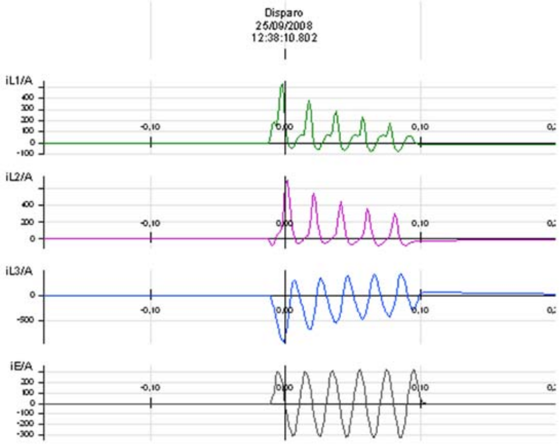

Fig. 2. The First Breaker Re-Close

II. Magnetizing Inrush Current- A Brief Analysis

Magnetizing inrush current in transformers results form abrupt change of the magnetizing voltage. When a fault occurred, magnetizing inrush may be caused by:

- Occurrence of an external fault.
- Voltage recovery after clearing an external fault.
- Change of the character of a fault. For example, when a phase-to-ground fault evolves into a phase-to-phase-to-ground fault.

If the input transformer voltage is sinusoidal, the magnetic flux too, and the magnetization current is a bell-shaped curve (Figure 3). The current harmonic spectrum declines significantly from the third harmonic. If the magnetizing current is sinusoidal, the third harmonic of the flux will be significant and also the third harmonic in the induced core transformer voltage. Figure 4 shows this case. The proposed method will be applied in both cases. The most common case in the real electric distribution lines is the first one.

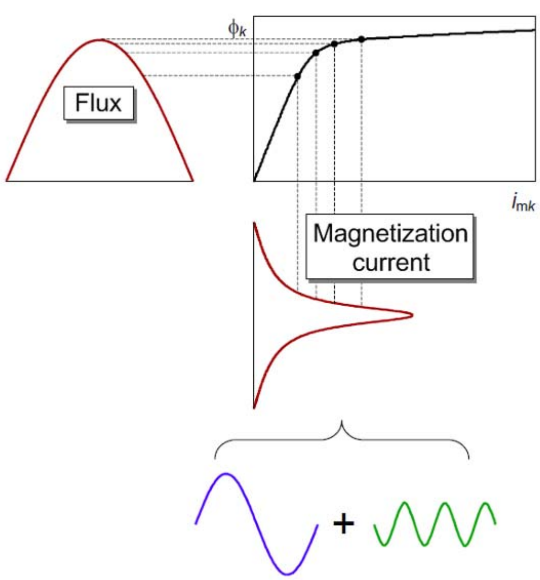

Fig. 3. Bell-shaped Magnetization Current

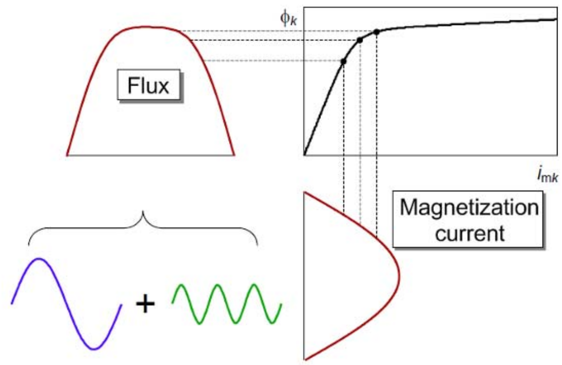

Fig. 4. Sinusoidal Magnetization Current

A. Inrush due to switching-in

Initial magnetizing due to switching a transformer is considered the most severe case of an inrush. When a transformer is de-energized (switched-off), certain remanent flux left in the core. When, afterward, the transformer is energized by an alternating sinusoidal voltage, the flux become also sinusoidal but biased in remanence. The flux-current trayectories for above the knee-point of the characteristic resulting in both large peak values and heavy distortions of the magnetization current. Figure 5 shows a typical inrush current shape.

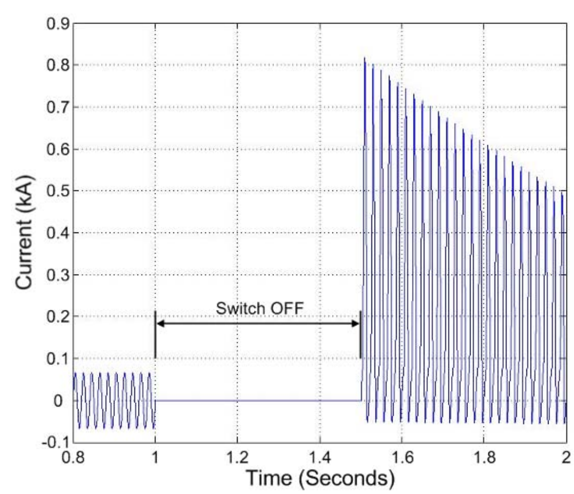

Fig. 5. Inrush Current in a Single Phase Transformer

B. Inrush in three phase transformers

Inrush current, or magnetization currents, measured in separated phases of a three-phase transformer (in the simple showed model: Iab_{mag}, Ibc_{mag} and Ica_{mag}, Figure 6) may differ considerably because of the following:

- The angle of the energizing voltages are different in different phases.

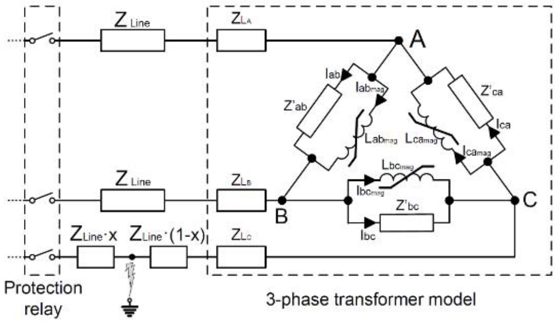

Fig. 6. Simple l-g Fault

- When the delta-connected winding is switched-in, the line voltages are applied as the magnetizing voltages. Line current on a giving phase is a vector sum of two winding currents.
- Sometimes, depending of the core type and others conditions, only some of the core legs may get saturated. In real faults, is not a very common case.

As a result of the aforementioned, the augment in a particular phase and in a grounded neutral may be similar to the single-phase inrush current pattern, or become distorted but oscillatory waveform. In the later case, the amount of the second harmonic may drop dramatically, creating problems for differential relaying. Figure 7 presents an example of energizing a three phase transformer. Magnetization currents and voltages are shown. In this example, the currents in the phases assume the typical inrush shape. Otherwise, only one current present a clear oscillatory waveform.

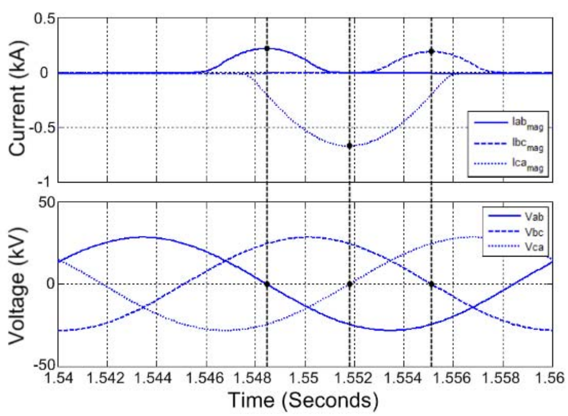

Fig. 7. Inrush Current and Associated Line-to-Line Voltages

III. Voltage Phase Estimation Method

This simple but innovative method to detect the phase of the voltages is based in the evolution of inrush currents with the re closed time. As it can easy be checked, the three magnetization currents, Iab_{mag}, Ibc_{mag} and Ica_{mag}, never overlap (see Figures 8 and 9). Thus, we can easy obtain magnetization current from the difference between fault current and inrush current.

The following steps describe the proposed method. The input variables are fault currents and inrush currents, recorded

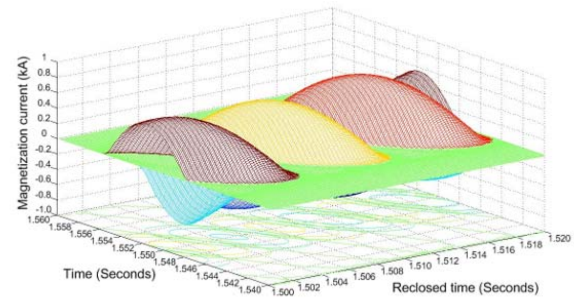

Fig. 8. Magnetization Currents in Transformers, Balanced Systems

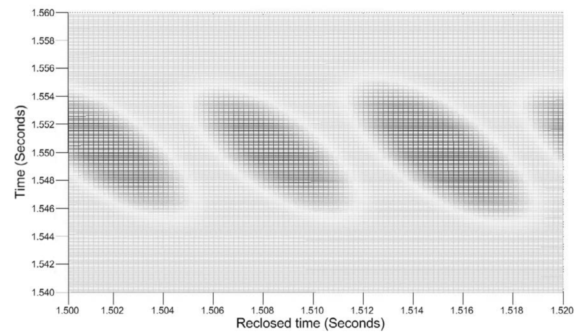

Fig. 9. Magnetization Currents Contour Plot

by the relay. The line voltages phases are unknown. Its are the target of this study.

1) Obtain the measured difference between fault and inrush currents: $Ia - Ia_{fault}$, $Ib - Ib_{fault}$ and $Ic - Ic_{fault}$. Figure 10 shows typical shapes of these differences. From these measured functions, estimation magnetization currents will be obtained.

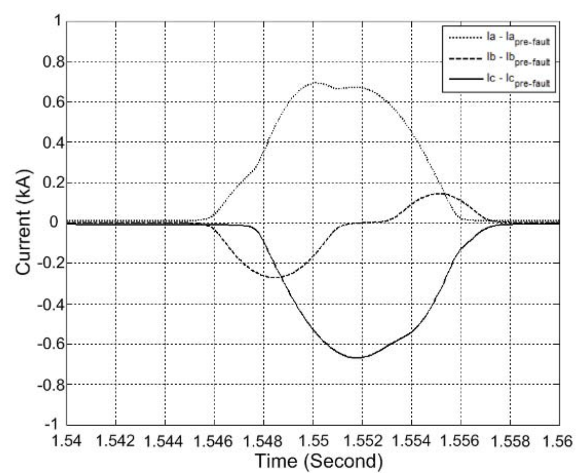

Fig. 10. $Ia - Ia_{fault}$, $Ib - Ib_{fault}$ and $Ic - Ic_{fault}$

2) *If the function with the lowest* $abs(maximum)$ *value ,* $Ib - Ib_{fault}$ *in Figure 10, is a clear oscillatory waveform*, the case is simple. A threshold will be fixed, and shapes A and B correspond, exactly, with the two smaller magnetization currents: Iab_{mag} and Ibc_{mag} (Figure 11
3) The third unknow magnetization current,Ica_{mag}, is estimated by $Iab_{mag_{ESTIMATED}} - [Ia - Ia_{fault}]$ or by

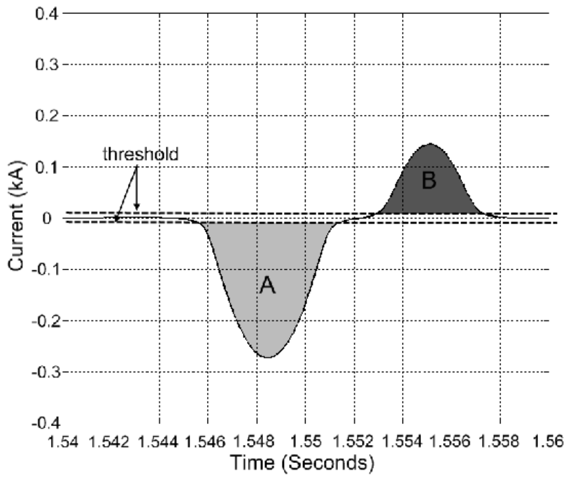

Fig. 11. Estimation of Iab_{mag} and Ibc_{mag} from $Ib - Ib_{fault}$

$Ibc_{mag_{ESTIMATED}} + [Ic - Ic_{fault}]$. The redundancy in the estimation of Ica_{mag} will be used to reduce the error of the global estimation.

4) *If the function with the lowest $abs(maximum)$ value is not 'a clear' oscillatory waveform (Figure 12)*, the method is the same, because the function with the lowest $abs(maximum)$ value is always an oscillatory waveform. Simple, one of the magnetization current is very small that the others, an it influence in inrush current is limited. Once the two minor magnetization current are estimated, the other will be easily estimated from measured $Ix - Ix_{fault}$. By this last point, authors emphasize the importance of the real limited measurement sampling in the estimation process.

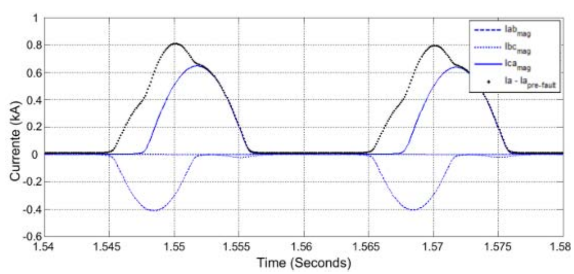

Fig. 12. $I_{ab_{mag}}$ has limited influence

5) At last, once the magnetization currents are estimated, its maximum values pointed when input transformer voltages are zero, and it set the voltage phase. Impedances show in Figure 6 will be know.

Once estimated voltage phases in transformer, known line currents and line impedances, it's possible to estimate the voltage phases in the substation; or known voltages in the substation, it's possible to estimate line characteristics.

Perhaps the process is simple than could be thought at first. For example, Ix_{fault} is not exactly the component of the post-fault Iab, Ica and Ibc (figure 6), but the difference in real balanced system studied is not significant.

IV. Conclusion

This paper deals with the amount of the available measurements in power lines, to detect electric faults. A new phase voltage estimation method, applied in a simple balanced systems, is presented, to find relevant knowledge about the particular characteristics of a non-linear electric phenomenon: inrush currents in transformers. This method might come in useful for complement a lack of information, in order to put into practice any of existing fault location methods.

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