IMPROVED FAULT LOCATION ALGORITHM FOR MV NETWORKS BASED ON PRACTICAL EXPERIENCE

Tongyou GU
Alliander N.V. – Netherlands
Tongyou.Gu@Alliander.com

Frans PROVOOST
Alliander N.V. – Netherlands
Frans.Provoost@Alliander.com

ABSTRACT

Faults in underground cables are a major cause of interruption time in medium voltage (MV) networks. Thus, recognition and location of faults are key steps to the outage restoration. This paper presents the recent improvement on fault recognition and location process implemented within the Dutch distribution system operator Alliander. Several issues from the practical situations are addressed properly, including compatibility with the universal sensor data from different vendors, false recognition of fault and non-fault events, and inappropriate calculation moment for fault location. The fault recognition and location process is also integrated in a fully automated DMS system, to further improve the process of fault restoring and reduce the outage duration.

INTRODUCTION

Component failure is a major cause of interruption time in medium voltage (MV) networks. Alliander, a Dutch distribution system operator (DSO) puts effort in faster location of faults in these networks, which entirely consist of underground cables.

Since 2007 Alliander has been exploring fault location system [1]. The recorded data from sensors is automatically processed to recognize what event type it is, e.g. fault, inrush current, etc. Based on practical experience, Alliander is improving the performance of the system. Furthermore, the system will be extended with sensors from different vendors who might use different data formats or contents. Therefore, activities are employed to achieve:

(1) A system which is universally compatible with the sensors from different vendors;
(2) Better recognition of event type;
(3) Higher accuracy of fault location result.

In this paper the algorithm design of event recognition is presented. Compared to the previously used algorithm, the new algorithm takes the format of universal data input into account, and solves the several misclassification issues from the previous method. In addition, the moment of calculating fault location is selected based on the evolving stages of the fault, which leads to a more accurate fault location result. Figure 1 illustrates the process of the recognition of event type and the localisation of the fault.

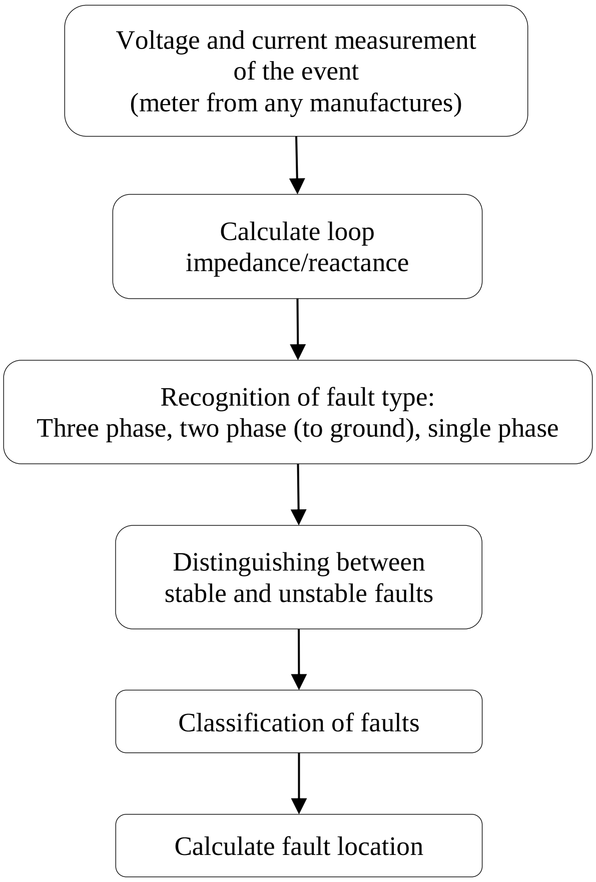


Figure 1 Process of event recognition and fault location

Finally, the paper updates the recent improvement of Alliander on the fully automation of the network analysis process, which guarantees the performance of the algorithm.

UNIVERSALLY COMPATIBLE WITH DIFFERENT VENDORS

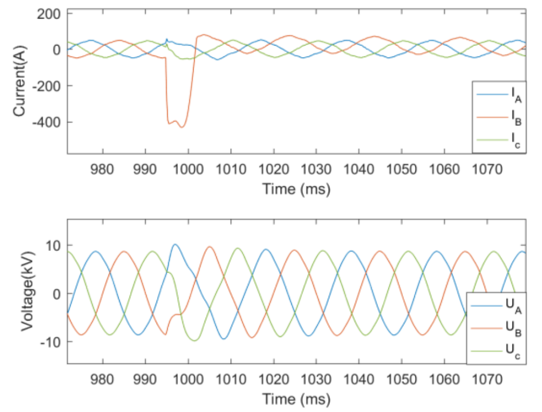
Besides the measurement of current and voltage, sensors from different manufacturers may or may not provide extra information about a fault. The algorithm is adjusted to use minimal available data. Only current and voltage data is used to calculate the fault loop impedance, type of fault and the fault duration. This makes the system universally compatible with sensors from different manufacturers. The methodologies are presented in following chapters.

EVENT RECOGNITION

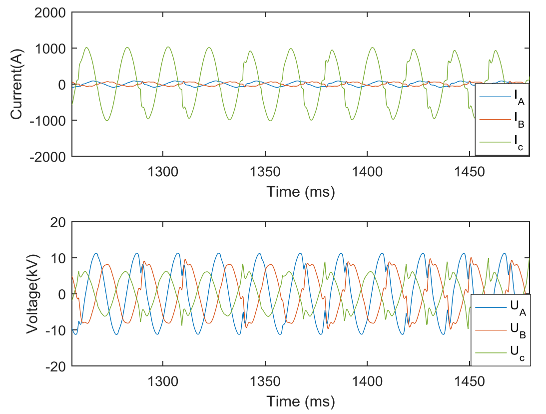
Misclassifications

The fault location system uses a high sampling rate and collects event recording data as soon as a set point for the current is exceeded. Therefore, also events like inrush currents and self-extinguishing faults [2] are recorded.

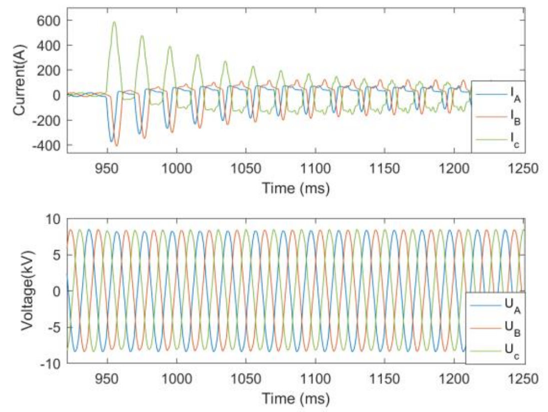
Figure 2 illustrates several examples of the event signals, some of which the system had difficulties to recognize the event type. Figure 2a shows a typical self-extinguishing fault. Figure 2b shows a single-phase fault. The waveform of the current contains a series of transients which are similar to a self-extinguishing fault as shown in Figure 2a. Therefore, errors could occur in the calculation of the correct fault impedance, resulting in the wrong fault location. Figure 2c shows an inrush current with high current value for a short time. This is similar to a multi-phase self-extinguishing fault. Thus, the event type of these signals might be misrecognized.



a. Self-extinguishing fault



b. Single-phase fault with transient waveform



c. Inrush current

Figure 2 Examples of event signals recorded by fault location system

Impedance Based Recognition

The previously used event recognition method takes the recorded trigger value of the measurement meters into account. However, this information may not be available in data input from other vendors. Therefore, the new algorithm should be purely based on measured (transient) current and voltage.

The concept of the new recognition algorithm follows a similar principle as a distance relay. The algorithm monitors the loop impedance/reactance based on the measured current and voltage, and recognizes the event based on different characterization of this impedance/reactance. Also, the ratio between negative/zero sequence components and the positive sequence component is used as one of the recognition criteria to determine which type of fault is present. Another important recognition criterion is the sequence components, especially the zero-sequence components of the current and voltage.

A simple example is given for three phase fault: usually the length of an MV feeder is less than 20 km and the positive sequence reactance of an MV cable is approximately 0.1 Ω/km. Therefore, for a three-phase fault, it is highly likely that the loop reactance (X) of the circuit is smaller than 2 Ω. However, also the absolute value of fault impedance (Z) must be smaller than a certain value in order to distinguish a fault from a high resistive load, which has also a low value of X. Thus, a maximum reactance and loop impedance are defined for the recognition criterion for a three phase fault.

For two phase (to ground) faults, similar boundaries of reactances and impedances are defined based on calculations for typical Dutch networks. The difference between two phase and three phase faults is the existence of negative sequence current for two phase faults.

The single-phase fault is difficult to recognize simply based on the impedance, especially in networks with isolated neutral. However they can be recognized by the

Table 1 Criteria of event recognition, the unit in the table is V, A and Ω. I_{fp} is the current of the event phase, I_{op} is the current of other phases.

	Criteria			
Event type	**Loop reactance**	**Loop impedance**	**Sequence ratio**	**Zero-sequence info**
Three phase fault	$X \leq 2$	$\|Z\| \leq 7.5$	$\|I_2\|/\|I_1\| \leq 0.1$	-
Two phase fault	$X \leq 6$	$\|Z\| \leq 15$	$\|I_2\|/\|I_1\| \geq 0.5$	$I_0 \leq 10$
Two phase to ground fault	$X \leq 6$	$\|Z\| \leq 15$	$\|I_2\|/\|I_1\| \geq 0.5$	$I_0 > 10$
Single phase fault	$\max I_0 > I_{0min,1}$, $\max I_{fp} / \max I_0 \geq 0.5$, $\max I_{op} / \max I_0 < 0.5$, $\max U_0 > 1$			

existence of both zero-sequence voltage and zero sequence current.

To sum up, Table 1 shows the criteria used for event recognition.

Distinguishing between Stable and Unstable Faults

The next step of event recognition is to determine if a fault is stable or not. The definition of a stable fault is that the fault current/voltage waveform is sufficiently close to an ideal sinusoidal waveform. Four quantities are used to judge the stable condition:

- MAX: maximum value of the waveform
- Delta: difference between data points in two sample steps (numerical differential)
- MaxDelta: the maximum value of Delta
- RMS: RMS value of the waveform

Table 2 presents the criteria to determine if a waveform is stable or not. These criteria are summarized from mathematical principles and practical experiences. They are different for phase/zero-sequence voltage/current.

For each fault type, different voltage/current are used to determine the stability:

Three phase fault: phase voltage and current
Two phase fault: phase voltage and current
Two phase to ground fault: phase voltage and current
Single phase fault: phase current, zero sequence voltage and current.

Classification of faults

The process firstly examines if the event is a stable fault. For a real stable fault, there must be at least 2 consecutive periods classified as the same stable event type. The algorithm checks at first if the event is a three-phase fault, followed by the check of two phase fault, then stable single phase fault.

If a stable fault is not identified, the process verifies if the event is an unstable fault. The event is classified as an unstable fault if the voltage/current waveform is categorized as unstable fault, or if there is only one (consecutive) period of voltage/current is categorized as stable fault.

For classification of all faults the minimal impedance (presented above) criteria are examined (reactance for two and three phase fault, impedance for single phase fault) in the periods with conditions satisfied. If a suspect unstable fault consists of several (non-consecutive) stable and unstable periods, the fault impedance is determined by using the time point at the stable periods.

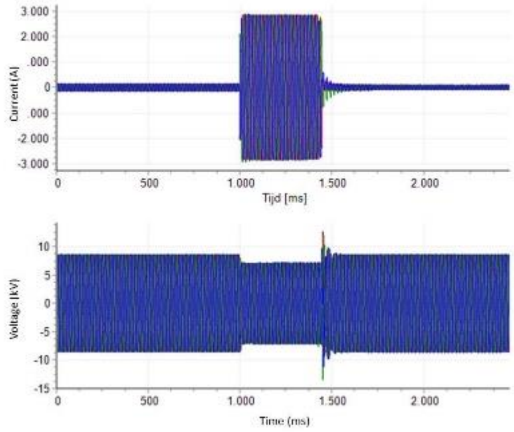
From practical experience the unstable single phase faults usually have a stable fault impedance within the faulted time periods, which means the fault location process can be performed.

Using the described new classification method, different types of event can be recognized correctly. The examples in Figure 2 will be classified as following:

Table 2 Criteria of distinguishing stable and unstable waveform, Ns is the number of samples per period

	Criteria		
Type	**Single phase**	**Two phase**	**Three phase**
Phase voltage	Max > 0	RMS /Max > 0.6	MaxDelta/Max < 8π / Ns
Phase current	Max > 0	RMS /Max > 0.6	MaxDelta/Max < 4π / Ns
Zero sequence voltage	Max > 0	-	-
Zero sequence current	Max > 0	-	-

- Figure 2a: the transient lasts for less than a half period and thus the calculated impedance does not trigger the threshold of fault. However, the zero sequence current and voltage are available. Therefore, the self-extinguishing fault is classified.
- Figure 2b: the loop impedance is lower than the pre-set threshold. However, the waveform is not a stable sinusoidal. Therefore, the event is classified as an unstable fault.
- Figure 2c: the loop impedance does not satisfy the fault condition, and no zero sequence current or voltage is available. Thus, the event is not classified as a fault.



CALCULATE FAULT LOCATION

The fault location is determined based on the short-circuit impedance, which is calculated from the current and voltage. In the previously used algorithm, the last period was selected to do the calculation, because usually it is the final status of the fault. However, sometimes the last period of a fault is a transient as shown in Figure 3. In this case a wrong (higher) impedance is calculated which leads to a wrong result of the fault location. The deviation could be several Ring Main Units from the real fault location.

In the improved algorithm, the moment of calculation is determined adaptively. Within the time-window of the steady state of the fault, the lowest value of impedance is selected to further calculate the fault location. The calculated result is exactly in the same Ring Main Unit of the fault location.

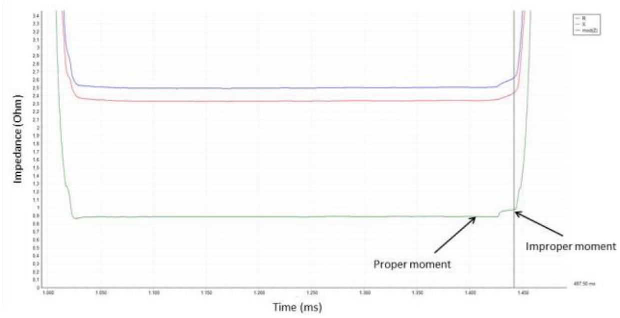


Figure 3 Example of the fault impedance at improper and proper moment of calculation

FULLY AUTOMATED GENERATION OF NETWORK FILES

The whole process of fault location is integrated in a fully automated DMS system. The calculations for correct fault location need to be performed on a correct model of the network. In the past network models were obtained from different regions in the company with each their own way of presentation. The implementation of these networks in the DMS system was time consuming due to many manual correction and adjustment activities and interpretations.

In 2016 Alliander realized a way of fully automating the process of generating the MV-network files and the calculations used for investment decisions [3].

This process, resulted in a uniform way of presenting MV-network models, which can simply be applied and updated in the DMS system. As a result, actual and correct network models are always available.

CONCLUSION

This paper presents several improvement approaches in the fault recognition and location in MV grid. The improvements address several issues from the practical experiences.

To cope with universal data format from different vendors, the new process uses the loop impedance to identify the faults, instead of trigger information. The loop impedance is compared with practically maximum impedance in normal operation. If the loop impedance is smaller than the defined threshold, the event is suspicious to a fault.

The recognition of event further checks if the waveform is sinusoidal, to determine whether a fault is stable. Moreover, the fault is classified based on the combined information of loop impedance, waveform stability and duration of the recognized transients. The new fault location system correctly classifies the events that were misclassified by the old algorithm.

The fault location is also improved by choosing the proper calculation moment for fault impedance. This solves the problem that the calculation moment was sometimes selected by the old algorithm in ending transient of the fault. The new fault location algorithm correctly calculates the fault impedance and faulted section along the feeder.

Finally, the fault recognition and location process is being integrated in a fully automated DMS system, to further improve the process of fault restoring and reduce the outage duration.

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