IMPROVING NETWORK PERFORMANCE BY RECOGNITION AND LOCATION OF SELF-EXTINGUISHING FAULTS

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ABSTRACT

Fault prediction is an important topic for grid operators on improving network performance. Many spontaneous faults in MV cable networks are preceded by a number of self-extinguishing faults. Therefore, the recognition and localisation of self-extinguishing faults will help to reduce the number and impact of persistent faults.

The self-extinguishing fault phenomena, as well as the process model to use in fault prediction were studied. By using statistic tools and observing historical measurement records, an algorithm is developed to automatically recognise self-extinguishing faults. This algorithm is implemented in the fault location system of the Dutch DSO Alliander, and proved to be able to recognize all self-extinguishing single phase faults. In addition, a possible method to estimate a global location of self-extinguishing faults is proposed.

INTRODUCTION

Fault prediction is an important topic for grid operators on improving network performance. Recent research by the Dutch DSO Alliander indicates that many spontaneous faults in MV cable networks are preceded by a number of self-extinguishing faults with a short duration (<1/2 period). In many cases it takes several weeks before such a fault finally develops into a persistent single- or multi-phase fault. Therefore, if a global location of a self-extinguishing fault is known in time, it might be possible to repair the cable in advance. Another possibility is to minimize the impact of the resulting persistent fault by rescheduling the network configuration. Both activities will improve the network performance.

Alliander uses information from the SASensor measuring and control system [1] for fault location in the MV network. Since the introduction of this system in 2007 many registrations of self-extinguishing faults were recorded. However the fault location algorithm was not developed to automatically recognise this kind of faults [2].

In order to reduce customers minutes lost, it was decided to extend the fault location algorithm to detect self-extinguishing faults. By analysing the data of these faults, and comparing it with previous (persistent and self-extinguishing) faults an indication of the location can be found and the control centre can take measures. This process model is shown in Fig. 1.

This paper first describes the self-extinguishing phenomena. Next follows the study of the typical parameters for recognizing this type of faults and the development of practical rules to recognise them. The paper ends with a description of a method to estimate the location of self-extinguishing faults.

PHENOMENA OF SELF-EXTINGUISHING FAULTS

Most self-extinguishing faults are single phase phenomena. The extinguishing occurs at the first zero crossing of the fault current. The first part of a single phase fault current consists of a high frequency transient which is superposed on the steady state wave shape. The transient part is caused by the discharge of the faulted phase. The magnitude and frequency of this transient are

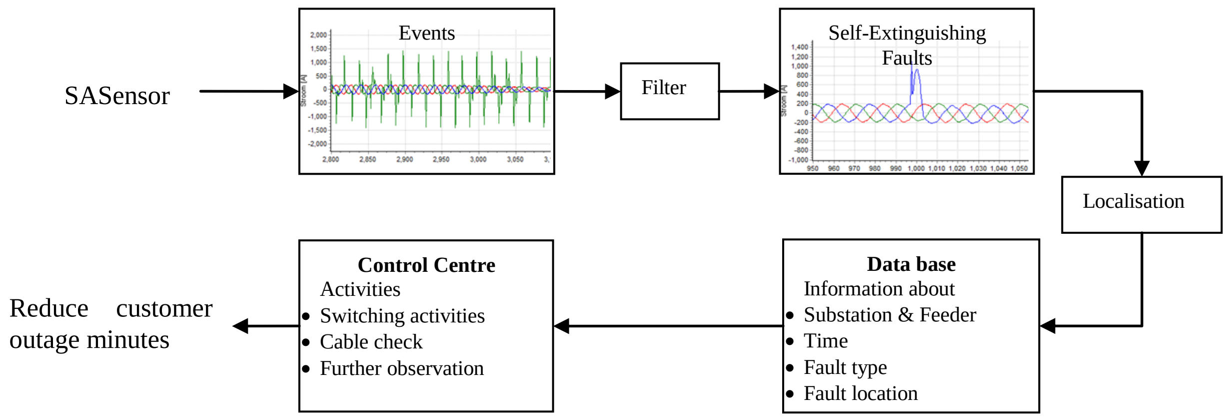

Fig. 1 Process model for self-extinguishing faults used in fault prediction

a function of the network capacitance and the reactance of the faulted cable between the substation and the fault location. The magnitude of the steady state current depends on the network earthing and (in case of earthed networks) on the location of the fault.

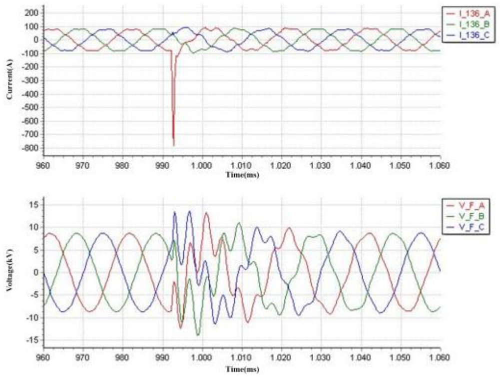

Fig. 2 Waveform of current and voltage for a typical self-extinguishing fault extinguishing at zero crossing of the transient current (short)

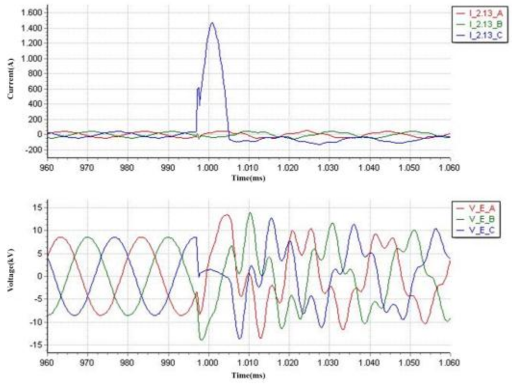

Fig. 3 Waveform of current and voltage for a typical self-extinguishing fault extinguishing at zero crossing of the steady state current (long).

Fig. 2 and Fig. 3 show the phase currents and voltages for two typical types of self-extinguishing faults. Both types of faults start with a rapid increase of the fault current. For the fault in Fig. 2 the extinguishing occurs due to the zero crossing in the transient stage of the fault. Typical durations of these events are around 2ms. These faults can be seen as short self-extinguishing faults. For the fault in Fig. 3 the extinguishing occurs at the first zero crossing of the steady state current. This happens normally after about half a cycle (10ms). These faults can be seen as long self-extinguishing faults. For these types of faults the magnitude of the transient current is too small to cause a zero crossing in the transient stage.

RECOGNITION OF SELF-EXTINGUISHING FAULTS

In order to automatically recognise self-extinguishing faults from the large amount of measured events, suitable rules should be defined.

These rules are obtained in two steps. The first step is to choose representative parameters which can describe the characteristics of self-extinguishing faults. The second step is to determine the thresholds of these parameters.

Typical parameters for recognizing

As self-extinguishing faults are single phase phenomena, it is obvious that the zero sequence current (I_0) has to be one of the parameters for recognizing these faults. The zero sequence current itself is a measure for single phase faults. A high value of its derivative (dI_0/dt) is a measure for the start of a fault. Therefore the rms value of I_0 (I_0_rms) and the maximum of the absolute value of dI_0/dt ($|dI_0|$_max), were selected as the main parameters.

After selecting these parameters, the C5.0 algorithm in the software SPSS Modeler was applied to generate rules and verify this selection, based on previously collected SASensor registrations.

The historical data in the last five years were used. In the preparation of the input database, the registrations for persistent faults were excluded, and the rest of the data were divided into several categories like earthing methods, voltage level and so on. Then rules for different categories were generated. As an example, the result rules for seven 150/10kV substations are shown in Table I. Four out of these seven networks are impedance-earthed and the other three are networks with isolated neutral.

Table I Recognition rules for 150/10kV substations with two different earthing methods

	Parameter	Impedance-earthed	Isolated-neutral	Unit
True	$\|dI_0\|$_max I_0_rms	>164 >2	>25 >2	A/ms A

Both rules show that if $|dI_0|$_max is larger than a certain value, and I_0_rms is little larger than zero, the event is a self-extinguishing fault.

The start of persistent single phase and two-phase faults with earth also fulfil the rules in Table I, and can therefore be mistaken as self-extinguishing faults. To prevent this, the persistent faults should be excluded in advance. Also other events, such as inrush, contain the same dI_0/dt characteristics. However the zero sequence part of these events has a very short duration (0.5ms), so the rms value of I_0 for these events is almost zero.

This algorithm can theoretically recognise self-extinguishing faults accurately. However there are two drawbacks in practical use. The first is that persistent faults should be excluded in advance. The second is that the earthing method of the network is needed. This earthing method can of course be included in the substation parameters of the fault location system. However, Alliander is changing the earthing method of the MV networks from isolated neutral to impedance earthed. When the earthing system is changed, the parameter must be changed and previous recordings can no longer be evaluated.

Practical rules for recognizing

In order to make a convenient algorithm for practical operation, global rules that can be applied in all kinds of networks were defined. Also these rules are based on both I_0 and dI_0/dt. Every cycle (20ms) the maximum instantaneous value and the rms value of these parameters are compared. In this way global rules can be achieved. By using relative values, it is no longer necessary to distinguish between earthing methods of the network.

The first step is to consider the difference between the maximum value and the rms value of a single phase event. In case of an ideal sine-wave, the ratio between the maximum value and the rms value equals √2. In case of self-extinguishing faults it is expected, that this ratio is much larger.

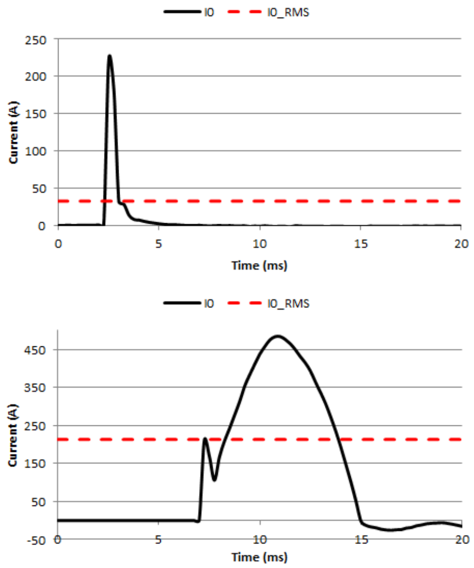

Fig. 4 Momentary and rms values of zero-sequence currents for a short self-extinguishing fault (top) and a long self-extinguishing fault (bottom).

Fig. 4 shows some typical waveforms for the two types of self-extinguishing faults. In case of a short self-extinguishing fault (top) the ratio between the maximum value and the rms value is larger than 6. It is therefore obvious, that short self-extinguishing faults can be detected by observing only I_0.

In case of a long self-extinguishing fault (bottom) the ratio is about two. However some registrations of long self-extinguishing faults show that the ratios do not differ much from persistent single-phase faults. Therefore also the derivative of I_0 (dI_0/dt) must be taken into account.

Fig. 5 shows dI_0/dt for the long self-extinguishing fault. It can clearly be seen that there is a large ratio between the maximum and the rms value. This means that the ratio between maximum and rms value of dI_0/dt is a good parameter for recognising long extinguishing faults,

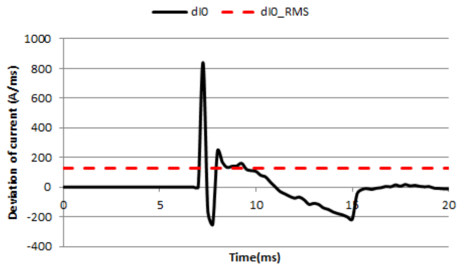

Fig. 5 Momentary and rms values of the deviation of the zero-sequence current for a long self-extinguishing fault.

which are not recognised by the I_0 criterion.

Based on historical data, and experience of data analysts, the threshold values given in Table II were deducted.

Table II Practical rules for self-extinguishing faults

	Parameter	Short	Long	Unit
True	$\|I_0\|$_max	>30	>30	A
	$\|I_0\|$_max/I_0_rms		>2	-
	$\|dI_0\|$_max/dI_0_rms	>3		-

The coefficients in Table II were also verified by statistic software as well. The same parameters used in this section were applied to generated rules by SPSS Modeler, which gives almost the same coefficients as experience values.

This algorithm is also able to distinguish between stable single phase faults and unstable single phase faults (repetitive sequences of self-extinguishing faults).

Results of use in practice

The new rules are implemented in the fault location algorithm and are executed when an event is not recognised as a multiphase fault. This new algorithm is tested on historical data, and detected all self-extinguishing faults correctly.

In September 2012 the new algorithm was implemented in the fault location system in the MV control centre of Alliander. Since then all occurring self-extinguishing faults have been detected and reported.

LOCATION OF SELF-EXTINGUISHING FAULTS

The transient part of the zero sequence current contains a resonance frequency. This frequency depends on the cable capacitances of the total MV network and the reactance of the faulted cable between the substation and the fault. A possible method to estimate the location of self-extinguishing faults is therefore to use the relation between the frequency spectrum of the current and the fault location.

Computer simulations were performed in Power Factory. An impedance-earthed network with 10 feeders was modelled, and the phase current and phase voltage waveforms of self-extinguishing faults along one feeder were calculated.

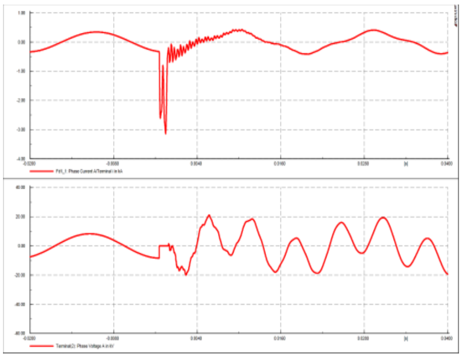

Fig. 6 Waveforms of phase current and phase voltage for a fault 1km to substation

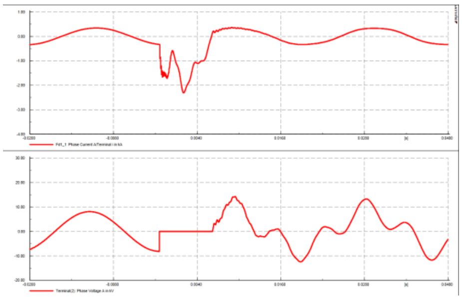

Fig. 7 Waveforms of phase current and phase voltage for a fault 5km to substation

Fig. 6 and Fig. 7 show the phase current and phase voltage of two self-extinguishing faults which occur at 1km and 5km from the substation. It is obvious to see that the frequency decreases with increasing distance from the substation.

The calculations show that the important frequencies are in the range of 1-4kHz. The sample frequency of the fault location signals is 4kHz. Therefore in practice it is difficult to accurately calculate the frequency, which makes it difficult to obtain an exact location.

However, it is possible to provide a global indication of the location, like close to or far away from the substation. Already this information can help the grid operators to check the weak points in the grid in advance, thus to prevent possible faults.

FURTHER APPLICATION

The approach of recognising self-extinguishing faults in this paper contains two steps: selection of parameters, and generation of rules. This approach can also be used in recognising other types of events in power systems, such as Power Quality problems, testing of equipment and measurement errors. The representative parameters are usually selected according to the characteristics of the events by examining historical data, and validated by statistic tools. The recognition rules can also be generated by statistic software and/or improved by experience of data analysts.

In further applications, a statistic tool can be used to improve the rules automatically, by updating the coefficients according to new measurement data.

CONCLUSION

A self-extinguishing fault is a kind of disturbance with short duration. Normally such a fault will sooner or later evolve into a persistent fault. In time recognition and localisation of such a fault will provide possibilities to repair the cable in advance, or to minimize the impact of the persistent fault by rescheduling the network configuration. This will improve the network performance.

Based on the characteristic waveforms of the current and voltage, I_0 and dI_0/dt are selected as basic parameters to recognise self-extinguishing faults. This selection is validated by a statistic program. The resulted rules can recognise this type of faults accurately, but more information, such as earthing method, is needed.

The rule set is improved by comparing the maximum of instantaneous value and the rms value of I_0 and dI_0/dt every cycle. The result rules turn to be suitable for global application in all network types. The rules are implemented in the fault location algorithm and proved to recognise self-extinguishing faults efficiently and accurately.

The location of self-extinguishing faults can be estimated by using the relation between the frequency spectrum of the current and the fault location. However, the important frequencies turn out to be close the sample frequency. However, it is possible to obtain a rough indication in terms of close to or far away from the substation. Usually after the first occurrence of a self-extinguishing fault, there is still time before it evolves into a persistent fault. Therefore, the grid operators do not need to know the exact fault location. Instead, the rough estimation of the fault location can provide them enough information to check the weak points in the grid in advance, thus preventing possible faults by proper actions or maintenance.

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