HVDC Faults Classification by Lab Color based Monitoring System

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Abstract: - This paper presents a new method for faults classification of HVDC system by analyzing the currents and voltages of the system under the Zero-Direct-Quadrature (DQ0) coordinates using Lab color chromatic based monitoring approach. Repeated for several healthy and faulty scenarios in DC side and AC side as well, The DQ0 transformed signals are evaluated for each case, Continuous chromatic monitoring is applied on all signals. A chromatic Lab mapping of short time-slot windows result in providing an early fault detection. The preliminary results show high accuracy in fault type classification as well with short processing time and without the need for any pretraining requirement.

Key-Words: - HVDC, Converter, Rectifier, Fault, Lab color, Chromatic monitoring, Classification.

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1 Introduction

The adoption of the HVDC system appears because of its significant benefits in connecting different systems, especially those with different frequencies or in the integration of wind and solar power resources to the main AC grid. Scientific researchers continue to work on improving various properties of the system with a special focus on reliability, but because faults are inevitable; protection researchers are concerned with minimizing and avoiding losses, and their first important task here is to have correct diagnosis of the fault.[1]

The high voltage direct current (HVDC) system consists of various integrated components, each with its own function that cannot be ignored, such as rectifiers whose functions is to convert AC to DC and inverters to convert DC to AC, in addition to, of course, the long transmission lines extending between the terminals. In view of the multiplicity of parts, a variety of faults can occur in the system in terms of type, i.e., faults on AC side or DC side in addition to the possibilities of different fault locations on the transmission line or the fault resistance whose value cannot be predicted.[2] For the purpose of rapid detection and fast clearance of faults its necessary and important to identify its characteristics such as its type, direction and location.[3]

Before choosing the method and deciding which actions to take, it is necessary to have accurate and fast detection of the event.

Protection is usually applied to each component of power system with extra care for important vital parts. Given the importance of the HVDC system, researchers have devoted large efforts to diagnose and classify its various faults to ensure the continuity of power delivery and to avoid power outages and blackouts.[4]

Several methods have been reported in the literature, many are based on the traditional travelling wave resulting from the system events and its characteristics[5-8], and limitations of some methods such as high processing requirements and expensive equipment cost [9,10] are reported, and some of the approaches are reported as efficient only for far fault due to noise interference with its detection abilities.[11,12]

Modern approaches have also been reported, based on waveform [13,14], artificial neural network[15] and fuzzy-logic support vector machine [16-18] and some of which are based on a combination of recent approaches such as wavelet transform fusion with neural networks.[19]

The continuous motivation for innovative approaches development or old method modifications is the significant error reported in traditional methods or the requirement of comprehensive training in some modern approaches. The Chromatic approach is one of the modern monitoring methods that have proven their efficiency and distinction in monitoring in many different fields, including recent applications in electrical power systems [20]. Due to its effective ability, it was chosen as a tool for the classification step in this proposed approach. Chromatic monitoring has various forms, such as the HSL, Lab and xyz.

The chromatic processing stage follows The DQ0 Transform of a monitored HVDC system currents and voltage waveforms. The Lab color chromatic processing algorithm was adopted in this work, and its implementation and general procedure are explained in the next section after the principles of DQ0 coordinate transformation are introduced and described. While classification results and discussion are presented in section (3).

2 Method Description

2.1 Overall Procedure

Novel approach for classifying the types of errors that occur in the HVDC system by applying chromatic monitoring is presented in this paper. The flowchart in Figure 1 illustrates the steps of the approach. The figure shows a few steps before the direct application of Lab chromatic monitoring, and these steps will be covered in the following subsections, such as the description of the simulated system in section (2.2). The DQ0 coordinates will be given in subsection (2.3), then samples of the results are given in subsection (2.4). The final step is the implementation of chromatic monitoring which includes the implementation of the RGB processor, the Lab color transformation and the final mapping step, the details of the algorithm and its various steps that define its parameters are explained in subsection (2.5).

2.2 Simulated System

To prepare a set of data for various potential fault conditions in the HVDC system, a bipolar 12-pulse transmission system is considered and simulated using MATLAB® software and its associated Simulink® and Simpowersystem® toolboxes. The standard model of HVDC system is selected from MATLAB libraries is utilized in this work and shown in Figure 2.

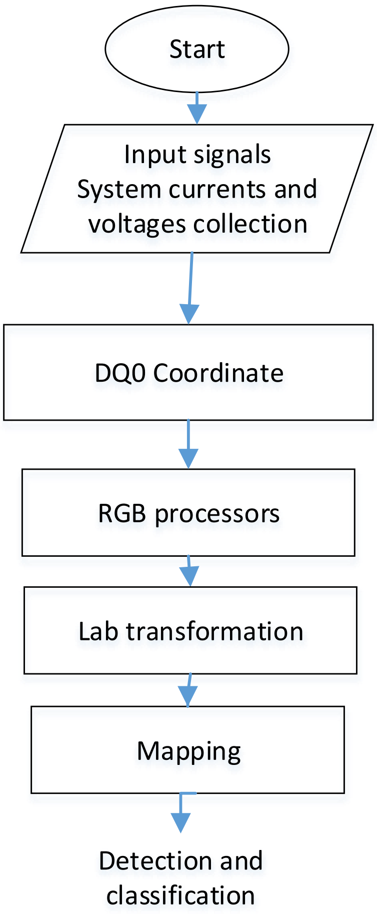

Fig. 1: Method Overall Procedure flowchart

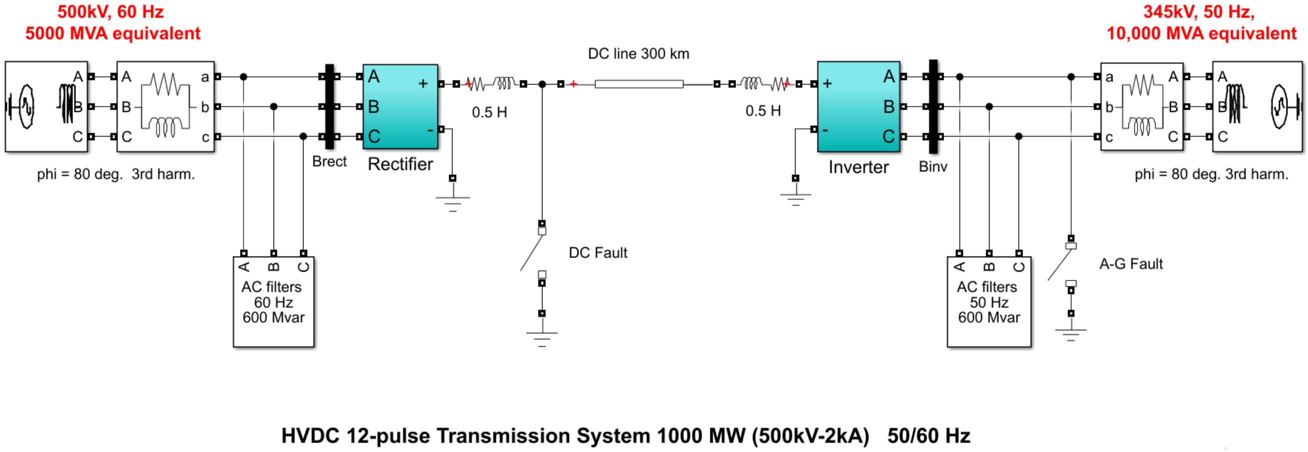

Fig. 2: The simulated system

The selected model represent part of a typical HVDC system, A 300 km long DC line with 0.5 H smoothing reactors is utilized to transmit power from a 500kv, 60 Hz 5000MVA convertor station to a 345kv, 50 Hz, 10000MVA station.

Both sides of the AC are represented as infinite sources, and simple parallel R-L branch are used to represent source impedances. AC filters are included to limit the harmonics to the level required by the network. The used HVDC transmission Line is of distributed model and its parameters are as given in Table 1.

Table 1. Transmission line parameter

Resistance Ω/km	0.015
Inductance mH/km	0.0792
Capacitance nf/km	14.4
Line length km	300

For the purpose of testing the proposed method, data is collected from the system in various fault conditions such as single line to ground fault, line to line to line, line to line to ground fault, and the three-phase fault in the AC side in addition to the DC side faults. The simulations involve various fault parameter variation such as the fault location and fault resistance for the DC faults and various fault types for the AC faults with different fault resistance and in addition to the normal system operation. The results will then be used to verify the effectiveness and robustness of the method algorithm under different operating conditions.

2.3 Zero-Direct-Quadrature (DQ0)

Signal transformations have useful and proven uses in research in many areas. It would transform ordinary system signals that carry a lot of invisible meanings or information into signals that are different in form but equal in content, but in a way that is more capable of extracting meanings and information from them in a clearer way and with the least amount of trouble.

Sometimes it is necessary to pass the results to a second transformation and processing stage with different equations to get better results. The complexity and repetition of the transformation and mapping process depends on the complexity of the observed phenomenon. Therefore, researchers may have to pass the signal through several transformations before the information begins to become clear. The multiple transformations based technique forms the idea of the proposed method in this research. Two types of transformations have been proposed; the first type is the DQ0 transformation, its algorithm and equations will be illustrated in this section. While the second transformation is the chromatic transformation which will be explained in detail in subsection 2.5.

Starting by the DQ0 transformation, the used algorithm can generate a new set; a rotating two-axis reference waveforms from the original three phase voltage waveforms as given in equations (1) and (2).[21]

$$V_d = \frac{2}{3}\Big[V_a \sin \omega t + V_b \sin(\omega t - \frac{2\pi}{3}\Big) + V_c \sin(\omega t + \frac{2\pi}{3})] \tag{1}$$

$$V_q = \frac{2}{3}\Big[V_a \cos \omega t + V_b \cos(\omega t - \frac{2\pi}{3}\Big) + V_c \cos(\omega t + \frac{2\pi}{3})] \tag{2}$$

The same equations are used but for the calculation of I_q and I_d as given in equations (3) and (4). With its simple calculation the algorithm can be used to reverse the transformation successfully.[21]

$$I_d = \frac{2}{3}[I_a \sin \omega t + I_b \sin(\omega t - \frac{2\pi}{3}) + I_c \sin(\omega t + \frac{2\pi}{3})] \tag{3}$$

$$I_q = \frac{2}{3}[I_a \cos \omega t + I_b \cos(\omega t - \frac{2\pi}{3}) + I_c \cos(\omega t + \frac{2\pi}{3})] \tag{4}$$

2.4 Simulation Results

For the purpose of testing the proposed method, data is collected from the system in various fault conditions. Figure 3 illustrates a sample of the recorded currents, voltages waveforms for a single line to ground fault encountered in the AC side of the simulated HVDC system while Figure 4 illustrates another sample for the recorded currents, voltages waveforms for a line to line to ground fault waveforms.

Equations (5) and (6) are used for the dq-axis magnitude calculations of the system voltage and the current and Figures 5 and 6 illustrate a sample of the dq-axis magnitudes of both current and voltage waveform variations respectively for a single line to ground fault case.

$$|V_{dq}| = \sqrt{V_d^2 + V_q^2} \tag{5}$$

$$|I_{dq}| = \sqrt{I_d^2 + I_q^2} \qquad (6)$$

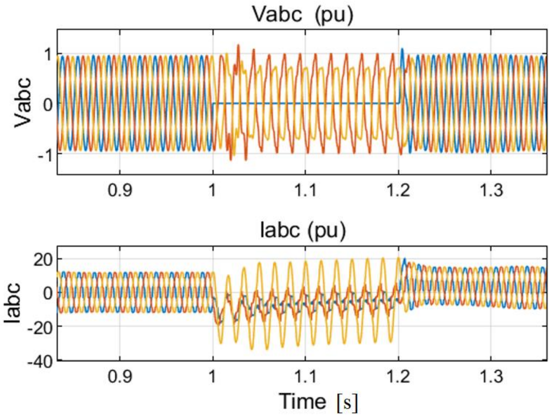

Fig. 3: Single line to ground fault

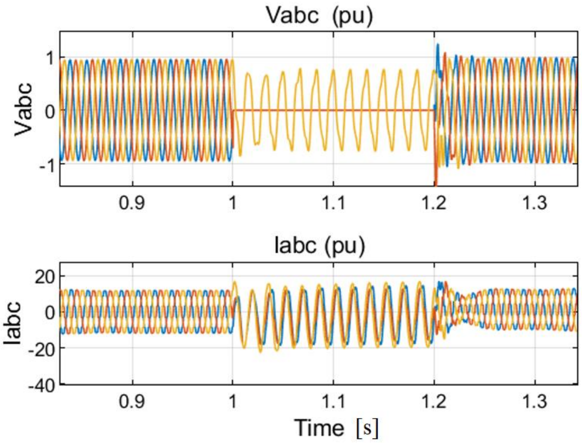

Fig. 4: Line to line to ground fault

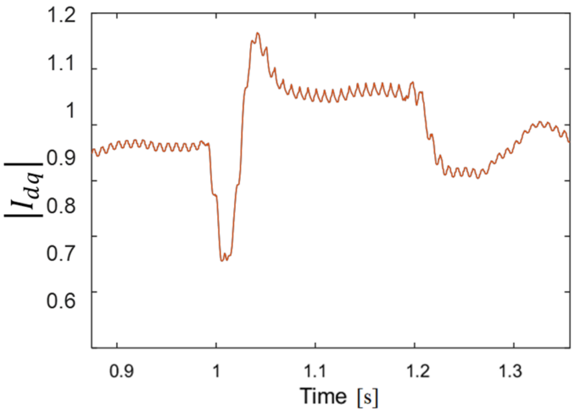

Fig. 5: The dq-axis magnitudes of current waveform changes for a single line to ground fault case

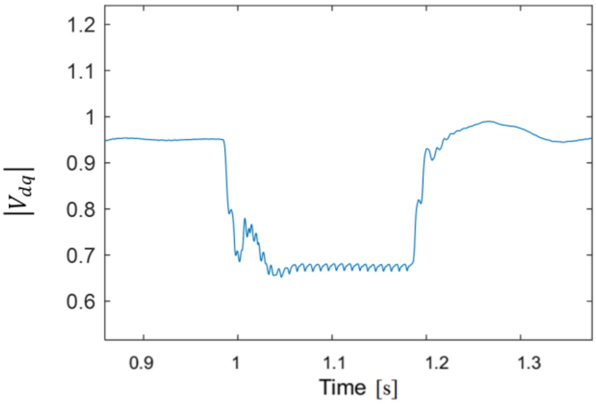

Fig. 6: The dq-axis magnitudes of voltage waveform changes for a single line to ground fault case

Same procedure is followed for all fault conditions as well as normal condition including various fault parameter variation such as the fault location and fault resistance for the DC faults and various fault types for the AC faults with different fault resistance as well.

2.5 Chromatic Monitoring

The used method in this work is based on exploring the nature of the event whose type and location leave fingerprints on the generated signals. In summary, signals from different events show great similarity, however, each event, due to its location and/or type, has the effect of altering the configuration of the system and thus leaves a trace that may not be clearly visible. So, to show this, transformations can reveal a hidden feature that enables different classes of events to be distinguished.

The initial idea of chromatic monitoring came from the working principle of the human eye; the sensitive observation element in humans' system. The eye contains powerful sensors whose purpose is to transmit the complete visual image for analysis in the brain, which includes a complete and accurate analysis of its spectrum, colors and contents.

In human vision system, covering the entire visible color spectrum is performed by Color-distinctive cells through a defined set of overlapping filters. Inspired by the same idea, it is possible to create a similar working principle system, in Figure 7, a set of filters is applied named R, G and B, may be similar in shape, but differ in their coverage range with the possibility of overlapping to monitor the signal P. For full coverage monitoring, the signal range P determines the beginning and end of the coverage range by all the different filters combined.

The response of each processing filter depends on the details and magnitude of the monitored signal in the covered range by its covering processing filter. The outcomes of three signal filters are given by equations 7, 8 and 9:

$$R=\int R(\phi)P(\phi)d\phi \tag{7}$$

$$G=\int G(\phi)P(\phi)d\phi \tag{8}$$

$$B=\int B(\phi)P(\phi)d\phi \tag{9}$$

$R(\phi)$, $G(\phi)$ and $B(\phi)$ are the filters profiles and ϕ is the monitored signals domain, and $P(\phi)$ is the monitored signal. The gaussian profile shape of the filters in Figure 7 can be replaced by other shapes such as the triangular shape and the number of processors can be altered as well depending on the application and the monitored signal. In this work, three processors with triangular shapes were selected.

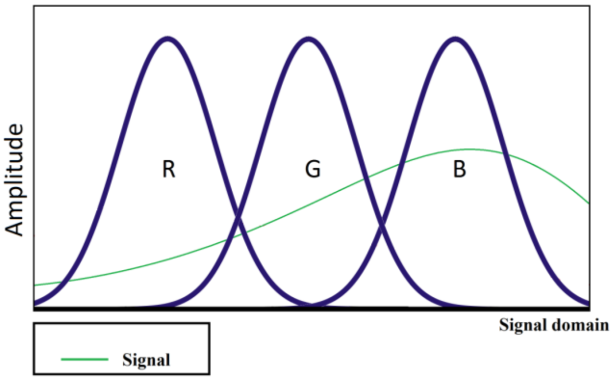

Fig. 7: Three gaussian filters coverage of monitored signal domain

For implementation of the adopted Lab color chromatic processing algorithm is in this work, a group of equations 4-6 are used for processing of the three R, G, and B processors outcomes. Equations 10, 11 and 12 produce three relative magnitudes (L, a, and b) respectively [20]

$$L=116(G/G_n)*1/3-16 \tag{10}$$

$$a=500[(R/R_n)*1/3-(G/G_n)*1/3)] \tag{11}$$

$$b=200[(G/G_n)*1/3-(B/B_n)*1/3)] \tag{12}$$

The R_n, G_n, B_n in color science are the processor outputs when addressing the illumination source directly. In this work, these terms will be used for normalization purpose.

The outcomes of the transformation process illustrated by previous equations are used for the detection and classification stage. Some parameters can be used to characterize and determine the occurrence of faults. Other parameters can be used for the classification stage.

3 Monitoring Results

The overall procedure presented in subsection (2.1) and as shown in the flowchart of Figure 1 is applied on the computed DQ0 transform signals waveforms under different condition for AC faults, DC faults cases in addition to the healthy condition of the simulated HVDC system shown in Figure 2.

The proposed scheme has been thoroughly tested. Test cases are repeated under different normal operating in addition to faulty conditions with different fault resistance and diverse locations for the purpose of sensitivity investigation. Variation of the L, a and b parameters are evaluated for both voltage and current waveform as well for all the different cases.

Figure 8 shows the relationship plot for the L parameter from the Vq waveform on the x axis, the L parameter from the Iq waveform on the y axis versus the b parameter from the Iq waveform on the z axis. Preliminary analysis of this variation for these selected chromatic monitoring transformation parameters shows successful indication of the condition occurrence detection upon fault incidence.

Mapping between the selected parameters can also serve the purpose of distinguishing between different conditions as the results identify a significant defining characteristic of well-defined clear boundaries for various clusters defining different conditions.

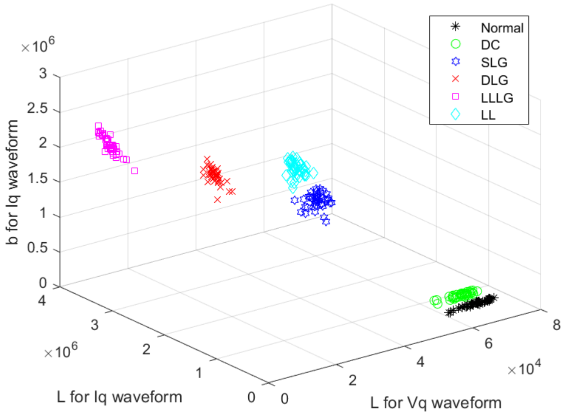

Fig. 8: L_{Vq} with L_{Iq} and b_{Iq} parameter plot for all cases

Although Figure 8 shows a possibility of ambiguate between the normal condition and the DC fault but there is a clear defining characteristic of well-defined clear boundaries between these conditions, and this is illustrated by zooming and as shown in Figure 9. But and to increase the proposed system sensitivity, further investigation by utilization of diverse color transformation is encouraged with monitoring of different domain such as the frequency and this is left as a future work suggestion.

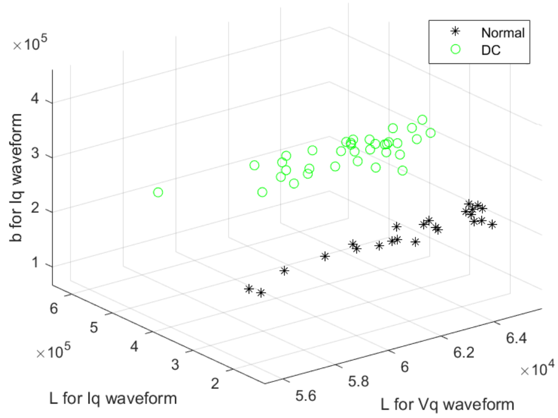

Fig. 9: L_{Vq} with L_{Iq} and b_{Iq} parameter plot for the Normal operation and the DC fault case

4 Conclusion

The preliminary results obtained with Lab color monitoring of the Zero-Direct-Quadrature DQ0 waveforms from a HVDC system under various faulty conditions have been presented. The proposed method has the potential to successfully distinguish between different cases without the need for prior training.

This paper presents a new method for classifying HVDC system faults. The analyses are applied on currents and voltages of the system under (DQ0) coordinates using Lab color chromatic based monitoring approach. Repeated for several healthy and faulty scenarios in DC side and AC side as well, The DQ0 transformed signals are evaluated for each case, Continuous chromatic monitoring is applied on all signals. A chromatic Lab mapping of short time-slot windows result in providing an early fault detection. Initial results show high accuracy in fault type classification as well with short processing time.

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