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A K-NN algorithm based fault locating system for HVDC transmission lines

***Abstract**: High voltage direct current power transmission HVDC is nowadays in full expansion in the world for different reasons; economic, technical and environmental ones. On the other hand, more recently, the energy transition has boosted this technology enormously for the integration of renewable energies and carbon neutrality strategy these last times. As any system, the HVDC are subject to different faults which can affect their operation functioning. The aim of this work is to use a classifier based on one of the artificial intelligence methods to localize these faults. We have chosen the k-NN classifier, the theory of statistical learning.in k-NN classification, the result is a membership class. An input object is classified according to the majority result of the membership class statistics of its k nearest neighbors then the proposed approach has the ability to help in the field of classification of defects because there is no restriction on the number of features. It's one of the supervised classifications and the result are a different fault location in dc cable*

Streszczenie. *Transmisja prądu stałego wysokiego napięcia HVDC jest obecnie w pełni rozpowszechniona na świecie z różnych powodów; ekonomicznych, technicznych i środowiskowych. Z drugiej strony, ostatnio transformacja energetyczna ogromnie przyspieszyła tę technologię w zakresie integracji energii odnawialnej i strategii neutralności pod względem emisji dwutlenku węgla. Jak każdy system, HVDC podlegają różnym awariom, które mogą wpływać na ich funkcjonowanie. Celem niniejszej pracy jest wykorzystanie klasyfikatora opartego na jednej z metod sztucznej inteligencji do lokalizacji tych uszkodzeń. Wybraliśmy klasyfikator k-NN, teorię statystycznego uczenia się. W klasyfikacji k-NN wynikiem jest klasa przynależności. Obiekt wejściowy jest klasyfikowany zgodnie z większościowym wynikiem statystyki przynależności do klasy jego k najbliższych sąsiadów, to proponowane podejście ma możliwość pomocy w zakresie klasyfikacji defektów, ponieważ nie ma ograniczeń co do liczby cech. Jest to jedna z nadzorowanych klasyfikacji, której wynikiem jest inna lokalizacja uszkodzenia w kablu prądu stałego.* (***System lokalizacji uszkodzeń oparty na algorytmie K-NN dla linii przesyłowych HVD**C*)

Keywords: HVDC transmission system; k-NN classification; faults location.
Słowa kluczowe: system przesyłowy HVDC; klasyfikacja k-NN; lokalizacja usterek

Introduction

High voltage direct current (HVDC) transmission is widely used in the field of long-distance transmission for an overhead line. But for submarine cables, a metallic ground return is added. According to the figure 1, there is a distance called "Break Even distance at which an HVDC link becomes economically more interesting than an HVAC link for the same transmitted power. In the case of overhead lines, this distance varies from 500 to 800 km, according to [1], and for submarine" type cables, the distance is estimated to be between 70 and 100 km, [1].

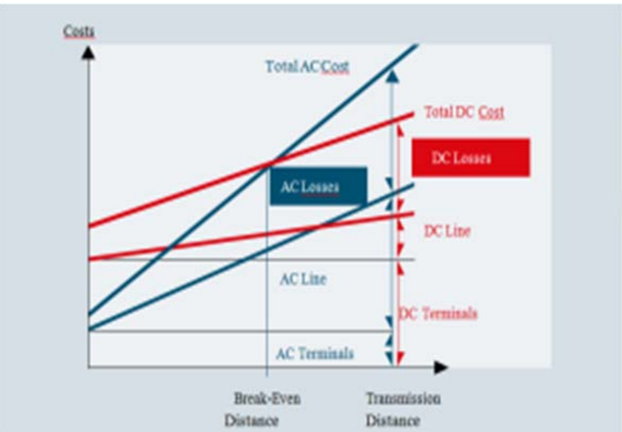


Fig. 1 comparison between the cost of DC and AC transmission line

Compared with AC transmission, HVDC transmission has a better economy and higher transmission capacity and also has many advantages such as easy power regulation, narrow line, and fast network interaction [3] [4]. A high voltage direct current-based system (VSC-HVDC bipolar) plays an irreplaceable role in the safe operation of the whole power grid. It should quickly and accurately locate the fault location, reduce the outage time and improve the power reliability. Therefore, the fault location technology of bipolar VSC-HVDC transmission systems should be studied.

At present, the fault location method of HVDC lines can be classified into four main categories namely, spectral analysis method, impedance method, machine learning method, and traveling wave method.

A pole-to-pole and pole-to-ground fault analysis based on VSC systems have been performed. to ground-based on VSC, in [4], [8]. Pole-to-pole faults are classified as severe but less likely to occur, on the contrary, pole-to-ground faults are the most likely but generally less harmful fault scenario. Further analysis of converter behaviour during such an event could be beneficial in improving the overall understanding of system operation, and fault behaviour in particular. Therefore, this paper provides a detailed analysis of the behaviour of a VSC-HVDC converter during pole-to-pole and pole-to-ground DC faults for two-level VSC-based systems with a range of fault resistances [9] (Fault Current Characterization in VSC-based HVDC Systems) but the major drawback of this method is that there is a lack of data as this method is based on simplifications on the complete model itself which can be said to be a theoretical approach.

Detection method the point of mutation of the signal by S-transform is used in order to locate the defects accurately, but this method cannot guarantee the accuracy when the defect signal is affected by strong noise as well as this method does not preserve the signal energy [10].

The paper [3] presented a two-ended fault location technique with the variational mode decomposition (VMD) method in this method, VMD is used to extract the fault features for fault location estimation, which is further improved but the method is based on a computational level simplification.

Several approaches found in the literature can be mentioned. The method based on traveling waves to classify the defect in VSC-HVDC systems using successive defects reflections is described in [11]. It detects the defect by reflection peak using the differentiator and smoother.

Another method developed an algorithm based on the traveling wave and used a cross-correlation with the sample space vector [12] that uses wavelet transforms to move the reflected wave to the estimated defect in the HVDC transmission system. This approach is also used to locate faults in orthodox two-terminal HVDC transmission networks and is also considered suitable for mixed aerial and cable VSC-HVDC transmission systems. Paper [13] presented an FFT and Pony transform approach based on single-ended current data used for fault location. Paper [14] using RBF neural network function with wavelet packet decomposition transform for HVDC transmission system fault estimation. Few papers have presented a coordination scheme based on the analysis of the relationship between wave front and wave velocity to locate the fault point. This detection scheme has also discussed the singularity of the wave front to detect the precise point of the face wave.

Paper [15] presented a high frequency-based method for fault location using asymmetric data in UHVDC transmission systems. Eigen frequency extraction could be done by examining the transient signals after the occurrence of faults. Continuous wavelet transformation can improve the accuracy of the DTFT approach and the accuracy of the DTFT method can be improved by using continuous wavelet transformation and verified by using a two-terminal traveling wave approach to predict the arrival time of the reflected wave. The research paper [16] proposed a line-parameter-free approach for fault location using two-terminal desynchronization data HVDC transmission system. The paper [17] used a voltage source converter and an anti-parallel diode rectifier for a voltage source converter-based modulation index dependent (VSC) equivalent circuit scheme. This impedance transfer the AC side with an orthogonal transition to the DC side of the converter using the transformer analogy. Due to the anti-parallel diodes connected in the converter configuration, a three-phase diode rectifier bridge is created, this article also deals with the equivalent representation of this diode peak bridge.

But the problem with the above-mentioned methods (impedance or spectral analysis) is that we cannot estimate the distance and time of the fault with accuracy by using simplified mathematical model, however with machine learning, we can locate and classify the faults with a very high accuracy based on intelligent statistics which is close to reality and this is the advantage of our proposed method and the contribution is in the accuracy of the classifier. we are going to use the distributed constant model in power transmission for collecting the data by measuring in every possible point the potential that has been generated by the defect to have a given base and make the diagnosis using machine in the 3rd section we will present the complete model of the hvdc vsc system with the topological structure and in the 4th section we will present the proposed method combining the distributed constant model with machine learning using KNN classifier

2 Principles of VSC-HVDC bipolar

2.1 Topological structure of VSC-HVDC

The bipolar configuration is an evolution of the monopolar transmission scheme. The topological structure of a two-terminal VSC-HVDC system is shown in Figure 1. Two VSCs are connected to the corresponding AC system and they are connected with DC cables. The transformer of the converter transformer is used between the VSC and the AC system for operational isolation and power optimization of the VSC. The transformer is used between the VSC and the AC grid for operational isolation and power optimization of the VSC, which is replaced by a resistor and a reactor. The shunt capacitors in the DC sides can provide a DC voltage and smooth the DC voltage. [20]

The bipolar configuration is actually two monopolar systems combined - one with positive polarity and one with negative polarity to the ground. It's the most commonly used configuration for a two-pole transmission system - high degree of operational flexibility

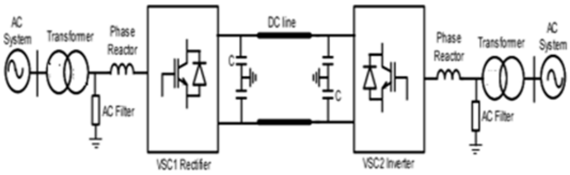


Fig. 2 schematic of two VSC-HVDC system

2.2 Mathematical model of the VSC-HVDC link

Since the HVDC-VSC system is composed of a rectifier and an inverter connected by an AC voltage source, the model will be that of a rectifier and an inverter.

(1)
$$
\begin{aligned}
L\frac{di_a}{dt} &= e_a - v_a - Ri_a \\
&= e_a - v_{dc}\left(s_a - \frac{1}{3}\sum\nolimits_{a,b,c} s_j\right) - Ri_a \; L\frac{di_b}{dt} \\
&= e_b - v_b - Ri_b \\
&= e_b - v_{dc}\left(s_b - \frac{1}{3}\sum\nolimits_{a,b,c} s_j\right) - Ri_b \; L\frac{di_c}{dt} \\
&= e_c - v_c - Ri_c \\
&= e_c - v_{dc}\left(s_c - \frac{1}{3}\sum\nolimits_{a,b,c} s_j\right) - Ri_c \; c\frac{dv_{dc}}{dt} \\
&= s_a i_a + s_b i_b + s_c i_c - i_{dc}
\end{aligned}
$$

Note: s_j (j=a, b, c) is the logical switching function, when s_j=1 the upper bridge arm is driven and the lower bridge arm is disabled, when s_j=0 the opposite case

Using the park d-q transformation we can deduce the following equations:

(2)
$$
\begin{aligned}
L\frac{di_d}{dt} &= e_d - v_d - Ri_d - \omega L i_q \\
&= e_d - s_d v_{dc} - Ri_d - \omega L i_q
\end{aligned}
$$

(3)
$$
\begin{aligned}
L\frac{di_q}{dt} &= e_q - v_q - Ri_q + \omega L i_d \\
&= e_q - s_q v_{dc} - Ri_q + \omega L i_d
\end{aligned}
$$

(4)
$$\frac{3}{2}c\frac{dv_{dc}}{dt} = s_d i_d + s_q i_q - \frac{3}{2} i_{dc}$$

$$p = \frac{3}{2}\left(e_d i_d + e_q i_q\right) \text{ and } q = \frac{3}{2}\left(e_q i_d - e_d i_q\right)$$

2.3 Connecting the VSC system to an alternative source

The active power P flowing from the converter to the AC system is given by the relation:

(5)
$$p = \frac{U_{sys} U_{vsc}}{X_t} sin\delta$$

U_{sys} is the AC system voltage, U_{vsc} is the voltage across the VSC;
X_t is the reactance connecting the VSC to the AC system
δ indicates the voltage angle between the VSC and the AC system.

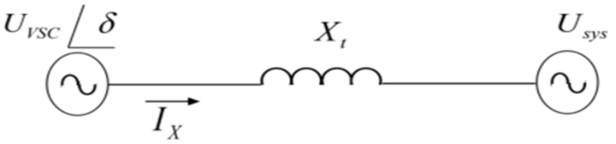


Fig 3 schematic of connection between VSC and the AC .ystem.

The reactive power that will be exchanged between the VSC and the system is given by the following relation:

$$Q = \frac{U_{vsc}\left(U_{vsc} - U_{sys}\cos\delta\right)}{X_t} \quad (6)$$

$U_{vsc}> U_{sys}$: Q is greater than zero and implies a capacitive operation (VSC delivers a reactive power to the network).
$U_{sys} > U_{vs}$: Q is less than zero and implies inductive operation (VSC absorbs the reactive power).
For equal voltage magnitudes, the reactive power is zero and the real power is determined by the voltage angle between the two vectors.
If $\delta > 0$ power flows from VSC to AC (inverter operation).
If $\delta < 0$ the power flow from the AC system to the VSC (rectifier operation).

For the voltages and currents shown in the following figure, the converter equations can be defined. The voltage of the converter is given by the relation:

$$U_c = U_f + X_r I_r \quad (7)$$

U_f is the AC filter node voltage, X_r is the reactance of the inductance of the converter and I_r is the current through the inductance of the converter

The current I_r is given by the relation:

$$I_r = I_t + I_f \quad (8)$$

I_t is the total current through the converter transformer and I_f is the current flowing through the filter impedance.

The voltage U_f of the AC filter node is given by the relationship:

$$U_f = U_t + X_{tr} I_t \quad (9)$$

U_t is the voltage on the primary side of the converter transformer X_{tr} is the reactance of the converter transformer.

The filter current I_f is given by the following relationship:

$$I_f = \frac{U_f}{Z_f} \quad (10)$$

3 Proposed methods

3.1 Data acquisition

The purpose of data acquisition is to import the data measured and organize it for use in data analysis applications and then going through a whole process that uses a variety of data analysis tools to discover the relationships in data. That can be used to make valid predictions. The simplest analytical is to describe the data, that is, to summarize its attributes statistically (such as means, root mean square (RMS), deviations and signal energy, median, kurtosis….) That is, using statistical measures to obtain useful features examining them visually using tables and graphs and looking for potentially significant relationships between variables. Data analysis takes advantage of advances in the fields of artificial intelligence (AI) and statistics. Both disciplines have worked on problems of regression and classification. We can define classification as predicting into what category or class a case falls [18]. In other words In machine learning and statistics, classification is the problem of identifying to which group of categories (subpopulations) a new observation belongs, from a set of learnings containing data (or instances) whose membership to a category is known.

3.2 KNN algorithm

K-nearest neighbors (K-NN) algorithm is one of the simplest methods in supervised machine learning algorithm which can be used for both classification and regression problems. However, it is frequently used for classification problems in the industry. It classifies a new observation (extracted feature vector) by calculating the distance to the training data and takes the k nearest neighbors (in terms of distance). Then, observe the class that is predominantly represented among the k-nearest neighbors and assign this class to the new observation. As shown in Fig. 1 As first given dataset $D_n = \left((x_1, y_1), \dots\dots\dots, (x_n, y_n)\right)$ we define the reordered data with respect to the new prediction value x as $\left(\left(x_{(1,x)}, y_{(1,y)}\right), \dots\dots\dots, \left(x_{(n,x)}, y_{(n,x)}\right)\right)$ where $d\left(x_{(i,x)}, x\right) \le d\left(x_{(j,x)}, x\right) \forall i < j$

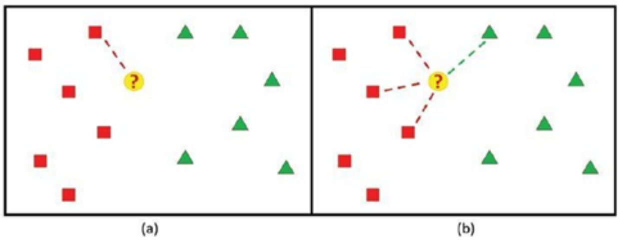


Fig. 5 [18] understand how k-Nearest Neighbors classifier work.

After defining the value of k neighbor we can go through the metric distance one of the most popular choices to measure this distance is known as Euclidean.

$$\sqrt{\sum_{i=1}^{n} (x_i - y_i)^2} \quad (11)$$

From unclassified points to other points the k-NN based diagnosis models are easily-implemented. However, it takes much computation cost to handle the large-volume dataset. In particular, the imbalanced distribution of the collected data would reduce the diagnosis accuracy of this kind of diagnosis model. Furthermore, the parameter k is difficult to be determined, which greatly affects the performance of the diagnosis models. [19]

Suppose there are two categories, i.e., Category A and Category B, and we have a new data point x1, so this data point will lie in which of these categories i.e unclassified point to other points With the help of K-NN, we can easily identify the category or class of a particular dataset. The below diagram illustrates the method . the distributed element model is usually only applied when the accuracy requires it. The location of this point depends on the accuracy required in a specific application in our case it is the location of fault we divided the impedance of the dc cable in several elements (20 identical impedances) and we created faults in different positions (30,15 ,75 km) and then we collected the data by capturing the signal in each point of the cable (taking the RMS value of each potential) and by changing in fault resistances to generate the datasets .

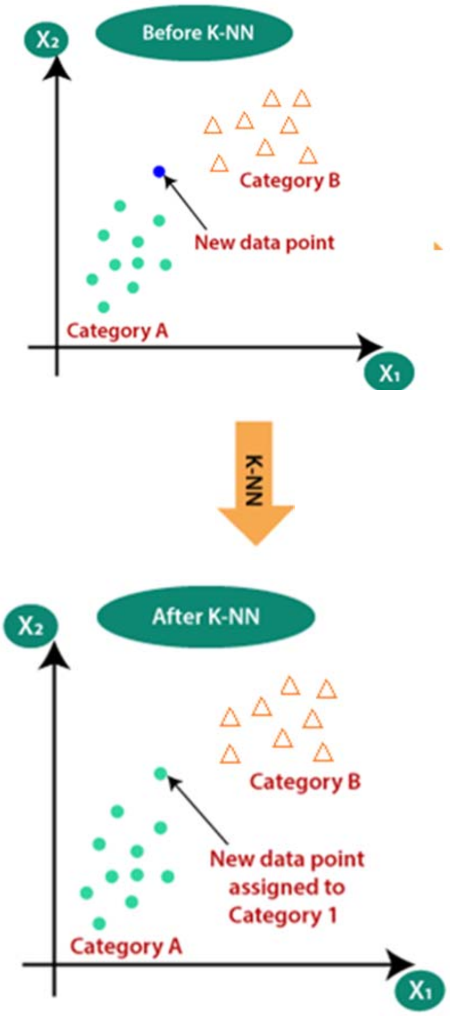


Fig 6 illustration of the help of K-NN method

4 Results and discussion

Performance of VSC-HVDC bipolar system has been simulated under these circuit specification. The transmission power capabilities of the system are 2000MVA at a voltage level of 230 KV. The nominal frequency of AC system is 50 Hz. The length of transmission cable is 75 km .we used Matlab to modelling the HVDC system and programming the previous method.

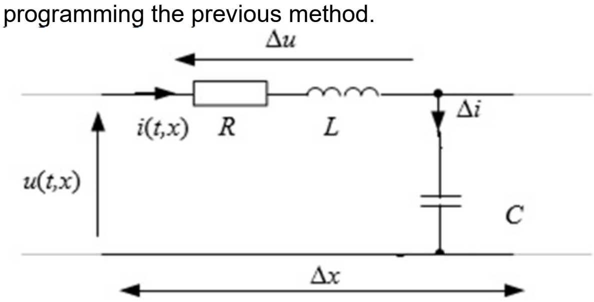
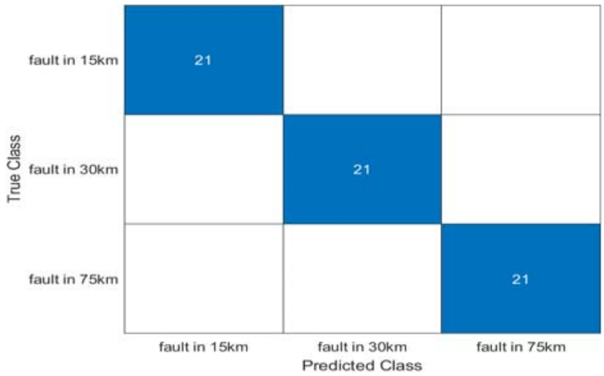


Fig. 7 Line equivalent model: line with distributed constants.



Fig/ 8 The confusion matrix of the KNN classifier with k=1 using the Euclidean measure.

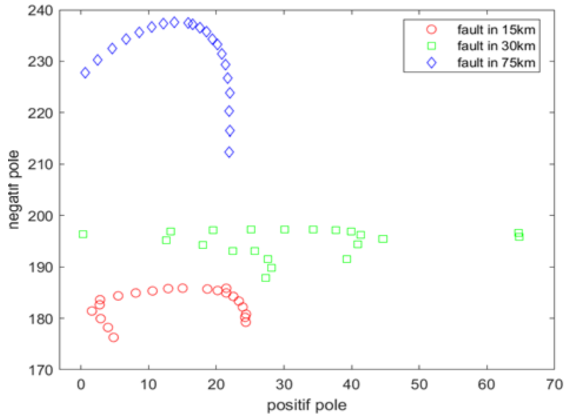


Fig. 9 the dispersion of the dataset with the inputs of this base are the positive and negative pole.

We divided the impedance of the dc cable in several elements (20 identical impedances) and we created faults in different positions (30,15 ,75 km) and then we collected the data by capturing the signal in each point of the cable (taking the RMS value of each potential) to generate the datasets and use the method proposed previously.

The figures above show the results of our application where we will process 126 features and the output is the default distance. So we can say that the accuracy of the classifier reach 100%. It is a scientific contribution that we can using machine learning to fault location.

5 ConclusionN

A method for fault localization based on k-NN machine learning has been presented in this paper. We will use the distributed constant method in the dc cable part the results showed that all types can be detected quickly and accurately. In addition, the location of the fault can be detected with 0% error. The k-NN-based method can be considered as a very effective method for HVDC VSC bipolar systems.

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