# Determining of Fault Locations with Hilbert – Huang Transformation on XLPE Cables between Land and Offshore Substations

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*Abstract* — **Using of mathematical transformations and digital signal processing (DSP) methods of recorded voltage and currents in power systems in order to extract important informations about physical processes is already known. Higher resolution of measurements and massive introduction of PMU devices in the power systems allows appliance of DSP - based fault location methods in complex power networks. High availability of power systems is required in the modern societies. Fast fault location algorithms and consequent fast repairing of faults is necessary condition for high availability of power networks. Here is represented a numerical procedure for fault location and testing of method already introduced in scientific literature on complex configuration of power network consisting of XLPE underground submarine and land cables between land and offshore substation connecting large wind park with main power system.**

***Keywords—Fault location, DSP, HHT, XLPE, Wind park, Offshore substation***

## I. Introduction

Application of the Hilbert-Huang transformation (HHT) in the fault location algorithms in combination with transformation of recorded fault voltages and currents into one-dimensional signal with complex space phasor is explained in [1] – [2]. A simple formula is used for fault location calculation after determining of singularities in the signal of empirical mode decomposition (EMD), method inherent to the HHT [1]. Method was already tested on simpler power network configurations. Hence, testing on more complex structures is logical step forward. One of the most demanding tasks is fast determining of faults location in the networks with feeders with various physical structures. Furthermore, power networks in distant areas with severe meteorological conditions (like offshore wind farms) require accurate and fast calculation of fault position in order to reduce repairing costs and speed up the repairing process.

### A. Configuration of power network for the case study

For the case study is selected a connection of a large wind park between the land and the offshore substations. This connection is characterized by junctions of long XLPE land and submarine cables which have different physical characteristics. As pattern for the case study is selected configuration common for connection of offshore large wind parks with the main power system similar to power network presented in [3]. In Figure 1 is presented configuration of power network between land and offshore substation connected with complex feeder consisting of connection of land and submarine XLPE cables. Geometry, electrical and dielectrical parameters of XLPE land and submarine cables are given in [3]. We assume that exists GPS synchronization between relay protection and measurement devices in both substations (however, precise fault recorder with high frequency sampling must be installed in just one substation - this assumption is necessary for testing of here presented numerical fault location procedure from both sides of considered complex feeder).

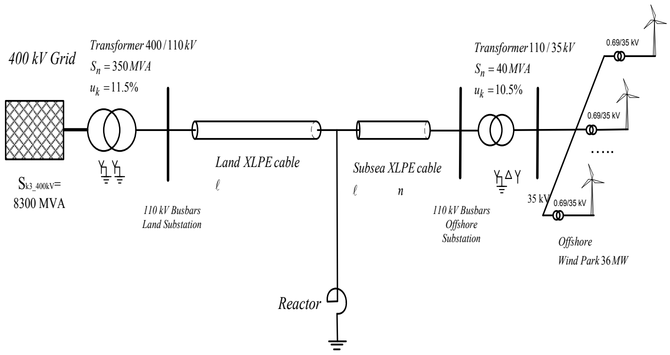


Figure 1: Single line representation of power network for the study case

### B. Speed of travelling waves on land and submarine cables

For usage of the proposed fault location method, few preprocessing operations must be performed. First of all, it is necessary to determine traveling wave speed of current and voltage waves along each part of considered mixed feeder. In [1] is presented procedure for traveling wave speed calculation. Short-circuit is simulated at the end of 10 km long power cable in the PSCAD software for the transient analysis [4], as presented on Figure 2. Recorded fault voltages are transformed into one-dimensional signal of complex values – complex space phasor. That phasor is then processed with HHT, in order to obtain series of Intrinsic Mode Function (IMF) values. Then, with HHT are extracted singularities in the IMF's along with its time of occurrences in high time resolution [1] - [2].

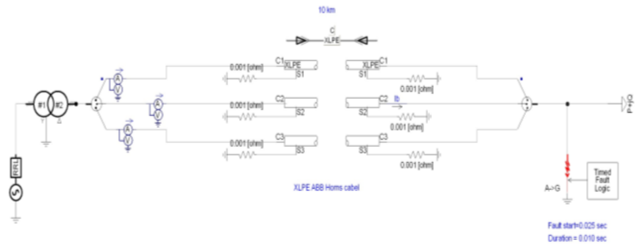

Figure 2: PSCAD configuration for determining traveling wave speed along land XLPE cable

Series of IMF's of the first order are presented in Figure 3. Single phase fault is applied at t=0.025 sec. Singularities and its time stamps are extracted with HHT.

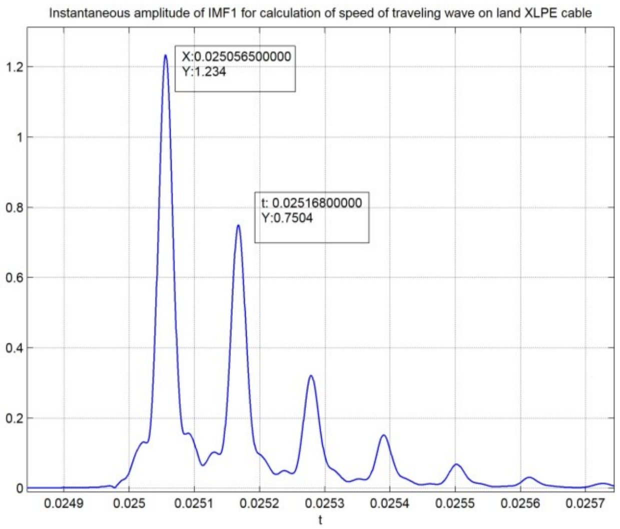


Figure 3: Singularities in IMF mode 1 of measured fault voltages for determination of traveling wave speed along the land XLPE cable

According the traveling wave theory, voltage or current wave traversed double length of the cable. According to that, speed of traveling wave is calculated with formula:

$$v_{XLPE} = \frac{2 \cdot \ell_{cable}}{t_{diff\_peak}} \tag{1}$$

In equation (1) $t_{diff\_peak}$ represents a time between consecutive peaks in the IMF's signal of the first order [1]. When inserting values presented on Figure 3 into equation (1), obtained speed of the traveling wave along the land XLPE cable is:

$$v_{XLPE\_LAND} = 1.793721973094170e+008\,(m/\sec).$$

With similar procedure, traveling wave along the submarine XLPE cable is:

$$v_{XLPE\_SUBMARINE} = 1.346801346801347 0e+008\,(m/\sec)$$

Different speeds are caused by different physical characteristic of XLPE land submarine and land underground cables [3]. The most important is difference in the permittivity of the outer insulation layer. In the case of the submarine cable that permittivity is modeled as $\varepsilon_2 = 100$.

## II. CASE STUDY - CHARACTERISTIC FAULT

### *A. Simulation configuration for characteristic fault*

Characteristic fault on the mixed feeder which consists of two different types of feeders, is the fault simulated (or physically applied) in their junction point. For better understanding of that concept, in Figure 4 is presented the PSCAD simulation for the characteristic fault in the junction point of land and submarine XLPE underground cable.

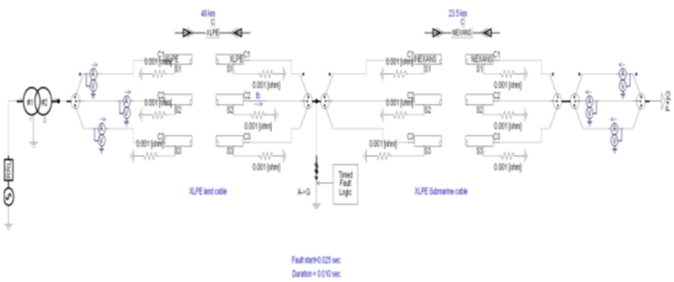

Figure 4: PSCAD configuration for fault in the junction point of land and submarine cable – characteristic fault

This special case is the most important in the fault location procedure on the complex feeders with HHT and serves as sample for comparison with all other types of faults.

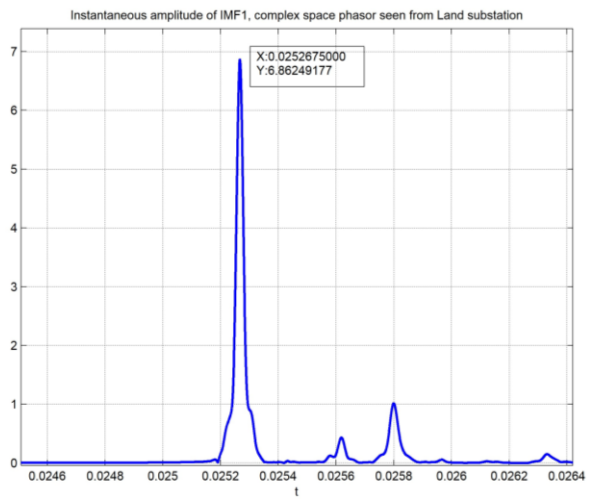


Figure 5: Singularities in IMF mode 1 of measured fault voltages seen from land substation

On Figures 5 and 6 are presented singularities in the IMF's first order series extracted with HHT as explained in [1], seen from land and offshore substation. It should be noted that it is not necessary to have high resolution measurements in both substations.

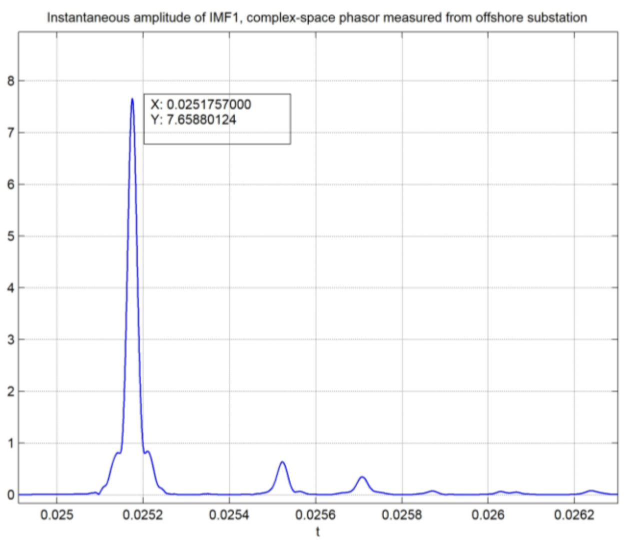


Figure 6: Singularities in IMF mode 1 of measured fault voltages seen from offshore substation

Fault is simulated at t=0.025 sec. Obtained time of occurrences of singularities are recorded in the IMF signals and extracted with HHT processing. Obtained values will serve as key times for comparison for all other faults.

## III. CASE STUDY - FAULT ON LAND XLPE CABLE

As first case for testing of HHT fault location algorithm, a single line to ground fault (SLG) is applied in the time t=0.025 sec on the land XLPE cable in considered power network, 20.5 kilometers seen from land substation (Figure 7). Furthermore, to make the case more difficult to calculate, we assume that the fault internal resistance is high and set to $R_{fault}$=100 Ω. Time step of simulation is $\Delta t = 0.5 \cdot 10^{-6}$ sec.

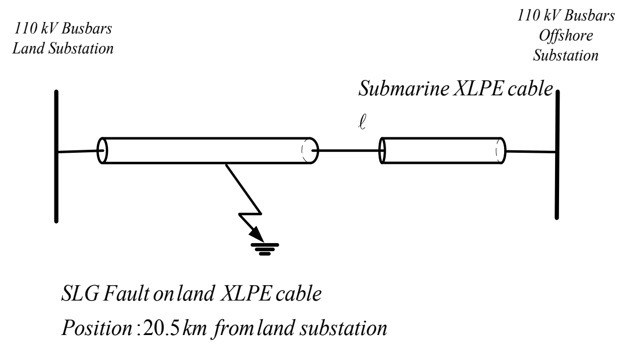


Figure 7: Position of SLG fault on land cable

Recorded fault voltages are processed as explained in [1] and [2] and singularity in IMF's mode of first order is obtained as presented in Figure 8. First conclusion is that the occurrence time of the first reflected wave is bigger than singularity time in the characteristic case. i.e. 0.0252675> 0.0251145. This indicates that fault is located somewhere on the land XLPE cable (traveling wave did not traverse all of the length of land XLPE cable). Calculating of fault location is then simple:

$dt =$ 0.0252675-0.0251145

$dt$-$v_{XLPE\_land}$ – 27500 m (real position) gives us error

$err$ = 56.05 meters

which is an acceptable error, considering the total length of the cable.

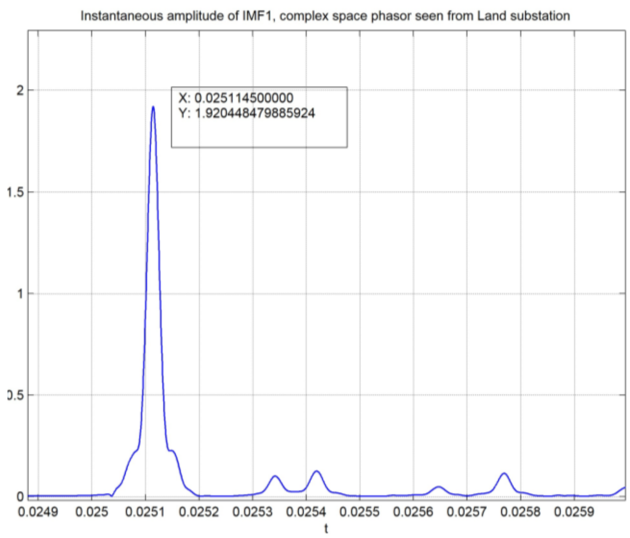


Figure 8: Singularities in IMF mode 1 of measured fault voltages seen from offshore substation

## IV. CASE STUDY - FAULT ON SUBMARINE XLPE CABLE

As second case for testing of HHT fault location algorithm, is a single line to ground fault (SLG) applied on the submarine XLPE cable in considered power network, 16 kilometers from the junction point of land and submarine XLPE cable (Figure 9). Again, fault internal resistance is set to $R_{fault}$=100 Ω.

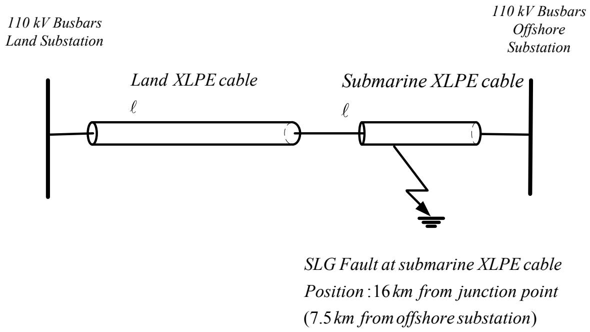


Figure 9: Position of SLG fault on submarine cable

Singularity in IMF's mode of first order seen from land substation is presented on Figure 10.

Same fault location procedure gives:

*dt*=0.025386-0.02526

*dt* •1.3468 $10^8$-16000 (real position of fault) gives error of 26.94 meters, which is again acceptable regarding complexity of considered power network.

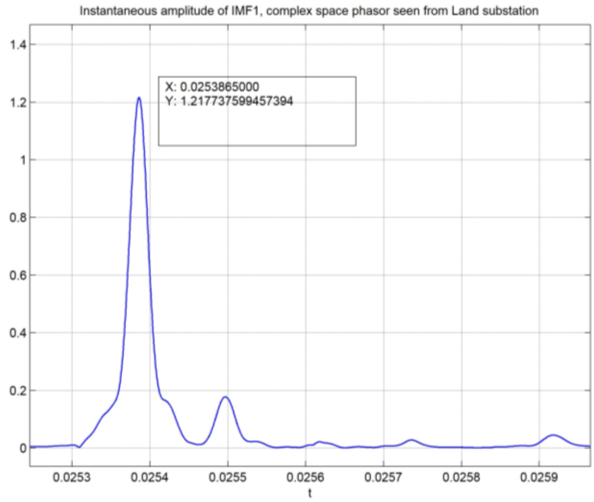


Figure 10: Singularities in IMF mode 1 of measured fault voltages seen from land substation – fault at submarine cable

## CONCLUSION

Mathematical transformations and DSP methods are the state-of-art numerical procedures in acquiring informations about physical phenomenology of power systems. Here represented study case is testing of relatively new fault location method introduced in earlier publications. High accuracy of determining of fault locations in complex power networks along with the low processing time consumption are reason for further examinations and testing of HHT in the power systems. In this paper is elaborated usual configuration for connecting of large offshore wind park on the main power systems. Obtained results are satisfactory accurate, even with applied high fault resistances, which is reason for further testing of here proposed fault location method. Very long two-system overhead lines; three-port overhead lines (T – junction structure) and high – impedance faults (HIF) are cases for final test of HHT in the fault location applications. Furthermore, some insufficiently examined properties of HHT as instantaneous frequency opens a way for prototyping off new relay protection device based on traveling wave theory and HHT.

## REFERENCES

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