



BSI Standards Publication

Communication networks and systems for power utility automation

Part 90-21: Travelling Wave Fault Location

National foreword

This Published Document is the UK implementation of IEC TR 61850-90-21:2025.

The UK participation in its preparation was entrusted to Technical Committee PEL/57, Power systems management and associated information exchange.

A list of organizations represented on this committee can be obtained on request to its committee manager.

Contractual and legal considerations

This publication has been prepared in good faith, however no representation, warranty, assurance or undertaking (express or implied) is or will be made, and no responsibility or liability is or will be accepted by BSI in relation to the adequacy, accuracy, completeness or reasonableness of this publication. All and any such responsibility and liability is expressly disclaimed to the full extent permitted by the law.

This publication is provided as is, and is to be used at the recipient's own risk.

The recipient is advised to consider seeking professional guidance with respect to its use of this publication.

This publication is not intended to constitute a contract. Users are responsible for its correct application.

This publication is not to be regarded as a British Standard.

© The British Standards Institution 2025
Published by BSI Standards Limited 2025

ISBN 978 0 539 35940 4

ICS 33.200

Compliance with a Published Document cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 28 February 2025.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

TECHNICAL REPORT

Communication networks and systems for power utility automation – Part 90-21: Travelling Wave Fault Location

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 33.200

ISBN 978-2-8327-0163-8

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD.....	5
INTRODUCTION.....	7
1 Scope.....	8
1.1 Scope of work.....	8
1.2 Published versions of the standard and related namespace names.....	8
1.3 Namespace name and version.....	8
1.4 Published versions of the standard and related namespace names.....	8
1.5 Code Component distribution.....	9
2 Normative references.....	10
3 Terms and definitions.....	10
4 Types of travelling wave fault location.....	10
5 Requirements and use cases.....	11
5.1 General.....	11
5.2 Use case 1: Single-ended fault location (Type A).....	12
5.2.1 Use case 1A: Single-ended fault location (Type A) – phase segregated.....	12
5.2.2 Use case 1B: Single-ended fault location (Type A) – 3-phase lines with modes at different speeds.....	18
5.3 Use case 2: Double-ended fault location (Type D) through communications between two devices.....	23
5.3.1 Description of the use case.....	23
5.3.2 Diagram of the use case.....	25
5.3.3 Technical details.....	26
5.3.4 Step by step analysis of the use case.....	27
5.3.5 Information exchanged.....	29
5.4 Use case 3: Double-ended fault location (Type D) through communications with a master station.....	29
5.4.1 Description of the use case.....	29
5.4.2 Diagram of the use case.....	31
5.4.3 Technical details.....	32
5.4.4 Step by step analysis of the use case.....	33
5.4.5 Information exchanged.....	35
5.5 Use case 4: Wide area fault location (Type W).....	35
5.5.1 Description of the use case.....	35
5.5.2 Diagram of the use case.....	37
5.5.3 Technical details.....	39
5.5.4 Step by step analysis of the use case.....	40
5.5.5 Information exchanged.....	43
5.6 Use case 5: Pulse radar echo method (Type C and Type FMCW).....	43
5.6.1 Description of the use case.....	43
5.6.2 Diagram of the use case.....	45
5.6.3 Technical details.....	47
5.6.4 Step by step analysis of the use case.....	48
5.6.5 Information exchanged.....	50
5.7 Use case 6: Integration with other fault location and disturbance recording functions in a substation.....	50
5.7.1 Description of the use case.....	50
5.7.2 Diagram of the use case.....	51

5.7.3	Technical details.....	52
5.7.4	Step by step analysis of the use case	53
5.7.5	Information exchanged	55
5.8	Use case 7: Testing and calibration	55
5.8.1	Use case 7a: Wave velocity calibration	55
5.8.2	Use case 7b: Simulation testing by remote commands.....	60
5.8.3	Use case 7c: Calibration for the pulse radar echo method	64
5.9	Use case 8: Fault location for hybrid lines.....	68
6	Information models	69
6.1.1	Mapping of the requirements of use case 1.....	69
6.1.2	Mapping of the requirements of use case 2.....	70
6.1.3	Mapping of the requirements of use case 3.....	71
6.1.4	Mapping of the requirements of use case 4.....	72
6.1.5	Mapping of the requirements of use case 5.....	73
6.1.6	Mapping of the requirements of use case 6.....	74
6.1.7	Mapping of the requirements of use case 7a.....	75
6.1.8	Mapping of the requirements of use case 7b.....	76
6.1.9	Mapping of the requirements of use case 7c.....	77
7	Logical node classes and data objects modelling.....	78
7.1	General.....	78
7.2	Abbreviated terms used in data object names	78
7.3	Logical node classes.....	78
7.3.1	General	78
7.3.2	Classes list.....	79
7.3.3	Logical nodes for protection related functions of 90-21 (LNGroupR)	79
7.3.4	Logical nodes for further power system equipment of 90-21 (LNGroupZ)	86
7.4	Data object name semantics	91
8	System configuration	92
8.1	General.....	92
8.2	Double-circuit line	92
8.3	Topology for single line with aerial mode and zero mode	94
	Annex A (normative) Conditions for element presence	95
	Annex B (informative) Explanation of percentage full scale	97
	Bibliography.....	98
	Figure 1 – Wide-area travelling wave fault location system	36
	Figure 2 – Class diagram LogicalNodes_90_21:LogicalNodes_90_21	79
	Figure 3 – Class diagram LNGroupR::LNGroupRext.....	80
	Figure 4 – Class diagram LNGroupZ:LNGroupZext	86
	Table 1 – Published versions of the namespace	8
	Table 2 – Attributes of (Tr)IEC 61850-90-21:2022A namespace.....	9
	Table 3 – Single-ended fault location use case requirement mapping over LNs.....	70
	Table 4 – Double-ended fault location through communications between two devices use case requirement mapping over LNs	71
	Table 5 – Double-ended fault location through master station communications use case requirement mapping over LNs	71

Table 6 – Wide Area fault location use case requirement mapping over LNs	72
Table 7 – Pulse radar echo method use case requirement mapping over LNs	73
Table 8 – Integration with other equipment use case requirement mapping over LNs	74
Table 9 – Line calibration use case requirement mapping over LNs	75
Table 10 – Testing by remote commands use case requirement mapping over LNs	76
Table 11 – Calibration for the pulse radar echo method – use case requirement mapping over LNs.....	77
Table 12 – Normative abbreviations for data object names	78
Table 13 – List of classes defined in LogicalNodes_90_21 package.....	79
Table 14 – List of classes defined in LNGroupR package.....	80
Table 15 – Data objects of RTWD	81
Table 16 – Data objects of RTWI	83
Table 17 – Data objects of RTWL	84
Table 18 – List of classes defined in LNGroupZ package	86
Table 19 – Data objects of ZCABExt.....	87
Table 20 – Data objects of ZLINEExt.....	89
Table 21 – Attributes defined on classes of LogicalNodes_90_21 package	91
Table A.1 – Conditions for presence of elements within a context	95

INTERNATIONAL ELECTROTECHNICAL COMMISSION

**COMMUNICATION NETWORKS AND SYSTEMS
FOR POWER UTILITY AUTOMATION –****Part 90-21: Travelling Wave Fault Location****FOREWORD**

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at <https://patents.iec.ch>. IEC shall not be held responsible for identifying any or all such patent rights.

IEC TR 61850-90-21 has been prepared by IEC technical committee 57: Power systems management and associated information exchange. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
57/2718A/DTR	57/2738/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

A list of all parts in the IEC 61850 series, published under the general title *Communication networks and security systems for power utility automation*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

INTRODUCTION

The travelling wave technique for locating faults in transmission, distribution and cable network system has been maturing in recent years due to the advancement in technology. The technique is potentially more accurate and has a much wider application scope when compared with the traditional impedance-based method. However, the technique and its associated information exchange have not yet been fully modelled in IEC 61850. There is a need to do this so that the equipment can be integrated with other IEC 61850 compliant equipment, both in the substation level and in the network level.

COMMUNICATION NETWORKS AND SYSTEMS FOR POWER UTILITY AUTOMATION –

Part 90-21: Travelling Wave Fault Location

1 Scope

1.1 Scope of work

This part of IEC 61850, which is a Technical Report, aims to provide background information, use cases, data models and guidance on the application of such a technique.

This document will

- 1) describe the principles of fault location based on travelling waves aided by communications;
- 2) specify use cases for this method under the following application scenarios:
 - a) Single-ended fault location,
 - b) Double-ended fault location through communications between two devices,
 - c) Double-ended fault location with communications to a master station,
 - d) Wide area fault location applications,
 - e) Pulse radar echo method,
 - f) Substation integration with other fault location and disturbance recording functions,
 - g) Testing and calibration;
- 3) describe the information model for each use case;
- 4) give guidance on scheme configuration.

1.2 Published versions of the standard and related namespace names

The table below provides a reference between all published editions, amendments or corrigenda of this document and the full name of the namespace.

Table 1 – Published versions of the namespace

Edition	Publication date	Webstore	Namespace
Edition 1.0	2024-10	IEC 61850-90-21:2024	(Tr)IEC 61850-90-21:2022A2

1.3 Namespace name and version

The parameters which identify this new release of this namespace are as follows:

1.4 Published versions of the standard and related namespace names

shows all attributes of (Tr)IEC 61850-90-21:2022A namespace.

Table 2 – Attributes of (Tr)IEC 61850-90-21:2022A namespace

Attribute	Content
Namespace nameplate	
Namespace Identifier	(Tr)IEC 61850-90-21
Version	2022
Revision	A
Release	2
Full Namespace Name	(Tr)IEC 61850-90-21:2022A2
Full Code Component Name	IEC_TR_61850-90-21.NSD.2022A2.Full
Light Code Component Name	IEC_TR_61850-90-21.NSD.2022A2.Light
Namespace Type	transitional
Namespace dependencies	
extends	IEC 61850-7-4:2007B version:2007 revision:B
Namespace transitional status	
Future handling of namespace content	The name space (Tr)IEC 61850-90-21:2022A is considered as "transitional" since the models are expected to be included in further editions IEC 61850-7-4xx. Potential extensions/modifications may happen if/when the models are moved to the International Standard status.

1.5 Code Component distribution

Each Code Component is a ZIP package containing the electronic representation of the Code Component itself, with a file describing the content of the package (IECManifest.xml).

The life cycle of a code component is not restricted to the life cycle of the related publication. The publication life cycle goes through two stages, Version (corresponding to an edition) and Revision (corresponding to an amendment). A third publication stage (Release) allows publication of Code Component in case of urgent fixes of InterOp Tissues, thus without need to publish an amendment.

Consequently new release(s) of the Code Component may be released, which supersede(s) the previous release, and will be distributed through the IEC TC57 web site at: <http://www.iec.ch/tc57/supportdocuments>.

The code component associated to this TR is an nsd file. It is available as a full version and a light version. The light version is freely accessible on the IEC website for download at: <http://www.iec.ch/tc57/supportdocuments>, but the usage remains under the licensing conditions.

The latest version/release of the document will be found by selecting the file for the code component with the highest value for VersionStateInfo e.g. *IEC_TR_61850-90-21.NSD.{VersionStateInfo}.Light*

In case of any differences between the downloadable code component and the IEC pdf published content, the downloadable code component is the valid one; it may be subject to updates. See included history files.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC TS 61850-2, *Communication networks and systems for power utility automation – Part 2: Glossary*

IEC 61850-7-2, *Communication networks and systems for power utility automation – Part 7-2: Basic information and communication structure – Abstract communication service interface (ACSI)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC TS 61850-2 and IEC 61850-7-2 apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

4 Types of travelling wave fault location

The types of travelling wave fault location are described as follows:

Type A TWFL – Fault distance is calculated based on the time difference between the first arrival of the surge and the surge reflected by the fault or by the opposite end. Also known as single-ended travelling wave fault location.

Type B TWFL – Fault distance is calculated by the difference in the time of arrival of fault surge detected by the devices located at both ends of the line. One of the devices transmit timing signal to opposite end after detecting surge to synchronize them.

Type C TWFL – Fault locator transmits and receives an impulse signal on the line and measures a propagation time from transmitting an impulse till receiving an echo signal to calculate a fault distance.

Type D TWFL – Fault distance is calculated by the difference in the time of arrival of fault surge detected by the devices located at both ends of the line. These two devices are time-synchronized by the same resources such as GNSS. Also known as double-ended travelling wave fault location.

Type E_s TWFL (single-ended) – Fault locator picks-up the transients generated when a line is re-energized by circuit breaker. It is applicable to permanent faults.

Type E_d TWFL (double-ended) – Almost the same as B type, except fault locator transmits timing signals repeatedly.

Type F/K TWFL – Type F fault locator transmits and receives equal interval impulse signals repeatedly on the line and measures a reciprocating time from transmitting an impulse till receiving an echo signal to measure a fault distance. Type K fault locator is almost the same as type F, except sweep trigger of oscilloscope is synchronized with interval of impulse signals.

Type FMCW TWFL – Fault locator transmits and receives a FMCW (frequency modulated continuous wave), and measures beat frequency by mixed wave of transmitted and received FMCWs. Fault distance is calculated by beat frequency.

Type W TWFL – Type W traveling wave fault location makes use of traveling wave data from various substations across the monitored transmission network to achieve reliable fault location even in the case that a detection device installed at a substation fails and/or that such a device is not installed. This method uses information exchange between devices located at the nodes of the network with a central station which determines the location of the fault based on the network topology and the information received. This is also known as wide-area fault location. This approach can also be employed by other applications using travelling waves.

5 Requirements and use cases

5.1 General

The objective of this clause is to go down to the general high-level requirements of the information exchange for travelling wave fault location systems. This is the starting point for proposing new logical nodes (LNs), the extension of the existing LNs, new communication services, communication profiles and configuration methods. This approach can also be employed to other applications using travelling waves.

The following use cases for travelling wave fault location do require the definition of new LNs and extension of the existing LNs as follows:

- **Single ended fault location** – To locate the fault position of a transmission line based on travelling wave signals measured at one end of the line only.
- **Double-ended fault location through communications** between two devices – To locate the position of the fault on a transmission line based on the travelling wave signals measured at both ends of the line. This method uses information exchange between the devices located at the line ends to achieve fault location.
- **Double-ended fault location through communications with a master station** – To locate the position of the fault on a transmission line based on the travelling wave signals measured at both ends of the line. This method uses information exchange between the devices located at the line ends with a master station. The master station determines the location of the fault using the information received.
- **Wide area fault location** – To locate the position of a fault on a transmission network, based on the travelling wave signals measured on various nodes of the network. This method uses information exchange between devices located at the nodes of a network with a master station. The master station determines the location of the fault using the information received.
- **Pulse radar echo method** – To locate the fault position on a transmission line based on time difference between transmitted and echo pulse. This method injects a pulse or burst of some probe waveform into transmission line.
- **Substation integration with other fault location and disturbance recoding functions** – to integrate travelling wave fault location device with other devices in the substation to achieve more intelligent and comprehensive fault location.
- **Testing and calibration** – To test and to calibrate the travelling wave fault location system by commands and info exchange through communications. E.g., commands can be sent by the master station to the devices to simulate a fault so as to check the integrity of the system. Line length calibration typically requires line energisation and single-ended analysis to determine the actual line length.

Travelling wave signals contain both voltage and current components. Acquisition of the travelling wave signals can be done through instrument voltage or current transformers with the suitable frequency response. For high voltage transmission systems with capacitive voltage transformers, or for HVDC systems, the signal can also be captured with current transformers located at the earth path, which captures the capacitance currents to earth.

5.2 Use case 1: Single-ended fault location (Type A)

5.2.1 Use case 1A: Single-ended fault location (Type A) – phase segregated

5.2.1.1 Description of the use case

5.2.1.1.1 Name of use case

Use case identification		
ID	Domain(s)	Name of use case
	Travelling wave fault location	Single-ended fault location

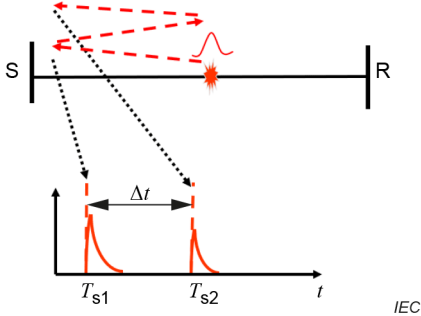
5.2.1.1.2 Version management

Version management						
Version management changes / Version	Date		Domain expert	Area of expertise / Domain / Role	Title	Approval status draft, for comments, for voting, final

5.2.1.1.3 Scope and objective of use case

Scope and objectives of use case	
Related business case	None
Scope	Travelling wave fault location by a single device at one end of the line
Objective	Achieve fault location by analysis of the records acquired at one end.

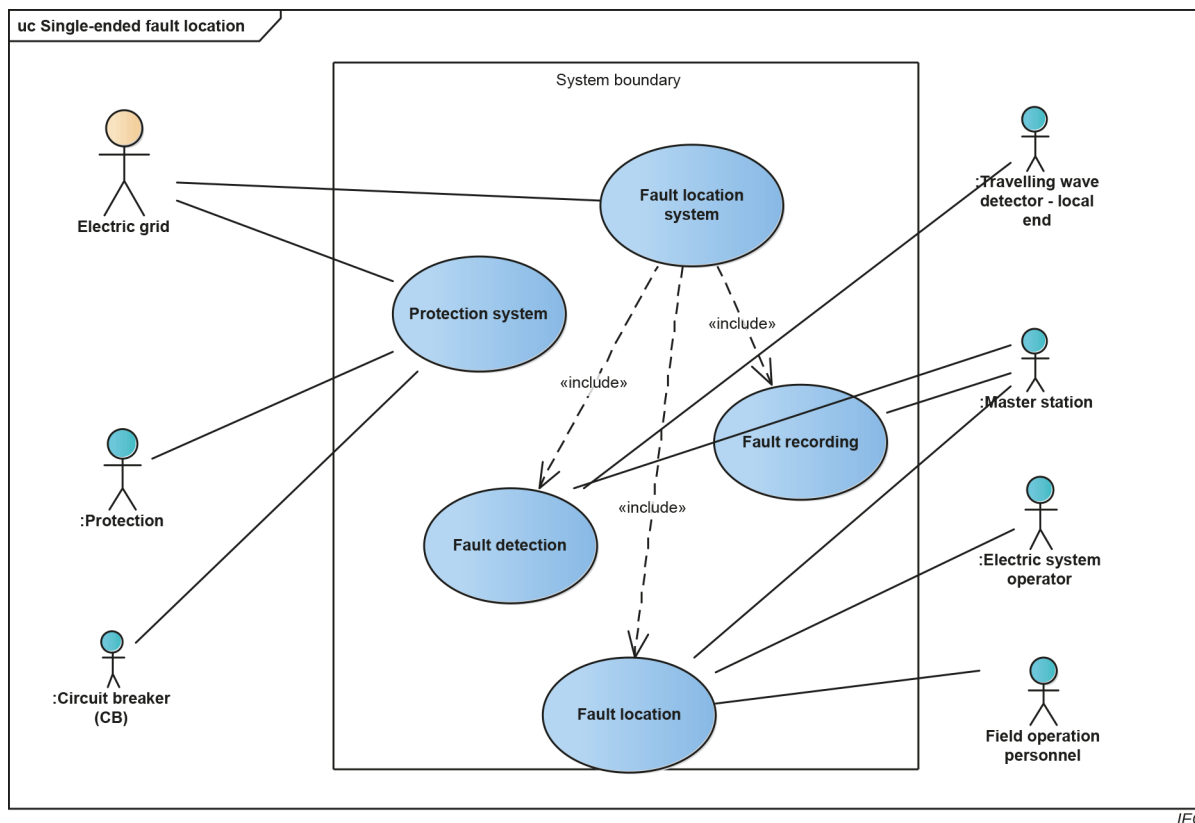
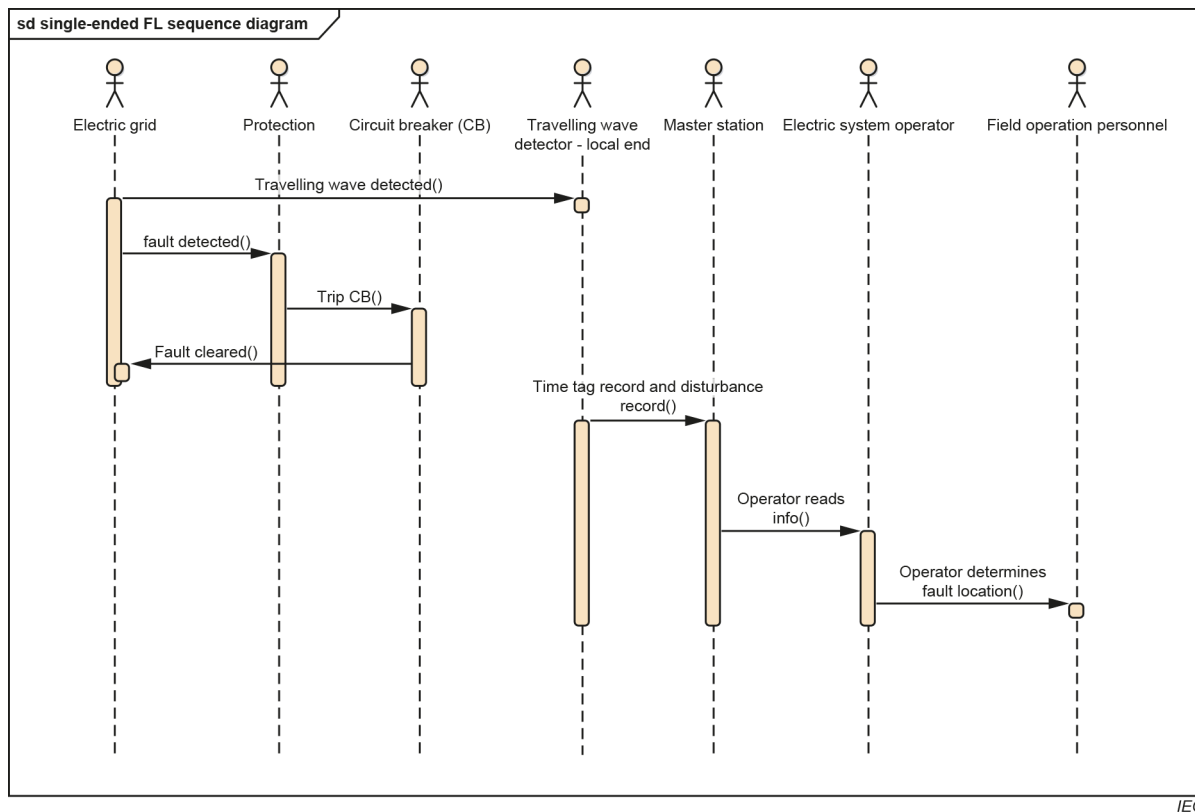
5.2.1.1.4 Narrative of use case

Narrative of use case
Short description
Single-ended travelling wave fault location is achieved by a device at one end of the line only. The device records the travelling wave signals generated by the fault, including those reflected from the line ends or other line feature causing a change of surge impedance. Through automatic or manual analysis of the record, the location of the fault can be established. This method works on a per-phase basis and does not require mode derivations for three-phase lines (see Use Case 1B).
Complete description
<p>Transient travelling waves are produced when a stable power system is disturbed, which can be under a fault, open conductor, CB operation or lightning condition. The disturbance can be represented as a voltage source at the fault point which produces both voltage and current surges propagating into two opposite directions.</p> <p>When the travelling wave signal reaches the end of the line terminated by a busbar, some of the signal will be transmitted through and some will be reflected back. When the reflected signal reaches the fault point, there will again be a reflection so that the signal will return back to the busbar a second time. The time difference between the first incident wave and the second incident wave is equivalent to twice the distance from the busbar to the fault. By multiplying this time with the wave speed and dividing the result by two, the distance to the fault can be established.</p> <p>This method is achieved by a device located at the line end capturing voltage and/or current signals from the line at high speed. When a fault occurs, the first incident wave and the second incident wave are captured and stored as a disturbance record. The record can be analysed either manually or automatically. The time difference between the first incident wave and the second incident wave is established through the analysis, from which the fault distance is then calculated.</p> <div><div>$X_s = \frac{1}{2} v \times \Delta t = \frac{1}{2} v \times (T_{s1} - T_{s2})$<p>Where</p><p>$X_s$ = fault distance from S</p><p>v = wave velocity</p><p>T_{s1} = time of arrival of the incident wave</p><p>T_{s2} = time of arrival of the second incident wave</p></div></div>

5.2.1.1.5 General remarks

None.

5.2.1.2 Diagram of the use case



5.2.1.3 Technical details

5.2.1.3.1 Actors: People, systems, applications, databases, the power system, and other stakeholders

Actors			
Grouping (community)		Group description	
Actor name	Actor type	Actor description	Further information
Electric Grid	System	Transmission, distribution and cable network	
Protection	Device	Protection device	
Circuit Breaker	Device	Circuit breaker device	
Travelling wave detector – local end	Device	Travelling wave signal detector at the local substation	
Master Station	System	Master station communicating with the travelling wave detectors, obtaining fault records and performing fault location function	
Electric system operator	Person	System operator managing the power system	
Field Operation Personnel	Person	Operator working in the field of the power system	

5.2.1.3.2 Preconditions, assumptions, post condition, events

Use case conditions			
Actor/System/Information/Contract	Triggering event	Pre-conditions	Assumption
Electric grid	Continuous		The electric grid is continuously being monitored
Travelling wave detector – local end	Line fault	Travelling wave signal level exceeds the trigger threshold of detector	The first arrival of the travelling waves and the reflections from the fault and from the remote end are captured, recorded and time-stamped
Master Station	Continuous		Continuously monitoring the grid and performs fault location function
Electric system operator	Alarm from Master Station		Able to interpret the fault record

5.2.1.3.3 References / Issues

None.

5.2.1.4 Step by step analysis of the use case

5.2.1.4.1 General

Scenario conditions					
No.	Scenario name	Primary actor	Triggering event	Pre-condition	Post-condition
1	Line Fault	Travelling wave detector	Fault detector is triggered by the travelling wave	Travelling wave exceeds the trigger threshold	Both the initial wave and the reflections from the fault and from the remote end are captured and recorded in a disturbance record, which can be interpreted either manually or automatically

5.2.1.4.2 Steps – Normal

Scenario								
Scenario name:			Normal					
Step No.	Event	Name of process/ activity	Description of process/ activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged	Additional notes or requirements
1	A line fault, open conductor, CB operations or lightning has occurred	Initial surge			Grid			
2	Detector detects the travelling wave	Traveling wave detection			Grid	Travelling wave detector	Initial Traveling wave signal	
3	Recording of initial and reflected waves	Information recording			Grid	Travelling wave detector	Initial and reflected Traveling wave signals	
4	Time tag record and disturbance record transfer to Master Station	Record transfer	The time tag record contains the precise time tag when the trigger occurs. The disturbance record contains precise timing of each sample, allowing Δt between incident wave and reflected waves to be measured		Travelling wave detector	Master Station	Time tag record and disturbance record	
5	Interpretation of waveforms to determine the fault location	Waveform interpretation			Master Station	Electric system operator	Location of fault	
6	Field personnel visits site for fault investigation	Site visit			Electric system operator	Field operation personnel	Location of the fault	

5.2.1.5 Information exchanged

Information exchanged		
Name of information exchanged	Description of information exchanged	Requirements to information data R-ID
Fault Record	For each detected surge: arrival time of travelling wave, channel triggered, type of fault, time of trigger	
Disturbance Record	For each detected surge: a record containing initial and reflected waves	

5.2.2 Use case 1B: Single-ended fault location (Type A) – 3-phase lines with modes at different speeds

5.2.2.1 Description of the use case

5.2.2.1.1 Name of use case

Use case identification		
ID	Domain(s)	Name of use case
	Travelling wave fault location	Single-ended fault location using modes with different travelling speeds

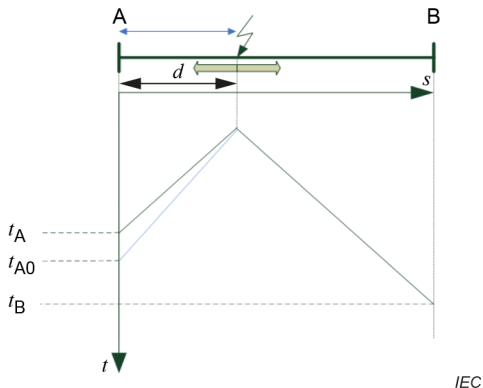
5.2.2.1.2 Version management

Version management						
Version management changes / Version	Date		Domain Expert	Area of expertise / Domain / Role	Title	Approval status draft, for comments, for voting, final

5.2.2.1.3 Scope and objective of use case

Scope and Objectives of use case	
Related business case	None
Scope	Travelling wave fault location by a single device at one end of the line
Objective	Achieve fault location by analysis of the records acquired at one end. The method uses different modes of travelling waves. Enhance fault location of a double-side fault locator to interconnected lines (when fault is outside of line supervised by double ended fault locator)

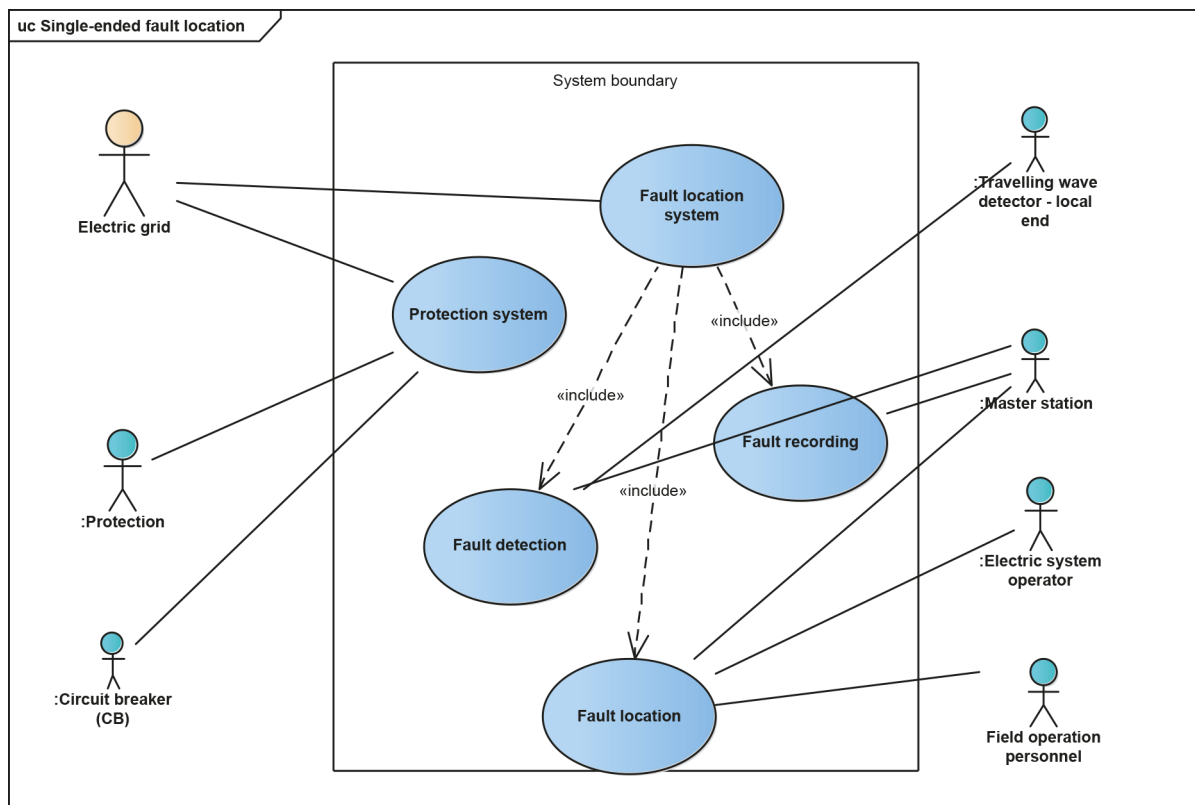
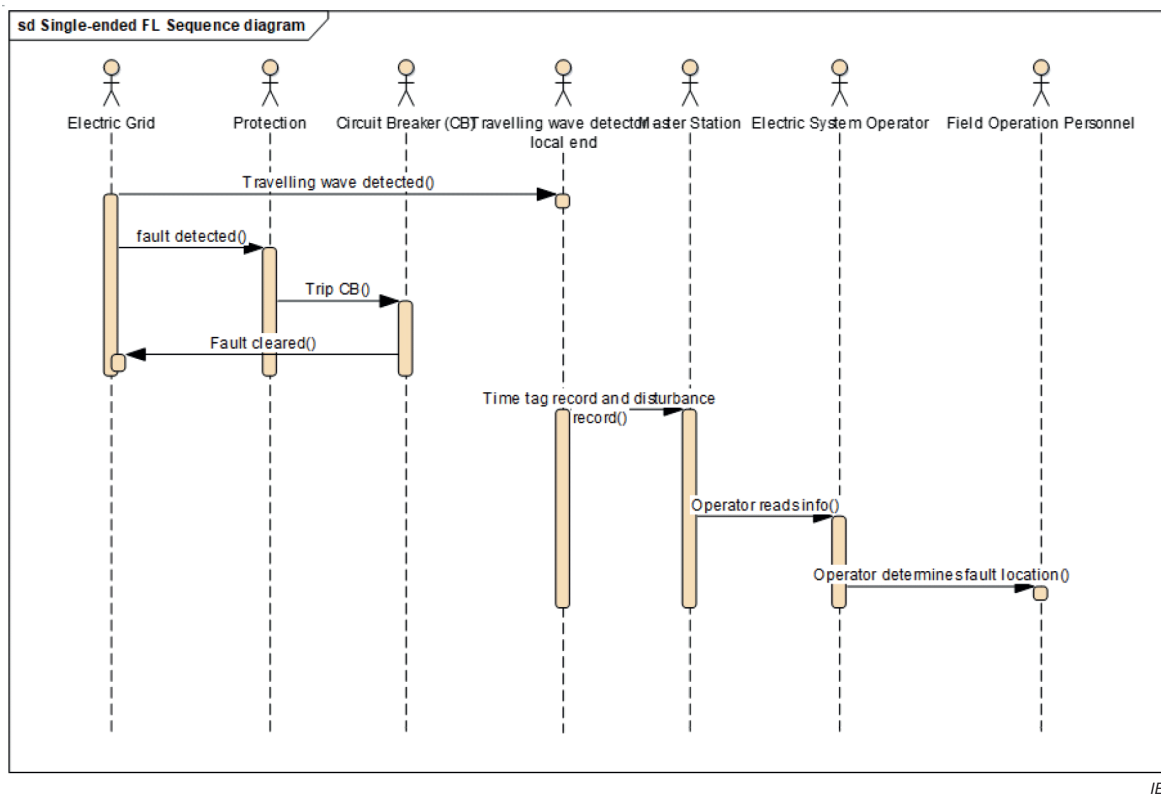
5.2.2.1.4 Narrative of use case

Narrative of use case	
Short description	
Single-ended travelling wave fault location is achieved by a device at one end of the line only. The device records the three-phase travelling wave signals generated by the fault. Through analysis of the record, the location of the fault is established by measuring the time delay between the arrivals of the aerial mode and zero sequence mode of the three-phase travelling wave signals.	
Complete description	
<p>Transient travelling waves are produced when a stable power system is disturbed, which can be under a fault, open conductor, CB operation or lightning condition. The disturbance can be represented as a voltage source at the fault point which produces both voltage and current surges propagating into two opposite directions.</p> <p>In 3 phase circuits it is common practice to use mathematical transformation such as Clarke or eigenvalue transformation to simplify analysis. Clarke transformation converts three phase quantities into α, β and zero modes, where α and β modes are stationary orthogonal axes. The transformation projects the three phase quantities onto two stationary quadrature axes, thus simplifying the three-phase calculations to two coordinate calculations under balanced conditions.</p> <p>Analysis has shown that three phase line's aerial and zero sequence modes have different travelling speeds. Whilst the aerial mode's wave velocity is relatively constant irrespective of distance, the zero sequence mode travels with reduced velocity as distance increases. The time difference between the arrival of the aerial mode and zero sequence mode can thus be used to calculate the fault distance.</p> <p>This method is achieved by a device located at the line end capturing voltage and/or current measurements from the line at high sampling frequency. When a fault occurs, the first incident wave in aerial and zero sequence mode are captured and stored as a disturbance record. Using signal processing technique such as wavelet transform, the time difference between the arrivals of the aerial mode and the zero mode can be established, from which the fault distance is then calculated.</p>	
	$d = \frac{t_{a0} - t_a}{\frac{1}{v_0} - \frac{1}{v_a}}$ <p>Where</p> <p>d = distance to the fault</p> <p>t_{a0} = time of arrival of zero sequence mode</p> <p>v_0 = Wave velocity of zero sequence mode</p> <p>t_a = time of arrival of aerial mode</p> <p>v_a = Wave velocity of aerial mode</p>

5.2.2.1.5 General remarks

None.

5.2.2.2 Diagram of the use case



5.2.2.3 Technical details

5.2.2.3.1 Actors: People, systems, applications, databases, the power system, and other stakeholders

Actors			
Grouping (community)		Group description	
Actor name	Actor type	Actor description	Further information
Electric Grid	System	Transmission, distribution and cable network	
Protection	Device	Protection device	
Circuit Breaker	Device	Circuit breaker device	
Travelling wave detector – local end	Device	Travelling wave signal detector at the local substation	
Master Station	System	Master station communicating with the travelling wave detector, receives fault records and performs fault location	
Electric system operator	Person	System operator managing the power system	
Field Operation Personnel	Person	Operator working in the field of the power system	

5.2.2.3.2 Preconditions, assumptions, post condition, events

Use case conditions			
Actor/System/Information/Contract	Triggering event	Pre-conditions	Assumption
Electric grid	Continuous		The electric grid is continuously being monitored
Travelling wave detector – local end	Line fault	Travelling wave signal level exceeds the trigger threshold of detector	Phase information of the travelling waves are captured
Master Station	Continuous		Continuously monitoring the grid
Electric system operator	Alarm from Master Station		Able to interpret the fault record

5.2.2.3.3 References / Issues

None.

5.2.2.4 Step by step analysis of the use case

5.2.2.4.1 General

Scenario conditions					
No.	Scenario name	Primary actor	Triggering event	Pre-condition	Post-condition
1	Line Fault	Travelling wave detector	Fault detector is triggered by the travelling wave	Travelling wave exceeds the trigger threshold	All modes of the initial travelling waves are captured and recorded in a disturbance record, which can be interpreted either manually or automatically

5.2.2.4.2 Steps – Normal

Scenario									
Scenario name:		Normal							
Step No.	Event	Name of process/ activity	Description of process/ activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged	Additional notes or requirements	
1	A line fault, open conductor, CB operations or lightning has occurred	Initial surge			Grid				
2	Detector detects the travelling wave	Traveling wave detection			Grid	Travelling wave detector	Initial Traveling wave signal		
3	Recording of initial and reflected waves	Information recording			Grid	Travelling wave detector	Initial and reflected Traveling wave signals		
4	Time tag record and disturbance record transfer to Master Station	Record transfer			Travelling wave detector	Master Station	Fault record and disturbance record		
5	Interpretation of waveforms to determine the fault location	Waveform interpretation			Master Station	Electric system operator	Location of fault		
6	Field personnel visits site for fault investigation	Site visit			Electric system operator	Field operation personnel	Location of the fault		

5.2.2.5 Information exchanged

Information exchanged		
Name of information exchanged	Description of information exchanged	Requirements to information data R-ID
Fault Record	Time of trigger, channel triggered, type of fault	
Disturbance Record	A record containing initial and reflected waves	

5.3 Use case 2: Double-ended fault location (Type D) through communications between two devices**5.3.1 Description of the use case****5.3.1.1 Name of use case**

Use case identification		
ID	Domain(s)	Name of use case
	Travelling wave fault location	Double-ended fault location through communications between two devices

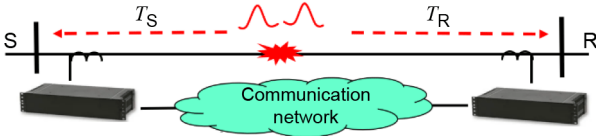
5.3.1.2 Version management

Version management						
Version management Changes / Version	Date		Domain expert	Area of expertise / Domain / Role	Title	Approval status draft, for comments, for voting, final

5.3.1.3 Scope and objective of use case

Scope and objectives of use case	
Related business case	None
Scope	Travelling wave fault location by two devices, one at each end of the line, and with some means of time synchronization and communication between the devices.
Objective	Following a disturbance in power line, achieve accurate fault location by exchange of travelling wave information acquired at the two ends of the line.

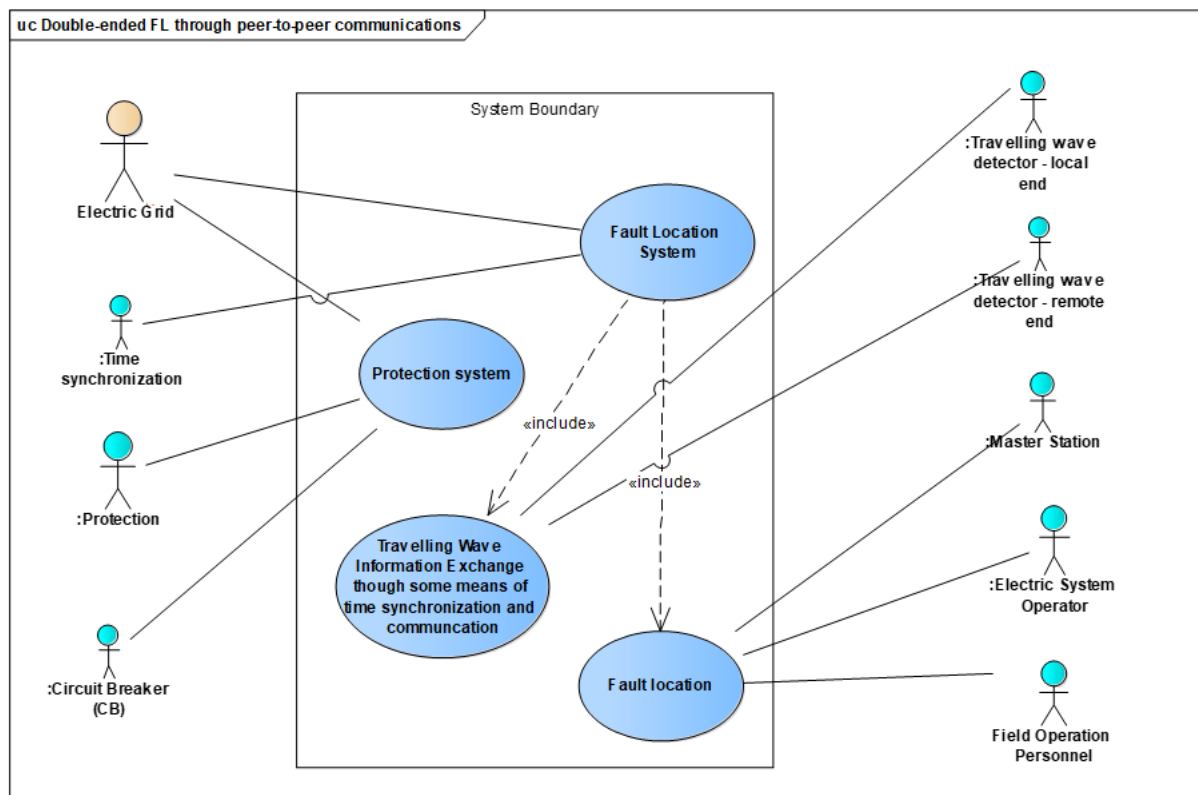
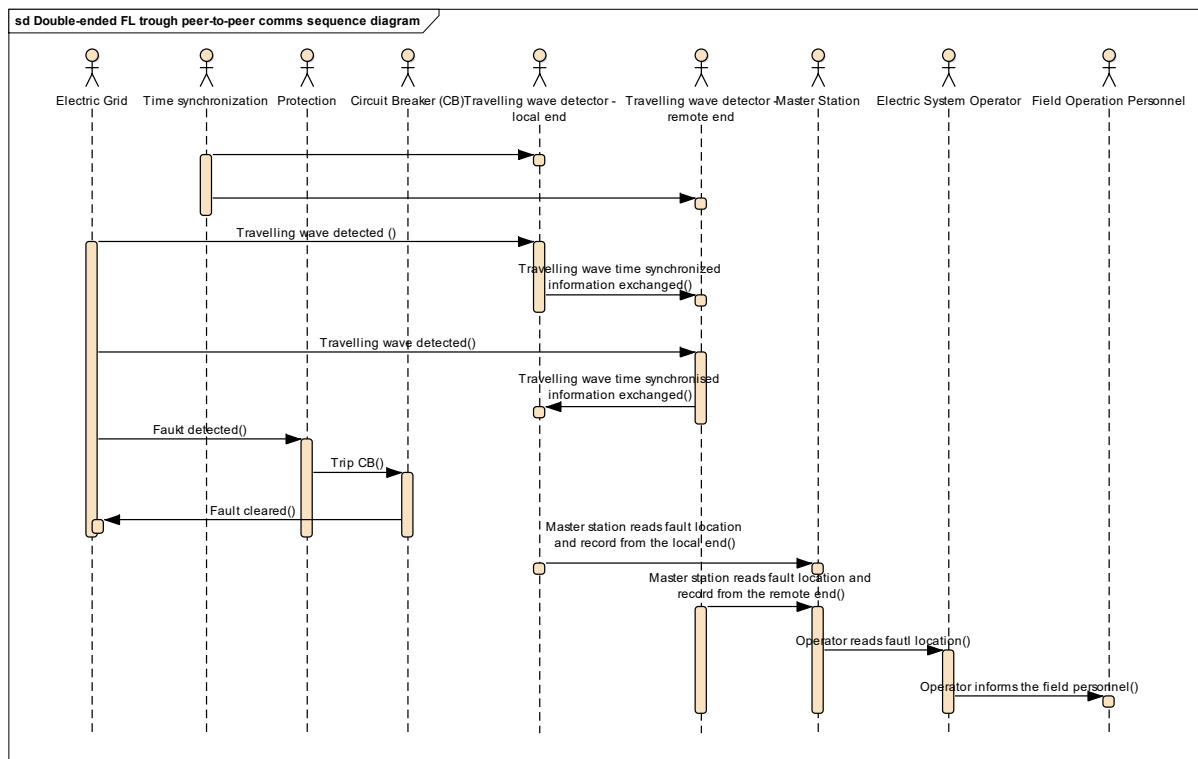
5.3.1.4 Narrative of use case

Narrative of use case
Short description
Double-ended travelling wave fault location is achieved by one device at each end of the line through the exchange of travelling wave information. Through automatic or manual analysis of the travelling wave information from both ends, the location of the fault can be established.
Complete description
<p>Transient travelling waves are produced when a stable power system is disturbed, which can be under a fault, open conductor, CB operation or lightning condition. The disturbance can be represented as a voltage source at the fault point which produces both voltage and current surges propagating into two opposite directions,</p> <p>Distance to the fault can be estimated using the travelling wave arrival time difference which is the time difference of the first travelling wave arriving at both the ends of the line upon disturbance in the line.</p> <p>If the device has information about the line propagation wave speed, then it can be multiplied with the travelling wave arrival time difference and added to the total line length, then by dividing the result by two, the distance to the fault can be calculated. In this case both the local and remote devices exchange the first travelling wave arrival time stamps. They need to have high accuracy external time source synchronization.</p> <p>If the device has information about the line propagation time, then the travelling wave arrival time difference is divided by the line propagation time and added to the total line length, then by dividing the result by two, the distance to the fault can be estimated. In this case both the local and remote devices can exchange the first travelling wave arrival time stamps or exchange the travelling wave samples. In this case both the local and remote devices can be connected to high accuracy external time source. If not, then by some means the internal clocks of the devices are to be phase locked.</p> <p>This method is achieved by devices located at the line ends capturing current and/or voltage measurements from the line at high speed. The disturbance records captured at both the ends can be analysed manually or automatically to calculate the distance to the fault, provided the time stamps in these records are time synchronized.</p>
<div><div></div><div>$X_S = \frac{1}{2}[(T_S - T_R) \times v + L]$$X_R = \frac{1}{2}[(T_R - T_S) \times v + L]$<p>IEC</p><p>Where</p><p>X_S = Fault distance from S</p><p>X_R = Fault distance from R</p><p>T_S = Time of arrival at S</p><p>T_R = Time of arrival at R</p><p>v = Wave Velocity</p><p>L = line length</p></div></div>

5.3.1.5 General remarks

None.

5.3.2 Diagram of the use case



5.3.3 Technical details

5.3.3.1 Actors: People, systems, applications, databases, the power system, and other stakeholders

Actors			
Grouping (community)		Group description	
Actor name	Actor type	Actor description	Further information
Electric Grid	System	Transmission, distribution and cable network.	
Time synchronization	System	Time source or time distribution system	
Protection	Device	Protection device	
Circuit Breaker	Device	Circuit breaker device	
Travelling wave detector – local end	Device	Travelling wave signal detector at the local substation	
Travelling wave detector – remote end	Device	Travelling wave signal detector at the remote substation	
Master Station	System	Master station communicating with the travelling wave detectors	
Electric system operator	Person	System operator managing the power system	
Field Operation Personnel	Person	Operator working in the field of the power system	

5.3.3.2 Preconditions, assumptions, post condition, events

Use case conditions			
Actor/System/Information/Contract	Triggering event	Pre-conditions	Assumption
Electric grid	Continuous		The electric grid is continuously being monitored
Time synchronization	Continuous	Both local and remote devices are time synchronized	A common time synchronization (e.g., GNSS clock) of sufficient accuracy is available
Travelling wave detector – local end	Line fault	Travelling wave signal level exceeds the trigger threshold of detector	Initial travelling wave samples are captured along with its time stamp referenced to some means of time synchronization. The travelling wave information is exchanged with remote device.
Travelling wave detector – remote end	Line fault	Travelling wave signal level exceeds the trigger threshold of detector	Initial travelling wave samples are captured along with its time stamp referenced to some means of time synchronization. The travelling wave information is exchanged with local device.
Master station	Continuous		Continuously monitoring the grid
Electric system operator	Alarm from Master Station		Able to interpret the fault record

5.3.3.3 References / Issues

None.

5.3.4 Step by step analysis of the use case

5.3.4.1 General

Scenario conditions					
No.	Scenario name	Primary actor	Triggering event	Pre-condition	Post-condition
1	Line Fault	Travelling wave detector	Fault detector is triggered by the travelling wave	Travelling wave exceeds the trigger threshold	Using both the traveling wave information from local and remote ends, fault location is calculated accurately, either manually or automatically

5.3.4.2 Steps – Normal

Scenario								
Scenario name:		Normal						
Step No.	Event	Name of process/ activity	Description of process/ activity	Service	Information producer (actor)	Information receiver (actor)	Information exchanged	Additional notes or requirements
1	A line fault has occurred	Initial surge	Initial surge caused by voltage drop at fault position propagates from the fault position in both directions along the line		Grid			
2	Detectors at both ends detects the travelling wave	Traveling wave detection	When the fault surge arrives at the line terminals, detectors will be triggered by the surge slopes (the wave fronts)		Grid	Travelling wave detector at both ends		
3	Recording of initial traveling wave peak time at both ends or travelling wave current and/or voltage samples.	Information recording	Time stamps of triggered events are captured at both line ends		Grid	Travelling wave detector at both ends	Initial traveling wave peak times or travelling wave current and/or voltage samples.	
4	Information transfer to Master Station	Fault Location and Record transfer	Event data and recordings are sent by the detectors to the master station		Travelling wave detector	Master Station	Fault Location and disturbance record	
5	Calculation of fault location by the master station	Master station fault location calculation	Calculate the fault position from the received data from the travelling wave detectors using line topology and line data information available by the master station		Travelling wave detector	Master Station	Fault Location and disturbance record	
6	Operator reads fault location and informs the field personnel	Read fault location			Master Station	Electric system operator	Location of fault	
7	Field personnel visits site for fault investigation	Site visit			Electric system operator	Field operation personnel	Location of the fault	

5.3.5 Information exchanged

Information exchanged		
Name of information exchanged	Description of information exchanged	Requirements to information data R-ID
Fault Record	Time of trigger, type of fault, fault location	
Disturbance Record	A record containing current and/or voltage samples captured at high speed	
Travelling wave information	Local and remote devices can exchange the first travelling wave arrival time stamps or exchange the travelling wave samples (currents and/or voltages captured at high speed)	

5.4 Use case 3: Double-ended fault location (Type D) through communications with a master station

5.4.1 Description of the use case

5.4.1.1 Name of use case

Use case identification		
ID	Domain(s)	Name of use case
	Travelling wave fault location	Double-ended analysis through communications with the master station

5.4.1.2 Version management

Version management					
Version management Changes / Version	Date		Domain expert	Area of expertise / Domain / Role	Title

5.4.1.3 Scope and objective of use case

Scope and Objectives of use case	
Related business case	None
Scope	Travelling wave fault location by two devices, one at each end of the line, and with some means of time synchronization and communication of the result or measurements to a master station for further calculations.
Objective	Achieve accurate fault location by analysis of the records acquired at two ends of the line. The records are sent to the master station for a precise calculation of the fault distance.

5.4.1.4 Narrative of use case

Narrative of use case
Short description
Double-ended travelling wave fault location with a master station is achieved by one device at each end of the line and a master station for fault distance calculation. The devices record the travelling wave signals generated by the fault and sends this to the master. Through automatic or manual analysis of the records from the two ends, the location of the fault can be established.