Distributed Intelligence in Critical Infrastructures for Sustainable Power
ENK5-CT-2002-00673

Simulation tool for fault detection and diagnostics in high-DG power networks

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References

Label	Reference
D1.1	M.Fontela & co, “Functional Specifications of electric Networks with high degrees of distributed generation”deliverable D1.1 of ENK5-CT-2002-00673 CRISP-project.
D1.2	R. Kamphuis & co, “Market-oriented online supply-demand matching ", deliverable D1.2 of ENK5-CT-2002-00673 CRISP-project.
D1.4	C. Andrieu & co, “Fault detection, analysis and diagnostics in high-DG distribution systems ", deliverable D1.4 of ENK5-CT-2002-00673 CRISP-project.

Abbreviations

Acronym	Means
CB	Circuit Breaker
CPU	Central Processing Unit
CRISP	Distributed Intelligence in CRitical Infrastructures for Sustainable Power
DG	Distributed Generation
DG	Dispersed Generation
DG-RES	Distributed generation based on renewable energy systems
DMS	Distribution Management System
DNO	Distribution Network Operator
DNS	Domain Name Server
DoS	Denial of Service (security study)
DR	Distributed Resources
EPS	Electric Power System
FCI	Faulted Circuit Indicator
FDD	Fault Detection and Diagnostics
FPI	Fault Passage Indicator
FR	Fault recorder (information from the protection system)
HF	High Frequency
HTFD	Help Tool Fault Diagnosis (main ICT component proposed in the dedicated application)
HV	High Voltage
ICT	Information and Communication Technology
IEEE	Institute of Electrotechnical and Electronics Engineers
IEC	International engineering consortium
IP	Internet Protocol
IVP	Integrity Validation Procedures
LAN	Local Area Networks
LV	Low Voltage
MV	Medium Voltage
PCC	Point of Common Coupling
PLC	Power Line Carrier
PPP	Point-to-Point Protocol
PQ	Power Quality
PS	Power System
QoS	Quality of Service
RES	Renewable Energy Systems
SCADA	Supervisor Control and Data Acquisition
SCL	Substation Configuration Langage
SW	Switch
UML	Unified Model Langage
WAN	Wide Area Networks

Summary

This document gives a description of a tool proposed for fault detection and diagnostics. The main principles of the functions of fault localization are described and detailed for a given MV network that will be used for the ICT experiment in Grenoble (experiment 3B).

The aim of the tool is to create a technical, simple and realistic context for testing ICT dedicated to an electrical application. The tool gives the expected inputs and outputs contents of the various distributed ICT components when a fault occurs in a given MV network.

So the requirements for the ICT components are given in term of expected data collected, analysed and transmitted. Several examples are given in order to illustrate the inputs/outputs in case of different faults.

The tool includes a topology description which is a main aspect to develop in the future for managing the distribution network. Updating topology in real time will become necessary for fault diagnostic and protection, but also necessary for the various possible added applications (local market balance and local electrical power quality for instance).

The tool gives a context and a simple view for the ICT components behaviours assuming an ideal response and transmission from them. The real characteristics and possible limitations for the ICT (information latency, congestion, security) will be established during the experiments from the same context described in the HTFD tool.

1. Introduction

Protection systems and localization means used in distribution EPS need still improvements nowadays, depending a lot on neutral grounding systems chosen. The introduction of DG in that voltage level will increase the existing issues on fault diagnosis. A solution proposed in this document to face this situation is to take profit from the fast progress in ICT and introduce a better integrated architecture to supervise and control the feeders. Dedicated apparatus and ICT components to massive DG introduction may be required depending on the final contribution to fault current, and possible fault indication caused by the new resulting power flow during faults.

The present document follows the work done in WP 1.4 (see [D1.4]) describing fault system diagnosis in the distribution EPS. The principle of a fault localization tool is described in this document, the master piece of the proposed system being the HTFD (Help Tool for Fault Diagnosis) which is a support tool for the DNO. This tool is also commonly called ‘decision support tool’ and ‘fault diagnosis (support) tool’.
The goals of the simulation tool are to present the solution of localization and to prepare the experiments on ICT components. The simulation tool includes the software expected for the operator, the input being the data exchanged with the EPS apparatus (the inputs as current or voltage being given by another and external EPS simulation tool) as currents or component states, the outputs being the messages sent to the operator. The simulation tool includes a simple model for the communication used (as ideal one): it allows the partners to define clearly the requirements for the real dedicated ICT components that will be tested further.
In addition to this expectation, the simulation tool includes an original analysis of signals during fault, entailing a research question about the ability of indicating properly the location of the fault, depending on the various local situations.
The experiment is based on the developed software, replacing the simulated communication part of ICT components by real ones. The expectation is to evaluate the dynamical characteristics of the ICT components (real time simulations for the experiment) for the application. There is a clear and logical way from the simulation tool to the experiment. The external real time EPS tool intended to be used for the experiment (to give the inputs to the simulation tool for fault diagnosis) is ARENE real time, the main part of the software used for localization being issued from the simulation tool.

A level 1 MV cell is described and modelled in the document to show and study the ability of the simulation tool, but also to define the main requirements for the data exchanges and the data analyses for the ICT components.

Various scenarios are taken into account to deal with the types of faults (three-phase, two-phase or single-phase), the types of conductors (lines, cables), the types of grounded systems (impedance grounded neutral, compensated neutral). The simulation results give current and voltage variations during the fault, the analyses of the data and the time expectations for the intermediate equipment converting the information.

The main principle proposed is a classic localization method combined with a specific fault distance evaluation, the goal being to allow the DNO operator to react as fast as possible and as efficient as possible when face to permanent fault.

The goal is to have a localization system working properly in the case of a possible and future wide DR installation in the distribution network. The system proposed is adapted to work with the existing MV EPS and equipment. It may thus reduce highly the time response of the existing localization methods used in Europe.

The chapter 2 gives a general description of the experiment, simulation tool included. The chapter 3 gives the description of the simulation tool proposed. Then the chapter 4 presents a description of the EPS benchmark and scenarios used for simulations. The chapter 5 show the simulation results with the expected exchanges of information between the various ICT components. The chapter 6 focuses on the selected scenarios that will be tested on real ICT components during the experiments.

2. Description of the experiment

The description of the experiment in WP2.1 deliverable has been pasted just below (this first part of chapter 2.) with some corrections and additional information is included hereafter (in the end of the chapter 2.). This experiment is a combination of network analysis (voltage and current analysis for evaluating the type and the distance of a fault) and communication (distributed FPI devices send information to the substation), allowing the operator to use a fault localization tool.

2.1 Fault detection and diagnostics

The protection system required for a distribution system is a complex combination of sequential and distributed actions, including moreover various response time for the relays and the equipments. A possible gain in time is expected for the DNO for a specific sequence: detection and fault location. The experiment is based on a new fast fault location system highly dependant on ICT, the target is a support tool for the operator decision (recommendation for the response to a detected permanent and cleared fault in the distribution EPS, it gives the associated automatic sequences to reduce the faulty area)
The experiment is composed of a simulated part and a real apparatus part: the ICT is expected to be tested (real part), the remaining parts are simulated by appropriate real-time simulators.

2.2 Characterisation of fault detection and diagnosis

The fault location sequence reduces the faulty area to the smallest area thanks to the distributed EPS switches: installed emergency connections may be used after disconnection of switches around the fault.
The indicators distributed in the EPS (MFPI: monitored fault path indicator) send information to a central 'help tool for fault diagnosis' (HTFD ICT component). A distance evaluation, based on industrial frequency variations of the measured voltages and currents, and combined with the information of the MFPI is carried out. A goal of the experiment is to find the minimal reachable time to complete the sequence.

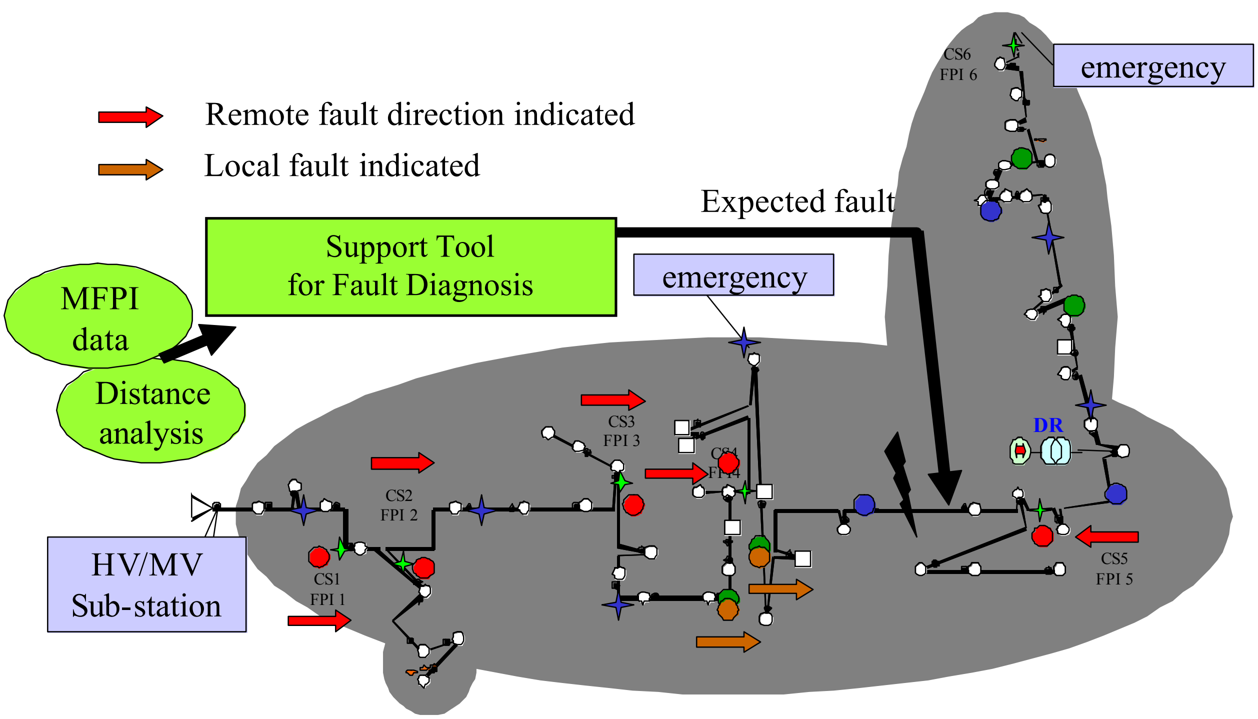

Figure.1.- Fault Detection and Diagnosis Context Diagram

The general context for the application assumes some existing functions and devices in the typical feeders of a public utility. Real time data monitoring and device control are needed in the context of the proposed solution of fault localization:

- real-time data needed for the Support Tool for Fault Diagnosis: fault path indicators, measured currents in feeders sending-ends, measured voltage on the main substation MV busbar, electrical power system configuration (breaker and switches states),

- Power system controlled by the operator or protection systems: openning and closing of the circuit breakers and EPS switches.

2.3 Short description of experiments

The proposed method is targeted to be tested for the ICT hardware and software available for the dedicated application. The remaining part of the EPS and needed control are simulated in adapted real time tools.
The part of intelligence covered by ICT is not yet decided, additional information is necessary on the detailed requirements for the equipments interconnected by the proposed method. Existing EPS components or computing system installed in the substation may be used, making this method very attractive for a DNO. On the other hand, if a more integrated ICT component is more profitable or induces needed technical characteristics, we keep the possibility to test this extended solution (this extended solution implies new requirements for existing EPS apparatus). It is important to keep in mind that EPS equipments are standardized, the DNO being in favour for reliable and experienced ones in general.

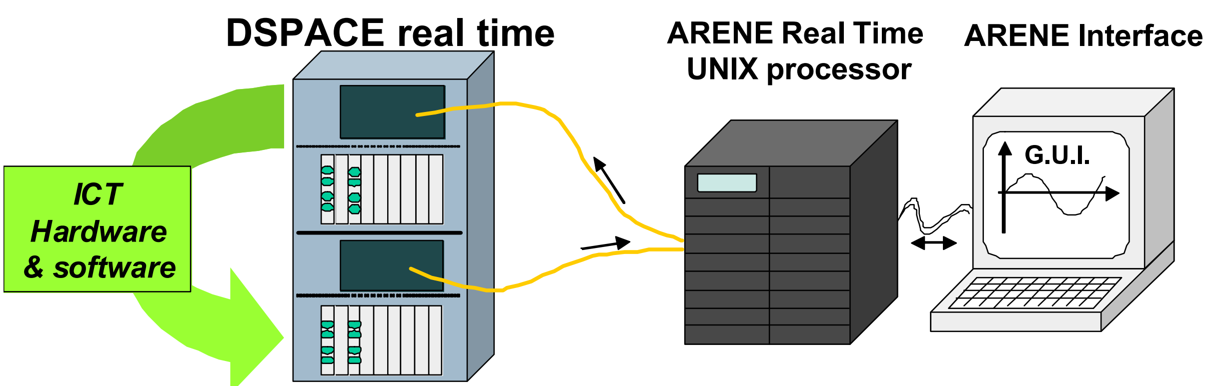

Figure.2.- The experiment studied case for the tests- WP3B.

The scenarios are composed of:

- Fault without DR: permanent fault, and three-phase or two-phase or single-phase fault
- Fault with massive DR: permanent fault, and three-phase or two-phase or single-phase fault

For non permanent fault, the protection system succeeds to clear the fault and information from the HTFD is not necessary (except for exploitation purpose in order to maintain properly the EPS).

The simulations will assume an ideal ICT data transmission inside DSPACE interface in order to check the scenarios and the dedicated programs for fault location and support to decision. Then the real hardware and software will be added (experiment step).

The fault detection and diagnostics experiments and simulations will be performed using the ARENE tool for digital real time power system simulations. The ARENE tool runs on different types of hardware, such as HP parallel computer and HP workstations; Sun workstations; and Windows environment under NT or XP.

2.4 Requirements and scenarios for fault detection and diagnostics

The fault detection and diagnostics experiments and simulations mainly concern the state of the EPS nodes, or the state observed in the EPS during the fault. It requires real-time measurements and capability not only to detect breakers and switches state changes, but also to be able to collect and memorize feeder currents and voltages needed for the fault distance evaluation.

Various requirements are to be met in the simulation tool and then in the experiment. Some requirements are relative to the real application of the localization tool in a global view, some requirements are focusing on latencies due to communication of information packages between remote points, and other requirements are relative to the proper experiment with a real time simulator (RTS).

The main requirements are:

- ☒ Polling and interrupt latencies should be in the range of milli-seconds for the real time simulator. Collecting, analysing and managing data in the various ICT components (MDFPI and numerical feeder protection giving primary information to them) distributed among the network; aggregating, analysing and managing data to a central location (HTFD); sending important information to the operator (who will order the circuit breakers and the controlled switches).

We assume the ICT includes at the same part analysis and transmission of information. It means that intermediate calculations may be done locally in order to reduce the contents of transmitted information. It is important to realize that the real ICT components in our application will have these two aspects to meet.

An example of interface between EPS apparatus and ICT component is given hereafter:

- ☒ From the real FPI (Fault Path Indicator) devices, the following condition is assumed: Two dry contacts to indicate the permanent fault and orientation relative to the FPI (up and down). These contacts are automatically reset by an appropriate control inside the device itself.

Another example of possible interface with a numerical SCADA system is:

- ☒ An Ethernet link delivers specific data files, with fault information memorized (with 12 samples per cycle for instance). Voltage and current are given for each phase. Specific filtering and selection in the file is needed to identify the fault signal and analyse it (cycles before, during and after the fault may be recorded).

The main ICT component (HTFD) has to include a topology description tool (or collects data from a specific tool describing the EPS and its characteristics). The collected data are then used for the fault location evaluation. The main output is a clear information (as a fault supervision) for the operator on the expected location and some important warning (to inform him about some systems failure for instance).

The deliverable D1.4 gave a general understanding of the system protection in distribution EPS, focusing on the specific interest of fault location. An important gain on time is expected by the proposed method of fault location.
The goal in deliverable D2.3 is to describe the proposed method as a tool composed of appropriate algorithms. Scenarios and simulations are carried out in order to present and characterize the principle.
The goal in deliverable D3.2 is to have a real time experiment of the ICT components and the proposed method associated. The ICT is expected to be real hardware and software, define by requirements previously given. A specific real time simulator will be used to represent the EPS response and give the inputs to the ICT components.

The ICT boundaries on monitoring EPS data are not easy to define, dedicated and complex equipment being normalized there. A low cost solution may be to use adapted existing devices to achieve the direct interface, these devices providing some ability to emit the desired information. This approach allows us to converge on a practical solution for our experiment, then to a feasible and easier experiment on a real distribution EPS and finally to an easy integration in the future distribution EPS (the two last aspects are not targeted in the CRISP project, but may be a logical perspective).

2.5 Additional information

The boundaries between the ICT and EPS equipment need to be detailed by the simulation and experiment.

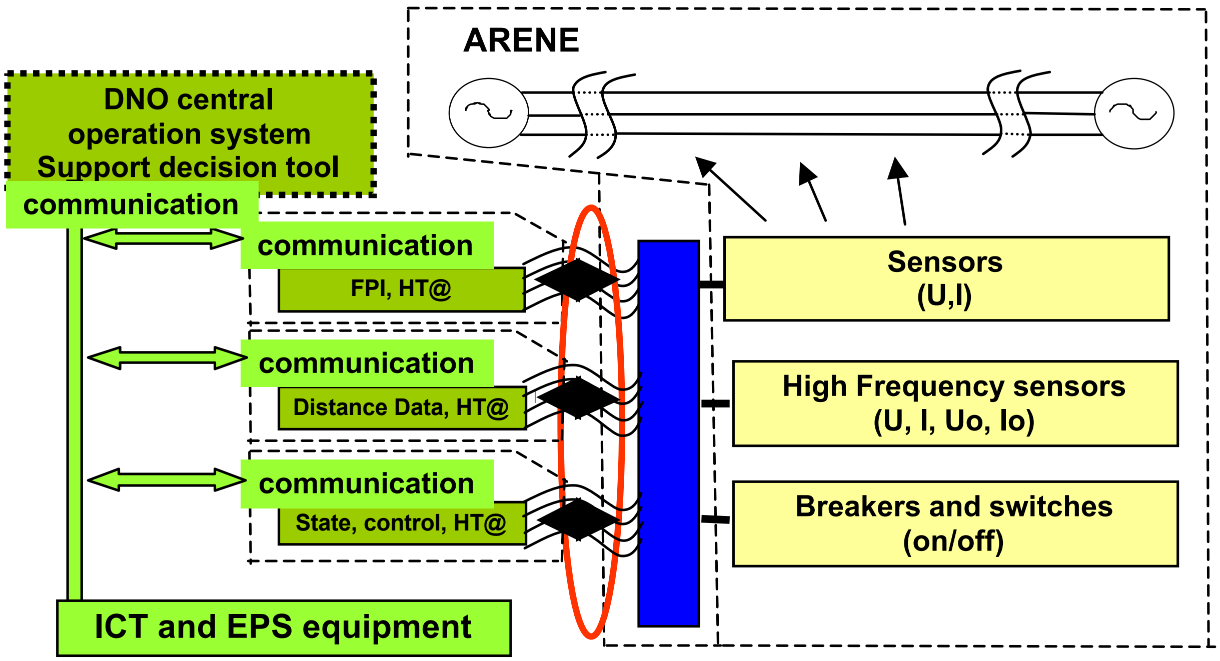

Figure.3.- experiment principle for testing ICT components

ICT definition

Information and Communication Technology (ICT) can be defined as: *"The technology involved in acquiring, storing, processing and distributing information by electronic means (including radio, television, telephone, and computers").*

Communication is the fact of transmitting information between two or more points/agents of the system. The information and communication processes are related very closely. The information system is responsible of obtaining or measuring the parameters/variables that the systems need for a normal operation. So, at this step the information exists and can be transmitted from this point of measure to other points of the system for further utilization.

The communication system is responsible of this transmission and it uses different communication medias to transfer the information and it can also choose between different ways of coding this information (analog or digital format) depending of the transmission devices. The information transformed into different signals (analog or digital) is transmitted by the communication system to different centers where these signals are converted into other formats (data formats exploitable by the centers) and finally the communication process finishes when these data (information) are stored, used or visualized by other system tasks or by the operator of the system.

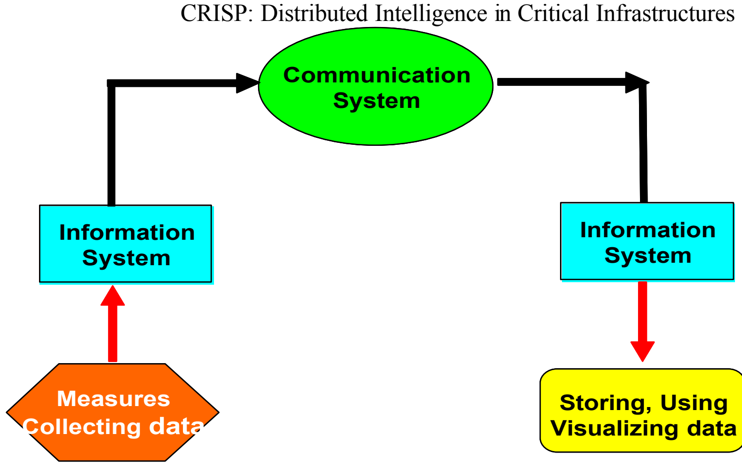

Figure.4.-Information vs Communication vs Computerization

The information systems may be defined in some applications as those which make possible the acquisition of the information on a primary way that is e.g. the measures of different parameters in the electric power system. In that way, all the intelligent electronic devices used to capture or obtain the information belong to the information system.

The computerization consists in using the information or data in order to analyze the system or to establish a support for taking conclusions and so elaborating decisions. The computerization can be carried out where there is the information (with or without communication between two entities because a same entity can obtain the information and computerized it). This computerization system corresponds mainly to the different computer tools that can be applied in a computer, PLC or Control unit.

Boundaries between ICTs and EPS

The boundaries between the ICTs and EPS are not clearly defined because the ICTs are a critical component inside the EPS operation. The EPS operation could not be developed in the way we observe today without the ICT collaboration and active role.

The limits between the EPS and ICT can be seen clearly in the physical components of each system. However, some EPS tasks such as protection, control, are carried out through the use of communication and information analysis. So, the efficiency of the EPS tasks depends on the associated ICTs.

In short, the EPS is composed of different physical elements (generators, transformer, lines, protections, market…). The control and coordination of these physical components are carried out with the help of ICTs components (information, communication and computerization).

3. Simulation tool for the fault diagnosis

The target of the simulation tool focuses on the MV network and on the specific application when a fault occurs. The results of the simulation tool for fault detection are the successive sequences in various ICT components with the resulting information exchanges caused by a fault occurring in a given network. The simulation tool combines the algorithms that will be distributed in several ICT components during the experiment. A great difference between the simulation tool and the experiment is the time scale: no real time constraints are included in the simulation tool, but some aspects of time scale are defined and taken into account.
At the input of the simulation tool, the various ICT components are informed of local device states or electrical signals by the intermediate of the EPS apparatus (FPI, Fault recorder for instance).

Four ICT components are defined depending on their functions. Furthermore, the tool needs the knowledge of the topology and the electrical description of the components present in the real network.

3.1 General description

3.1.1 Domain description around the HTFD system

The tool proposed is an additional function to the existing protection system. This tool assumes the operation of a whole level 1 cell of a MV network (see CRISP deliverable D1.4). The main actors and existing systems are taken into account in the proposed tool, requiring information exchanges as describe in the following figure.

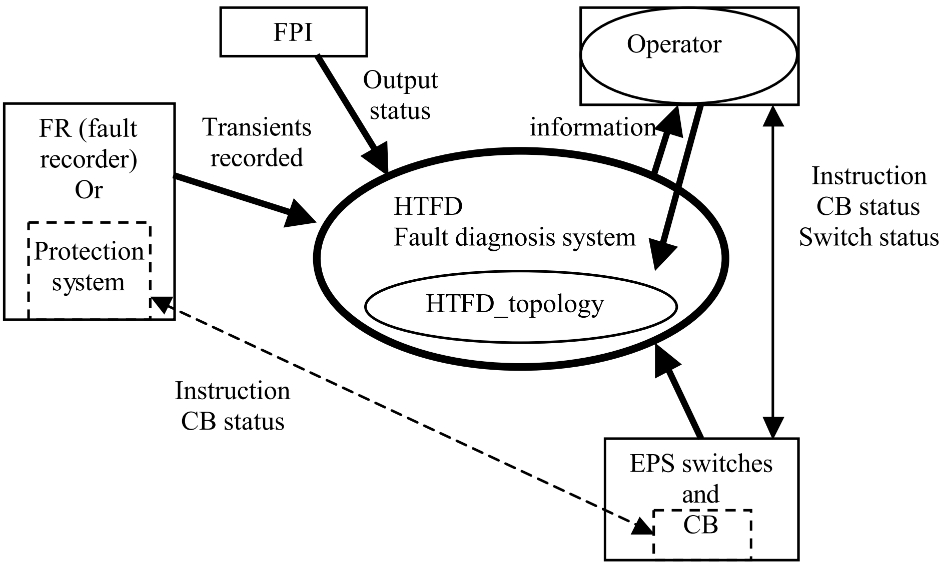

Figure.5.- Context diagram for the Fault Diagnosis system

The Fault Diagnosis ICT System has four main sources of information:

- The Fault Passage Indicator: The FPIs are distributed in general at key points of the distribution EPS, on the main feeder and derivations, being associated in general with the boundaries of elementary areas.
  The FPI sends state information to the Fault Diagnosis System. Hereto the FPI_ICT_component is developed as part of the system. See Ch.3.2.1.

- The Fault Recorder or the protection system: The voltage and the current are measured in magnitude and in phase at a given point of the network: the sending-end of a feeder in general.
  The FR sends electrical variable information to the Fault Diagnosis System. This information may involve a heavy file (transients), while the real information need by the localization tool is low: a solution with a

local analysis and data reduction is proposed. Hereto the FR_ICT_component is developed as part of the system. See Ch.3.2.2.

- The EPS Switch: EPS Switches allow reconfiguration of the power network by opening or closing a flow point. They may or may not be associated with an FPI, depending on the planning and exploitation choices of the operator. Each switch change in the network has to be taken into account properly in the topology description inside the Fault Diagnosis System: the reconfiguration has a great influence in the fault localization evaluation.
  The EPS Switch communicates its state to the Fault Diagnosis System and receives orders from the operator to switch its state. Hereto the EPS_ICT_component is developed as part of the system. See Ch.3.2.3.

- The Operator: The main role of the operator is to make decisions when different actions are needed and may endanger the EPS proper running.
  The Fault Diagnosis System contains a HTFD tool as support for the operator. The HTFD tool communicates information and proposes decisions to the operator. The operator send orders to CB and EPS switches with existing control system. See Ch.3.2.4 and Ch.3.2.5.

The Fault Passage Indicator and the EPS Switch all are connected and distributed into the power grid. The Fault Recorder is linked to the protection system, collecting transients measured by the protection devices distributed at each sending-end feeder. Their location is given by the operator in the network topology included in the HTFD tool. See 3.3. So each signal from these components should be identified by a component identifier from which the location identification can be derived.

3.1.2 Description of ICT components exchanges in the HTFD system

The following Base Class Diagram gives the proposed information exchanges inside the Fault diagnosis system. The HTFD is linked to the operator by a necessary HMI (human machine interface) which allows the operator to modify topology data and to be informed of the results of the local analyses.

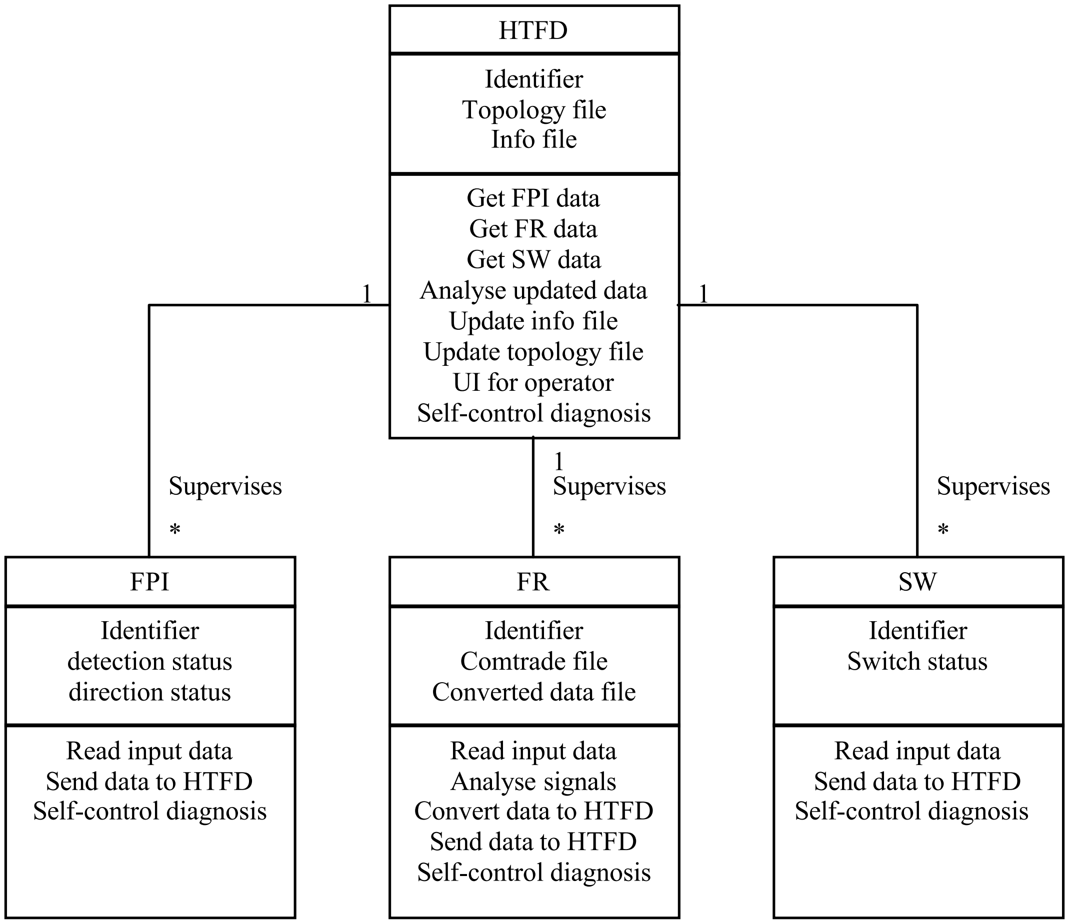

Figure.6.- Class diagram for the ICT main components in the Fault Diagnosis System

Class diagram for the ICT main components in the Fault Diagnosis System

In the above scheme the network components (FPI, FR and SW) are represented by objects / classes within the Fault Diagnosis System. The system is deployed in such a way that it reflects the system architecture described in more detail in Chapter 3.2. The network components will then have their ICT counterparts as distributed subsystems within the Fault Diagnosis System. The network component objects will then have their 'controlling' part, including intermediate calculations, deployed on the ICT component and an information part on the HTFD subsystem.*

The operator role (Ch. 3.2.5.) is not depicted in the diagram, but is represented by the UI 'attribute' of the HTFD class. The UI (User Interface) takes care of representing the right information to the operator and receiving information from the operator. The operator sends the instructions to the EPS switches by an existing control system. The HTFD needs to know the state of the switches in order to update the network configuration.

3.1.3 Reconfiguration and topology update in the HTFD system

The network topology is important in this application and some data required are specific to the fault localization. But some other data are common with other possible applications to be developed in the future: local demand supply matching (local market may introduce temporary changes in the local power system configuration) (see [D1.2] and associated work in WP2.2), power quality and technical constraints studies (voltage profile, harmonics) (see [D1.1]). It is the reason why the future location of topology data may change in the future in order to share properly the common information required. But for the current purpose of simulation tool and experiment, the location chosen is inside the fault diagnosis system.

An essential function of the HTFD - or at least a consequence of HTFD solution proposal to the operator - is the reconfiguration of the network caused by a switch change. In the previous figure a HTFD ICT component is illustrated. Each MV cell may have several HTFD linked to the same network components: when EPS switches have status changes, new configuration has to be taken into account. The HTFD knows the exact location of the FPI components and knows the current topology. So the analysis of the information from the FPI has to be done in the HTFD ICT component, and the FPI ICT component has to inform the various HTFD ICT components belonging to the same cell.

The HTFD - HTFD connection is established in order to compare data and contribute to self-control check.

3.2 Summary of requirements and data for the ICT components

The communication media used to link the different ICT components are expected to be IP network, optic link or PLC (power line carrier). The wireless solution may experience some troubles concerning the electromagnetic distortions in case of fault, but is highly useful when the ICT components are away from the others with several km .

3.2.1 ICT component associated to the directional FPI

Object diagram:

FPI_ICT_component
FPI_topology FPI_communic_identifier FPI_communic_detection_status_output FPI_communic_direction_status_output
Read input data Send converted information to HTFD comp. Self-control diagnosis (internal failure detection)

The ICT components associated to the directional FPI have several functions to fulfil. These functions can be summarized as follow:

- Collect the state of the FPI output
  - Detection state ON or OFF (could be converted into 1 or 0), (1 means permanent fault detected)
  - Directional state ON or OFF (could be converted into 1 or 0), (1 means fault oriented to the substation)
- Send this state to the HTFD (linked to this FPI at the given moment)

Essentially, the ICT component will take the information given by the FPI and it will send it to the tool present in the substations (HTFD). The communication process could be based on a master-slave guideline that is the sending of information to a decision bus present in the substation. The ICT would have only a communication role transmitting the information given in output by the FPI and transmitting the information to the tool for further analysis. Besides, the possibility of changing the information given by the FPI into other format may be an option to take into account. This data conversion should be integrated inside the ICT component that it is described in this paragraph.

Today manufacturer product gives a time delay of a few tens of seconds for existing devices. This time could be drastically reduced by new process validation inside these kinds of devices.

In the future an expected minimum time for collecting information from the fault occurrence may be around 100ms (new kind of devices to develop). With this possible future FPI (information boosted in nearly 100ms: time between the fault occurrence and the input information for the FPI ICT component), a specific information validation will be required (to validate the state of permanent fault and avoid nuisance tripping on non permanent fault).

This ICT component is close to the FPI device, meaning that is could be far away from the HTFD: a few tens of km. Tens of FPI ICT components may be distributed inside a level 1 MV cell.

The communication media which could be applied for the communication should take into account the distances between the substation and the electric buses where the FPI are placed. The communication media is expected to be able to carry the data files above mentioned latencies. A possible solution is based on a IP private network in order to associate IP address to each FPI. This IP network solution may have some advantages faced to the bad issue of the congestion in the network (congestion, errors in the sending of messages and so the latencies would be increased because the resending of messages). Another possible solution is to use optic communication media or power line carrier (PLC).

3.2.2 ICT component associated to the fault recorder or protection system

Object diagram:

FR_ICT_component
FR_topology FR_communic_identifier FR_communic_data_output FR_main_data_file_input
Read input data file Analyse signals Convert information into FR_HTFD format data Send converted information to HTFD comp. Self-control diagnosis (internal failure detection)

The ICT associated to the fault recorder have its own functions which can be summarized as follow:

Collect a COMTRADE file from a numerical protection device (associated to the same circuit-breaker) when a fault is detected (see appropriate standard IEC60255-24),
(proposed data with 3 currents and 3 voltages measured, sampling frequency nearly 1kHz, 200ms before fault and 300ms after fault)

- ☒ Convert file into appropriate data format in order to make calculation
- ☒ Identify the type of fault (3-p, 2-p or 1-p)
- ☒ Evaluate appropriate parameters for the HTFD

3-p: fault type (identifier to be defined), current magnitude averaged on the 3 phases

2-p: fault type (identifier to be defined), current magnitude averaged on the 2 phases

1-p: fault type (identifier to be defined), current magnitude on the faulted phase (during the fault and before the fault), voltage magnitude on the faulted phase (reference phase for imaginary component extraction), zero sequence current evaluated or measured, zero sequence voltage evaluated or measured.

- ☒ Send parameters to the HTFD

Time delay due to COMTRADE file generation and file transmission to ICT may be a problem (a few minutes depending on the manufacturer product).

The aim of the ICT component associated to the fault recorder is double: first making the decentralised computation of the type of fault (near to the fault recorder or the protection device used), this computation allowing the identification of the faulty phase, the evaluation of the main characteristics of the fault, and then in a second sequence making the transmission of the adapted information (reduced to the only useful data required) to the HTFD. This distributed computation reduces the total time of process in two ways for the communication aspect: in one hand a few data are computed to prepare the data transmission, and on the other hand few packages of information are transmitted (just the data needed by the HTFD).

The most critical point related to this ICT is the conversion of data format, the COMTRADE data format takes some minutes to be created. The amount of data is another critical point because the need of the 3 voltages and 3 currents with a sampling frequency around 1 kHz.

Some technical improvements are proposed to reduce drastically this time of transient data exchange. An integrated solution (inside the protection devices) being the faster solution in the long term.

3.2.3 ICT component associated to the EPS switch

Object diagram:

SW_ICT_component
SW_topology SW_communic_identifier SW_communic_status_output
Read input data Send converted information to HTFD comp. Self-control diagnosis (internal failure detection)

The ICT associated to the EPS switch has its own functions which can be summarized as follow:

- Collect the state of the switch or transmit an order to change the state of the switch
  State ON or OFF (could be converted into 1 or 0)
- Send this state to the HTFD (interested by this switch at the given moment)

The update of the data may be achieved in an asynchronous mode: when a change of switch state occurs or an order open/close is sent. An expected duration for this updating process or order transmission is nearly 100ms: time between the state known by local ICT and the state known by the centralized HTFD ICT.

This ICT is close to the EPS switch and may be far away from the HTFD ICT component (expected location in the main substation): the expected longest distance may be up to about 40km. The network may be composed of several tens of EPS controlled switches distributed inside a level 1 MV cell.

The ICT associated to the EPS switch transmits information to the HTFD ICT component about a change in the topology of the electric network (configuration network). A warning message with a high priority may be used to highlight the attention of the operator or the HTFD on the changes occurring in the network.

3.2.4 ICT component associated to the HTFD

Object diagram:

HTFD_ICT_component
HTFD_topology HTFD_communic_identifier HTFD_communic_data_output HTFD_FPI_data_input HTFD_FR_data_input HTFD_fault_history
Read input data from FPI Read input data from FR Analyse_updated_information (fault_type, grounding system) Convert information into operator format data Send converted information to operator Self-control diagnosis (internal failure detection)

The ICT associated to the HFTD is the most complex ICT of those detailed in this application: it represents the core of the proposed solution for a given level 1 MV cell. The HTFD ICT component accumulates data and makes the main combined analysis. It need a clear interaction with the operator, giving to him the main results on fault diagnosis and collecting from him the main information about the characteristics of the topology (updating if necessary). The main actions that it is supposed to fulfil are the following ones:

- Collect the data from the 3 other types of ICT components (described above)
- Update the network topology if necessary
- If a fault is detected
  - Combine the analysis with FPI data and fault recorder data >> fault location
- Give the information to the operator
- Propose a response to the permanent fault detected (new configuration of the network)
- Send information to the other HTFD associated to the same level 1 cell

The first goal of the ICT-HTFD is the collection of all ICT components information. The collection of the data is carried out in a specific data format that could be changed for the information analysis in the computerization part of the ICT-HTFD. So, if the information supplied by the others ICT is not in the adequate format to be used directly by the ICT-HTFD a data format change step must be taken into account. After the accumulation of data, they must be computerized inside the ICT in order to locate the occurrence of the fault in the network. Then, the information about the fault (type, localisation…) must be sent to the operator and other ICT-HTFD in order to propose the configuration of the network which isolates the faulty area.

The ICT-HTFD requires the three roles of the ICT: information, communication and computerization. Thus, a microprocessor, PLC (programmable logic control) or computer is necessary to run the algorithm of fault detection. The use of a specific IP network for this application seems to be the right choice. A right location may be in the main substation, including in general some LAN applications (Ethernet network of 100 Mbps). This LAN system should be efficient enough to support all the data arrival without major problems.

The communication with the operator is generally developed with a WAN (Wide Area Network), e.g. the IP network.

3.2.5 Operator role

Object diagram:

operator
SW_status_input SW_status_output (control) CB_status_input CB_status_output (control) HTFD_communic_data_input
Read input data from SW Send output control to SW Read input data from CB Send output control to CB Analyse updated information from HTFD Take decision on SW and CB control

The main role of the operator is to make decisions when different actions are needed and may endanger the EPS proper running. A type of action is related to the change of the state of the EPS switches through the network. The HTFD ICT component role is to inform the operator, but also to propose him some response options. If the process proposed may be properly achieved in less than 10s, the localization sequence could be introduced in the protection sequence, saving a lot of time and energy supply loss. In that perspective, the role of the operator is described as it was an ICT component, allowing for the future a faster and clear automation of its action.

- Collect the data from the HTFD: expected faulted sections, type of fault
- Define the appropriate response: controlling CB and EPS switches

Sequential procedure in case of multiple possible fault location
Switching off on a fault condition is possible by the circuit-breaker, but not by the EPS switches.

A default process is defined in case of no indication from the location evaluation tool: a basic try and test process is adapted to the local and updated topology of the network.
By the mean of simulation tool, the operator may launch some studies of coherency of the situation proposed by the reconfiguration tool (for instance the expected power flow following a fault and a new configuration of the network (configuration proposed by the simulation tool from fault diagnosis). The operator may also check there is no connection error on the exploited topology (no intentional and internal closed loop between substations).

3.3 Topology and electrical description

This part is mainly included in the HTFD ICT component, and is given and updated by the operator.

Object diagram:

HTFD_topology
Conductors_sections_topo (node_A, node_B, R, X) FPI_topo (node_A, node_B, identifier, type) CB_topo (node_A, node_B, identifier) SW_topo (node_A, node_B, identifier) FR_topo (node_A, node_B, identifier)
Modify conductors_sections_topo Modify FPI_topo Modify CB_topo Modify SW_topo Modify FR_topo

Level 1 cell must be first described and updated when changes occur during long term exploitation (see definition of level 1 cell in the CRISP project deliverable D1.4).
Different solutions may be found to describe the network and to update easily this description (interaction between the operator and the HTFD ICT component). One kind of solution is described hereafter. Many other solutions exist and may be followed for the design of the algorithm.

Example for naming and associating the components in the network (components oriented):
Each conductor section and each EPS switch is a component having two extremities, and so, two node names (using letters and/or numbers). A default radial operation of the distribution EPS is defined, enabling to define a table of combined data for the topology and the electrical useful parameters (T&D table for topology and data table).
The connectivity between components is directly defined by the two node names (N1, N2) of each component, an orientation being given by the position of the nodes in two columns (in reference to the default radial distribution EPS). For instance N2 is closer to the substation than N1

N1	N2	Component type	Electrical characteristics and miscellaneous data
N2	N3	Component type	Electrical characteristics and miscellaneous data
N3	N4	Component type	Electrical characteristics and miscellaneous data

Table.1.- Example of connectivity data

This example of connectivity is not based on a simple incremental number of components since the concept of cell implies a possible deep new configuration (the main substation may be different from time to time).

Three main types of components are taken into account for our dedicated application and for the description of the topology of the local power system: the EPS switch, the FPI and the conductor sections. The main data required are summarized in the following items:

1/ EPS switch, the Electrical characteristics and miscellaneous data are:

- State ON or OFF (could be converted into 1 or 0)

2/ FPI, the Electrical characteristics and miscellaneous data are:

- Detection state ON or OFF (could be converted into 1 or 0), (1 means permanent fault detected)

- Orientation state ON or OFF (could be converted into 1 or 0), (1 means fault oriented to the substation, or in another way 'upstream fault', the assumption being that the main contribution of fault current comes from the interconnected EPS via the main HV/MV substation)

3/ Conductor, the Electrical characteristics and miscellaneous data:

PARAMETER	CODE
Length	
Direct sequence resistance	**R_D_CS**
Zero sequence resistance	**R_Z_CS**
Direct sequence reactance	**X_D_CS**
Zero sequence reactance	**X_Z_CS**
Direct sequence capacitance	**C_D_CS**
Zero sequence capacitance	**C_Z_CS**

(_CS for Conductor Section, meaning the whole length of line or cable in the given component)

Other useful electrical characteristics necessaries are:

- Active power consumed in the section (then assumption needed for load distribution)
- Reactive power consumed in the section (then assumption needed for load distribution)
- Nominal power of synchronous generators connected
- Indication for a permanent fault located inside: state 1 or 0 (keeping history of a previous event)

General parameters and data are required for defining the surrounding of the MV level 1 cell studied:
a/ Expected short-circuit current on primary side of the HV/MV transformer due to interconnected HV EPS and the nominal voltages of the HV and MV EPS.

PARAMETER	UNIT	CODE
Nominal MV between phase and neutral	kV	V_N_MV
Nominal MV between phases	kV	U_N_MV

The short-circuit current is converted into two parameters expressed in the MV side:

PARAMETER	UNIT	CODE
Direct sequence resistance	ohm	R_D_IN
Direct sequence reactance	ohm	X_D_IN

b/ Series impedance of the HV/MV transformer expressed in the MV side:

PARAMETER	UNIT	CODE
Direct sequence resistance	ohm	R_D_TR
Direct sequence reactance	ohm	X_D_TR

c/ installed capacity of the synchronous generators located in the adjacent feeders

PARAMETER	UNIT	CODE
effective power	MVA	S_DR_AF

d/ Grounding system chosen for the neutral of the HV/MV transformer

- Impedance grounded neutral: resistance R_IGN and reactance X_IGN in series

- Compensated neutral: resistance R_PCN and updated reactance X_PCN in parallel (an automated system may change X_PCN in order to adapt regularly the reactance to the cable capacitance of the network, depending on its real configuration).

e/ Expected current due to the capacitance of the cables and the lines in the adjacent feeders

PARAMETER	UNIT	CODE
associated zero sequence current	A	C_CAP_C

By an iterative process in the topology and data table (T&D), taking into account the information coming from the MV cell (states of EPS switches and circuit breakers), the HTFD is able to update the real lines and cables connections states in the MV cell.

Comments:

Default values and tables of typical values should be proposed to support the operator to set and check the parameters. The inverse sequence impedance of passive components is assumed to be similar to the direct one.

Before reconfiguration, a dedicated program may check the future expected load flow: checking voltages and currents in conductor sections for the final state of the localization sequence before using the emergency EPS switch.

3.4 Fault distance evaluation

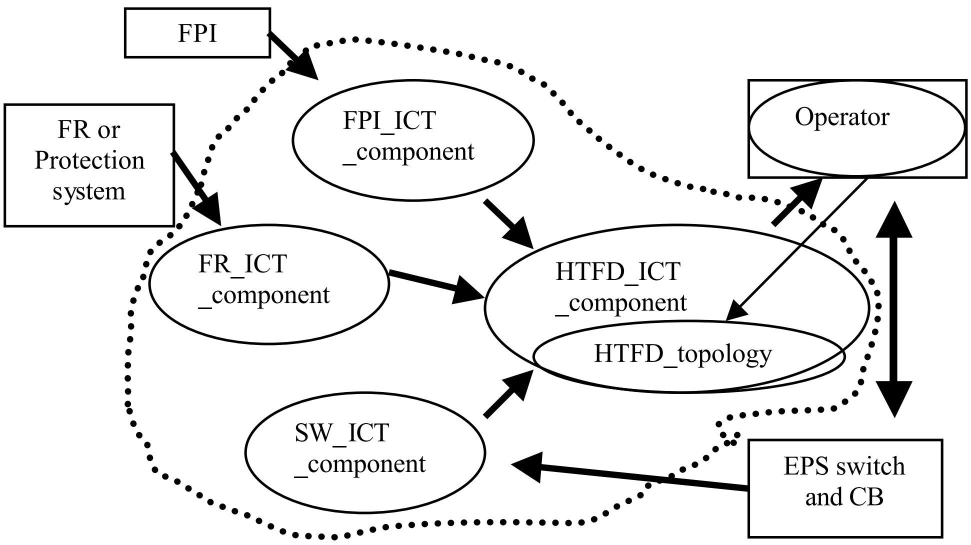

Figure.7.-Context diagram of the HTFD system including ICT components

A first selection of the type of fault is done from the data collected on the phase currents during the fault:

- The phase current overlaps a given threshold for the three phases >> three-phase fault,
- The phase current overlaps a given threshold for two phases only >> two-phase fault,
- Only one phase current or no one overlaps a given threshold, and zero sequence current is overlapping a given threshold >> single-phase fault

This selection may be done in or close to the protection device of the feeder.

The approach is proposed for permanent fault current and is based on the steady-state fault current.

The main difficulty expected is the case of a single-phase fault in a compensated neutral, the phase fault current being low compared with the compensated current (circulating between the distributed capacitance of the network and the Petersen coil) and the load current. This situation induces a high dependence on the accuracy of the measurements and of the parameters evaluation. In our case a parallel resistance to Petersen coil is needed in order to hope to collect sufficient information to locate the fault. It needs that the proposed method is not available for single-phase fault in a full isolated neutral or in a full compensated neutral without any parallel resistance. The parallel resistance is designed to have a minimal current circulation during the fault (around 20Amps in France for instance).

Another additional aspect is the specific and transient aspect of the possible intermittent earth-fault: locating this kind of permanent fault is an important feature not taken into account in this document, and is still a high challenge for the future. As indicated in the deliverable D1.4, this fault occurs periodically but remains a few time (around 40ms) making them very difficult to detect and localize (test and try method possible).

The method followed hereafter could be understood as a localization method itself, but in fact some points of fault may be found. In fact, the common parameter for the various possible solutions is an equivalent electrical distance.

3.4.1 Three-phase fault

An iterative process is defined to converge to the identification of a conductor section, and then up to a location inside the conductor section. Since the main fault current contribution comes from the interconnected network, the main information to evaluate the fault distance is the direct impedance of the HV/MV transformer and of the HV interconnected network (data known by the operator), the direct impedance of the conductor sections of the feeder and the measured current during the fault.

In the protection device or near a fault recorder:
1/ detection of the fault type and sending the associated identifier
2/ evaluation of the three-phase current RMS value, averaging values measured on the three phases
I_M_RMS value sent to the HTFD

In the HTFD
The feeder sending a message is identified, the fault type and the I_M_RMS value are collected
1/ If information from FPI is available, the fault passage indicated is used to initiate the calculation.
2/ If not, the search is initiated from the sending-end feeder

In case of no initial fault passage indication, the first section is tested:
The following value EVA_TEM3 is calculated by the formula:

$$(R\_D\_IN + R\_D\_TR + R\_D\_CS1)^2 + (X\_D\_IN + X\_D\_TR + X\_D\_CS1)^2 - \left(\frac{V\_N\_MV}{I\_M\_RMS}\right)^2$$

1/ if < 0: the fault is further in the EPS, the second section is tested:
R_D_CS1 is replaced by R_D_CS1 + R_D_CS2
X_D_CS1 is replaced by X_D_CS1 + X_D_CS2
And so on adding a following section if the calculated value (EVA_TEM3) is still < 0
Various different derivations may be tested: multiple solutions are possible finally.

In fact, because of measurements, conversion and transmission accuracy, a threshold near zero is preferred to the exact zero reference. The value of this threshold is chosen taking into account the calculation of the EVA_TEM3 value (associated to the square root of differential impedance). For instance the given threshold for the line CS6 may represent 5% of the associated length and is given by: $5\% \cdot \left((R\_D\_CS6)^2 + (X\_D\_CS6)^2\right)$

2/ if > 0: the fault may be inside this section (assuming a previous calculation < 0 and a simple addition of one section down),
>> the program sends information of the possible faulted section

>> when the possible faulted sections have been identified, a slower and more detailed approach may be followed in order to evaluate the location inside the identified faulted section. A dichotomizing approach is launched, VAR_DIC = 0.5
R_D_CS1 is replaced by R_D_CS1*VAR_DIC
X_D_CS1 is replaced by X_D_CS1* VAR_DIC
And changing the value VAR_DIC depending on the iterative results > 0 and < 0
(VAR_DIC converging to a value between 0 and 1)
(increase VAR_DIC if < 0)
(decrease VAR_DIC if >0)

If the indication of a fault passage exists, this passage is directly tested (taking into account the various direct impedances between the sending-end feeder and the identified section before indication). The calculation of EVA_TEM3 should be negative (if not a warning message is sent to the HTFD): then the iterative process previously described is followed.

The stop of the dichotomizing process is based on the threshold given previously and representing a % of the length of the conductor section. The value of 5% of this distance is kept as reference value in the scenarios simulated.

3.4.2 Two-phase fault

A quite similar approach to the three-phase fault is followed, assuming a main contribution of the interconnected HV network to fault current.

In the protection device or near a fault recorder:
1/ detection of the fault type and sending the associated identifier
2/ evaluation of the two-phase current RMS value, averaging values measured on the two faulted phases
I_M_RMS value sent to the HTFD

In the HTFD
The feeder sending a message is identified, the fault type and the I_M_RMS value are collected
1/ If information from FPI is available, the fault passage indicated is used to initiate the calculation.
2/ If not, the search is initiated from the sending-end feeder

In case of no initial fault passage indication, the first section is tested:
The value EVA_TEM2 is calculated by the formula:

$$(R\_D\_IN + R\_D\_TR + R\_D\_CS1)^2 + (X\_D\_IN + X\_D\_TR + X\_D\_CS1)^2 - 0.75 \cdot \left(\frac{V\_N\_MV}{I\_M\_RMS} \right)^2$$

Then the same process as described for the three-phase fault is followed (see previous chapter: three-phase fault) with the new calculated value EVA_TEM2.

3.4.3 Single-phase fault

In the protection device or near a fault recorder:
1/ detection of the fault type, the fault phase and sending the associated identifier
2/ evaluation of the phase current RMS value on the faulted phase, of the phase-to-earth voltage magnitude on the faulted phase, of the zero sequence current (1/3 the residual current) evaluated or measured and of the zero sequence voltage evaluated or measured during the fault steady-state. The phase of each value is evaluated, the voltage phase being the reference.

For impedance neutral:
I_M_RMS, I_M_PHA values sent to the HTFD [Vm_M_RMS (phase reference)]

Iz_M_RMS, Iz_M_PHA values sent to the HTFD [Vm_M_RMS (phase reference)]

For compensated neutral:

In the HTFD
The feeder sending a message is identified, the fault type and the (I_M_RMS, Vm_M_RMS, Iz_M_RMS, Vz_M_RMS, I_M_PHA, Vm_M_PHA, Iz_M_PHA, Vz_M_PHA) values are collected
1/ If information from FPI is available, the fault passage indicated is used to initiate the calculation.
2/ If not, the search is initiated from the sending-end feeder

In case of no initial fault passage indication, the first section is tested:
The value EVA_TEM1 is calculated

For impedance neutral:

$$2 \cdot X\_D\_CS1 + X\_Z\_CS1 + X\_D\_TR + 3 \cdot X\_IGN - 2 \cdot \mathrm{Imag}\left(\frac{V\_N\_MV}{I\_DF\_R - I\_BF\_R - Iz\_R + j(I\_DF\_I - I\_BF\_I - Iz\_I)}\right)$$

I_DF_R: real component of I_M during fault (steady-state current at power frequency)
I_BF_R: real component of I_M before fault
Iz_R: real component of Iz_M during fault (1/3 of the residual current)
I_DF_I: imaginary component of I_M during fault
I_BF_I: imaginary component of I_M before fault
Iz_I: imaginary component of Iz_M during fault (1/3 of the residual current)

For compensated neutral:

$$2 \cdot X\_D\_CS1 + X\_Z\_CS1 + X\_D\_TR + 3 \cdot X\_IGN - \left(\frac{V\_N\_MV \cdot Ir\_DF\_I}{Ir\_DF\_R^2 + Ir\_DF\_I^2}\right)$$

Ir_DF_R: real component of current inside R_PCN during fault (phase reference with V_N)
Ir_DF_I: imaginary component of current inside R_PCN during fault (phase reference with V_N)

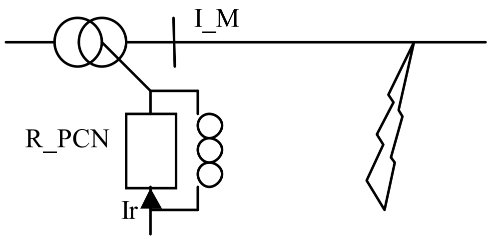

Figure.8.- Neutral impedance connected to the local substation ground

Then the same iterative process as described for the three-phase fault is involved (see previous chapter: three-phase fault) with a new calculated value EVA_TEM1 including a new section of conductor. The direct sequence and zero sequence of section 1 are replaced by the direct sequence and zero sequence of sections 1 and 2, and so on. Depending on neutral earth grounding system (impedance neutral or compensated neutral), the evaluation of EVATEM1 needs different input data as indicated.

3.5 FPI information

In the FPI:
1/ detection of the fault, sending the indication and the evaluated direction

In the HTFD
The feeder sending a message is identified, the fault indication and the direction are collected
1/ evaluation of the faulty section
identification of the last indication of fault when going down into the network
identification of the no indication in the following sections >> list of possible faulty sections
2/ sending this analysis result to the program evaluating the fault distance (for initialization or validation of results)

3.6 Combined iteration

A prime analysis of the FPI information may give directly the expected result: the elementary faulty area. If this information gives only the main path for the fault current, this information is useful to initiate the fault distance analysis: oriented choice for the conductor types depending on the possible path.

The coherency of FPI information may be checked by simple rules (taking into account a possible failure of an indication along the fault passage). For instance a no indication with an indication below in the network may be interpreted as a false indication (maybe a problem of threshold setting or measurement accuracy or device failure).

The results of fault distance analysis and FPI indication are crossed to check finally the possible solutions. If the network is properly equipped with sufficient FPI at the right locations, the final result should be unique and coherent by the two ways of indication.

4. Network and scenarios: simulation of the fault localization

4.1 Network general description

The network proposed is based on realistic impedance data and is kept as simple as possible for representing various expected tests. Various derivations are defined to test the accuracy of the fault distance analysis. Load, dispersed generation and fault events are distributed along the network depending on the scenario.
The network is sectionalized into 5km sections by isolation devices. A normally opened switch is taken into account between the two main feeders: it makes it possible to study some aspects of reconfiguration for two HV/MV substations interconnected by this emergency path.

18 isolation devices (including a normally opened one)
2 circuit-breakers
9 fault passage indicators

The following drawings show the feeders under study. The surroundings components are also taken into account in the simulation (interconnected HV EPS, HV/MV transformers, adjacent feeders).

During the normal operation and for the given electrical data, the load supplied in the feeder controlled by CB1 is (2.8MW and 1.4MW) and the load supplied in the feeder controlled by CB2 is nearly (3.2MW and 1.6MW). The load and the conductor type allow the operator to supply all the level 1 cell by any substation 1 or 2, it means (6MW and 3MVar) in case of emergency or reconfiguration for maintenance purpose.

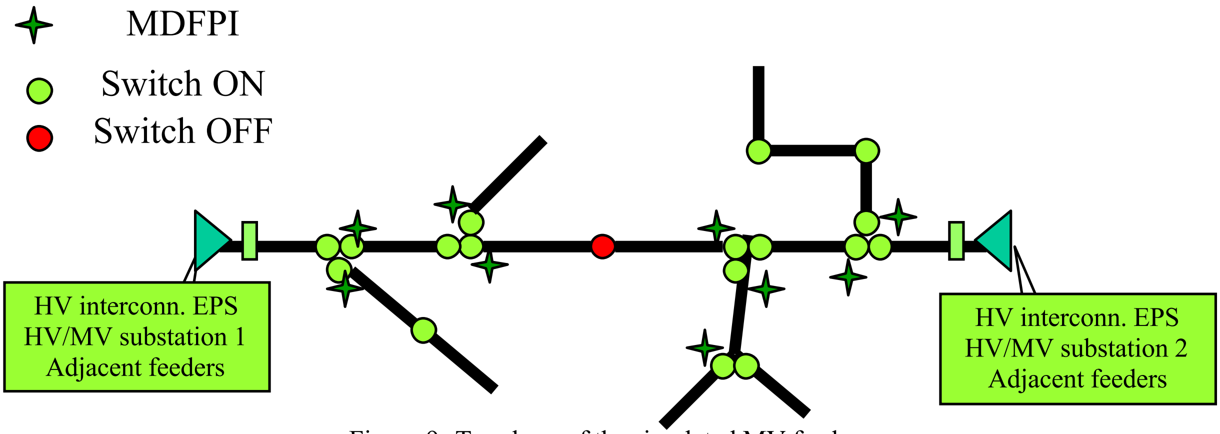

Figure.9.-Topology of the simulated MV feeders

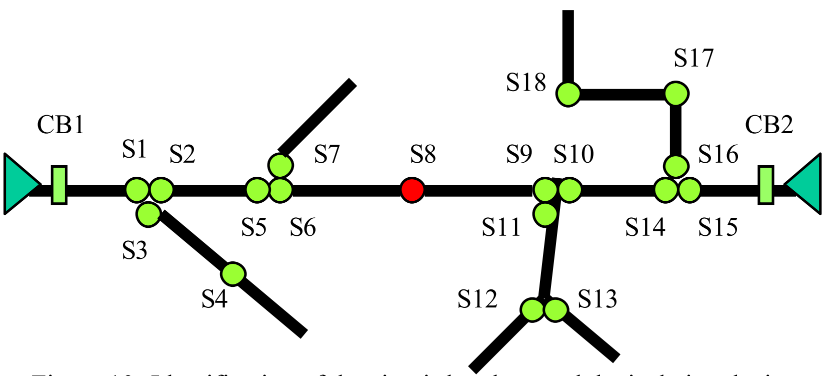

Figure.10.-Identification of the circuit-breakers and the isolation devices

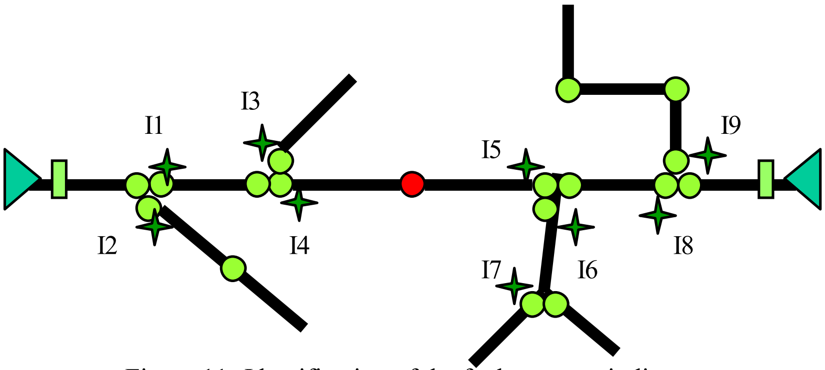

Figure.11.-Identification of the fault passage indicators

load 400kW 200kVar

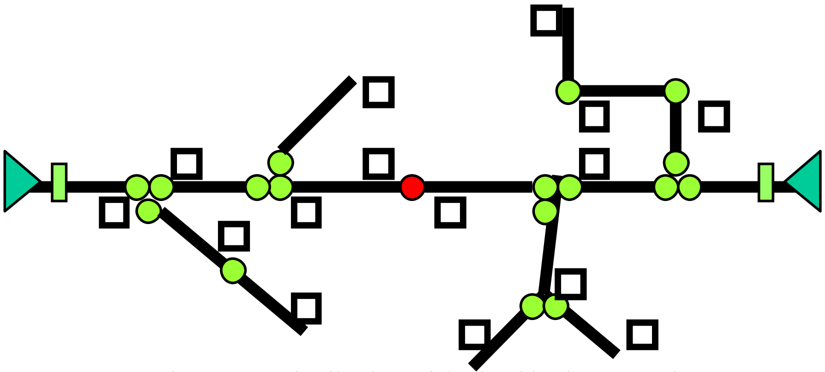

Figure.12.-Distribution of the load in the network

DR 200kW

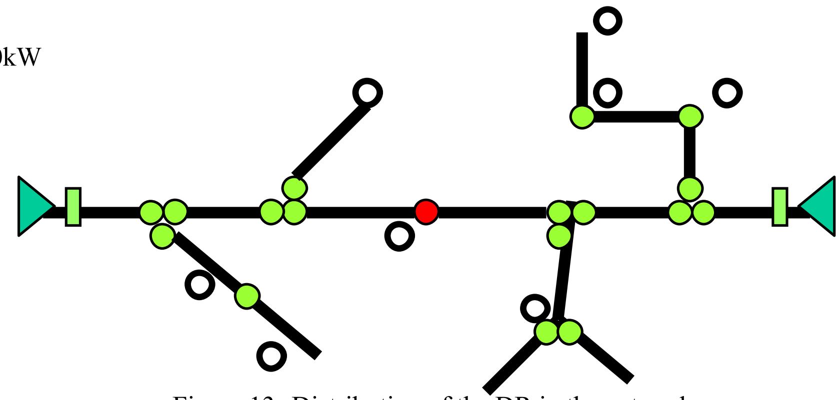

Figure.13.-Distribution of the DR in the network

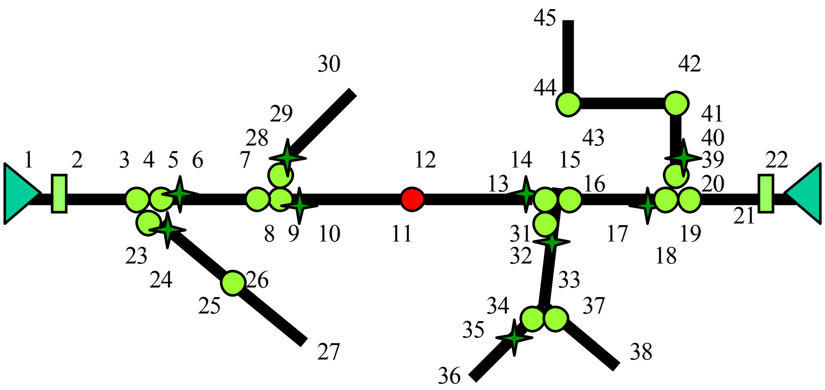

Figure.14.- Naming the network nodes

The nodes 3, 4, 5, 6, 23, 24 have a similar voltage (quite the same node) but are necessary to clarify the topology by separating all the components involved. So the node names for the topology description in the HTFD ICT component give all the nodes between components, including circuit breakers, EPS switches, FPI and conductors (lines or cables). The conductor data includes the accumulated load on the associated conductor. The EPS switch gives the state information useful for updating the network configuration. The FPI has 3 possible output states: no indication (OFF), and directional information (indication (ON, node name A of the FPI) or (ON, node name B of the FPI).

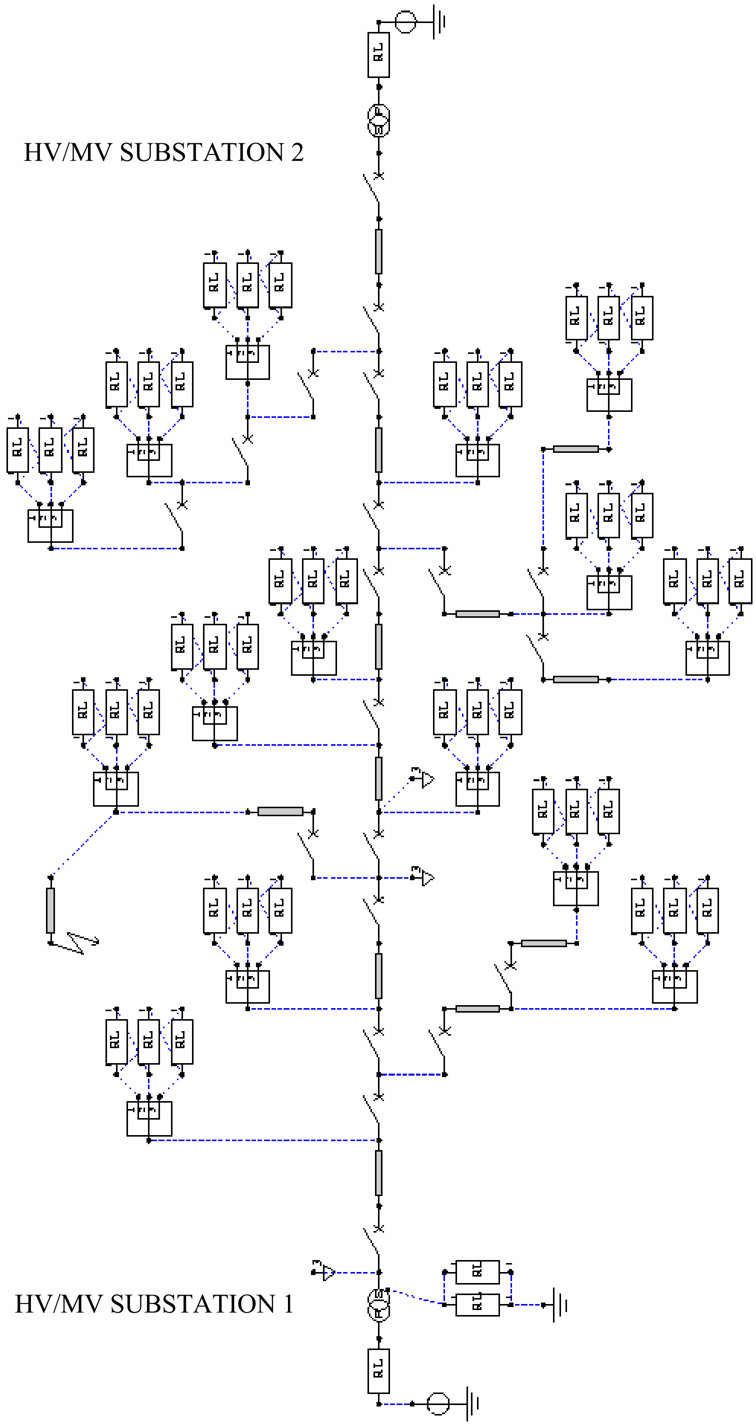

Figure.15.-Network description in Arene for scenario 1

4.2 Electrical characteristics and models

Classical model are defined corresponding to the electrical characteristics observed at the fundamental frequency (50Hz in Europe). Typical electrical data are used in the network proposed, the main final targets being the description of the simulating tool and simulation scenario. The data selected are the main data useful for fault diagnosis.

4.2.1 Interconnected network characteristics on HV nodes

The short-circuit current is assumed to be nearly 9kA on the 63kV side (transformer primary). The corresponding short-circuit power is 1000MVA. A ratio X/R of 15 is taken into account (possible and typical ratio in a transmission system). The model of the surrounding HV interconnected EPS is modelled by a pure sinusoidal voltage source associated with RL components: R = 0.264ohms, L = 12.6mH (X = 3.95ohms) expressed in the HV reference.

4.2.2 HV/MV Transformers

Typical HV/MV is used for the simulation:
Nominal voltages: 63kV/20kV,
Nominal power: 36MVA,
Short-circuit data: Usc = 15% with test short-circuit loss = 150kW,
The resulting impedance is expressed in the MV reference is: R = 0.0463ohms and X = 1.664ohms,
The neutral of the secondary is connected to the earth with RL series impedance or with a Petersen coil depending on the chosen grounding system.

4.2.3 Lines

5km lines sections are defined with a typical 148mm2 almelec conductor
The assumed characteristics for this conductor are:
Direct sequence resistance: 0.2ohms/km
Inverse sequence similar to the direct sequence
Zero sequence resistance: 0.36ohms/km
Direct sequence inductance: 0.955mH/km
Inverse sequence similar to the direct sequence
Zero sequence inductance: 5.73mH/km
Direct sequence capacitance: 10nF/km
Zero sequence capacitance: 7nF/km

4.2.4 Cables

5km cables sections are defined with a typical 150mm2 aluminium conductor
The assumed characteristics for this conductor are:
Direct sequence resistance: 0.203ohms/km
Inverse sequence similar to the direct sequence
Zero sequence resistance: 1.205ohms/km
Direct sequence inductance: 0.4mH/km
Inverse sequence similar to the direct sequence
Zero sequence inductance: 2.86mH/km
Direct sequence capacitance: 264nF/km
Zero sequence capacitance: 264nF/km

4.2.5 Neutral grounding systems

Two types of grounding system are taken into account:
1/ Impedances grounded neutral: 12 ohms resistance and 12 ohms reactance in series (expressed 12+j12 in complex figures)
2/ Compensated neutral: the neutral coil is chosen in order to balance the high value of capacitive current induced by the capacitance of all the MV conductors. This current may reach hundred of amps in case of network including a long length of cables. We assume that a resistance is installed in parallel to the Peterson coil in order to have a minimal indication of the existing single-phase fault: the current in this resistance is of main importance in the solution proposed.

In case of full isolated neutral or compensated neutral by the Peterson coil alone, we don't have enough information to locate properly the fault.

4.2.6 Loads

The loads are modelled by passive components connected to 20kV buses: combination of resistances and inductances. The loads are delta type: RL series components are connected between two phases. So the resulting power is less sensitive to the neutral point voltage, what is close to the real situation with a general use of MV/LV transformer with delta/star coupling.
The model used for the (400kW, 200kVar) load is resistance R and inductance L in series at each branch of the delta:
R = 2400ohms
L = 3820mH
In the normal situation, the expected supplied power in the feeder under study connected to the substation 1 corresponds to 7 loads, so nearly 2.8MW and 1.4MVar. 8 loads for the feeder connected to the substation 2 leads to 3.2MW and 1.6MVar.
The nominal current supplying each load is nearly 13A (view from 20kV conductors).

4.2.7 Distributed resources

Earth-fault is not supplied because of the operator technical requirements imposed to the production units.
Multi-phase fault is supplied by DR, but the main expected contribution should be caused by synchronous machines: each unit may inject a transient current up to six times the nominal value, depending on design and excitation characteristics.
The distributed resources are assumed controlling the output flow of active and reactive power (P/Q control) by adapting the current injection to the existing voltage at the point of connection.
The response to a voltage drop is an increase on injected current (a protection may trip the unit depending on the reached value and on the time involved).
For each 200kW unit, the expected current feeding the 20kV network under normal condition is nearly 6A.

4.2.8 Adjacent feeders

Adjacent feeders from each substation may be modelled by equivalent loads and capacitances. The contribution of the cable capacitances in the fault current amplitude may be important: up to hundreds of ampere in some cases of long cables conductors. This fault current contribution inside the fault point is highly reduced by shunt reactance in the case of a compensated neutral.
An equivalent load of 20MW and 10MVar (consumed) is assumed for all the different adjacent feeders.
The equivalent capacitance between cables and earth depends on the studied cases (cables, lines)
For instance 100km cable is nearly 20µF, what entails 2.5MVar produced under normal voltage.
When DR is taken into account in the simulated feeders, the adjacent feeders of each substation are assumed to totalize 5MW DR. As explained in the previous chapter (4.2.7), the control is assumed to be P/Q type for each unit (normal control when DR is connected to the public EPS). A drop in voltage induces a proportional increase of current (maintaining a given injected power by the generating unit). Depending on the initial condition of the DR current injection, some protections of units may be tripped during the fault. The 5MW production is assumed to be widely distributed through the adjacent feeders, by units of 200kW for instance.

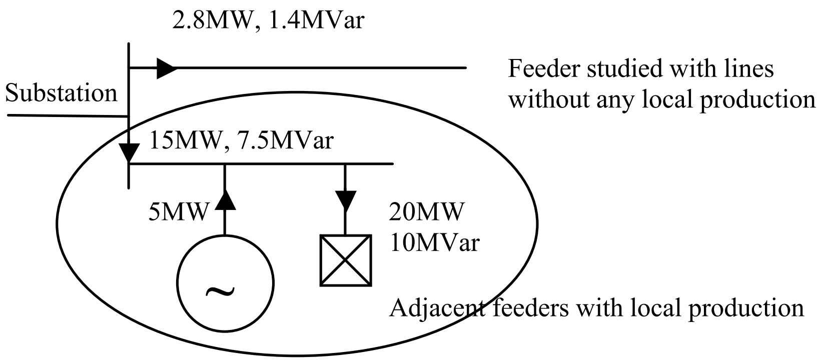

Figure.16.- Context diagram for the Fault Diagnosis system

4.3 *Fault characteristics*

In order to present the studied network, the main short-circuit current caused by fault is evaluated with load and without any distributed resource (DR) in the network. This approach allows the reader to have main figures about fault current values in the given MV network. This evaluation is interesting since the main component of fault current comes from the interconnected network in any case, as we will see in the simulation results.

4.3.1 S8 opened

This state is the normal situation (default configuration) for the network. The network is assumed to be equipped with lines for all the conductors sections or with cables for all the conductors sections (the two cases are studied separately and not combined to avoid too much complexity). Various fault locations are taken into account for various types of fault. The following tables give the expected RMS value at the MV side of the HV/MV substation for the steady-state fault current at the fault location indicated.

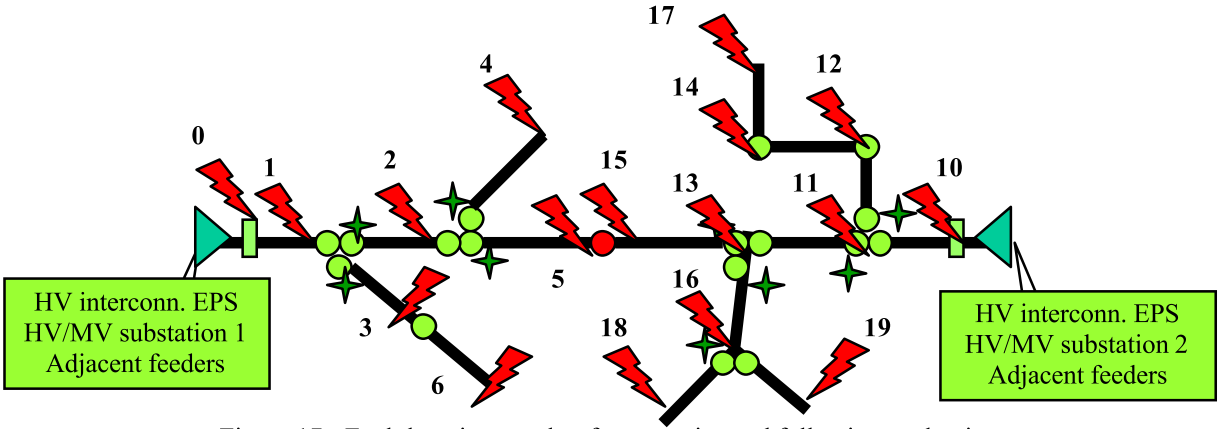

Figure.17.- Fault location number for scenarios and following evaluation

Case with lines for all the conductors sections and with neutral impedance (12+J12)ohms in the substation:
For single-phase fault, the fault current in the circuit-breaker (CB1 or CB2) is given with amplitude and phase (Rad for radian)

Fault Location (fig.12)	Distance from subst. (km)	Node name	Three-phase fault (A)	Two-phase fault (A)	Single-phase fault (Rf = 0ohms) I_M (A / Rad)	Single-phase fault (Rf = 20ohms) I_M (A / Rad)
0	0	1	5588	4839	664 / 0.81	336 / 0.37
1	5	3	3110	2693	544 / 0.89	311 / 0.46
2	10	7	2115	1832	458 / 0.95	287 / 0.54

3	10	25	2115	1832	458 / 0.95	287 / 0.54
4	15	30	1596	1382	395 / 1.00	266 / 0.6
5	15	11	1596	1382	395 / 1.00	266 / 0.6
6	15	27	1596	1382	395 / 1.00	266 / 0.6
10	0	22	5588	4839	664 / 0.81	336 / 0.37
11	5	20	3110	2693	544 / 0.89	311 / 0.46
12	10	41	2115	1832	458 / 0.95	287 / 0.54
13	10	16	2115	1832	458 / 0.95	287 / 0.54
14	15	43	1596	1382	395 / 1.00	266 / 0.6
15	15	12	1596	1382	395 / 1.00	266 / 0.6
16	15	33	1596	1382	395 / 1.00	266 / 0.6
17	20	45	1280	1108	347 / 1.03	247 / 0.66
18	20	36	1280	1108	347 / 1.03	247 / 0.66
19	20	38	1280	1108	347 / 1.03	247 / 0.66

Table.2.- Expected current for the different fault location (lines)

The table shows how the current magnitude depends on the fault distance and fault type. For comparison purposes the load current expected at the sending end of the feeders is nearly 90Amps (in case of no DR inside the studied feeder).

Case with cables for all the conductors sections and compensated neutral in the substation:
For single-phase fault, the fault current amplitude (I_M) on the faulty phase at the feeder sending-end is given and the imaginary component of current in the parallel resistance of the neutral impedance (Ir_I) is given.

Fault Location (fig.12)	Distance from subst. (km)	Node name	Three-phase fault (A)	Two-phase fault (A)	Single-phase fault (Rf= 0ohms) I_M / Ir_I (A)	Single-phase fault (Rf= 20ohms) I_M / Ir_I (A)
0	0	1	5588	4839	57.22 / 0.03	58.07 / 0.02
1	5	3	3994	3459	57.27 / 0.11	58.12 / 0.11
2	10	7	2953	2557	57.32 / 0.20	58.16 / 0.19
3	10	25	2953	2557	57.32 / 0.20	58.16 / 0.19
4	15	30	2306	1997	57.37 / 0.29	58.21 / 0.27
5	15	11	2306	1997	57.37 / 0.29	58.21 / 0.27
6	15	27	2306	1997	57.37 / 0.29	58.21 / 0.27
10	0	22	5588	4839	57.22 / 0.03	58.07 / 0.02
11	5	20	3994	3459	57.27 / 0.11	58.12 / 0.11
12	10	41	2953	2557	57.32 / 0.20	58.16 / 0.19
13	10	16	2953	2557	57.32 / 0.20	58.16 / 0.19
14	15	43	2306	1997	57.37 / 0.29	58.21 / 0.27
15	15	12	2306	1997	57.37 / 0.29	58.21 / 0.27
16	15	33	2306	1997	57.37 / 0.29	58.21 / 0.27
17	20	45	1880	1638	57.41 / 0.37	58.25 / 0.35
18	20	36	1880	1638	57.41 / 0.37	58.25 / 0.35
19	20	38	1880	1638	57.41 / 0.37	58.25 / 0.35

Table.3.- Expected current for the different fault location (cables)

4.3.2 S1 opened

This is the expected situation for this network when a permanent cleared fault has been located between CB1 and S1. The table gives the lowest fault current expected in that configuration. The fault location corresponding to this minimum current is the longest possible path, as indicated in the following draw (35km, short-circuit point 6).

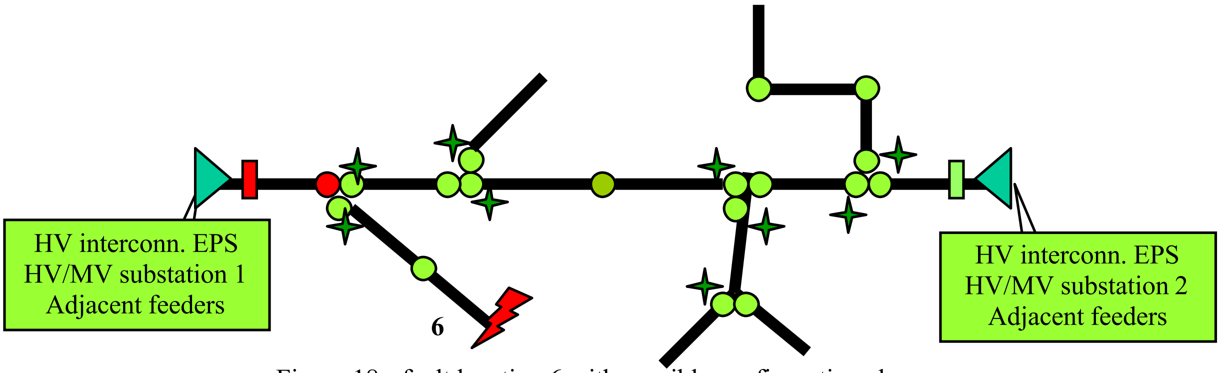

Figure.18.- fault location 6 with possible configuration change

Case with lines for all the conductors sections:
For single-phase fault, the fault current is given with amplitude and phase

location	Distance from subst. (km)	Node name	Three-phase fault (A)	Two-phase fault (A)	Single-phase fault (A) (Rf = 0ohms) A / rd	Single-phase fault (A) (Rf= 20ohms) A / rd
6	35	27	802	694	253 / 1.1	200 / 0.78

Table.4.- Expected current for fault 6 and configuration change (lines)

Case with cables for all the conductors sections:
For single-phase fault, the fault current amplitude (I_M) is given and the imaginary component of current in the parallel resistance of the neutral impedance (Ir_I) is given.

location	Distance from subst. (km)	Node name	Three-phase fault (A)	Two-phase fault (A)	Single-phase fault (A) (Rf = 0ohms) I_M / Ir_I	Single-phase fault (A) (Rf = 20ohms) I_M / Ir_I
6	35	27	1199	1038	57.57 / 0.63	58.39 / 0.58

Table.5.- Expected current for fault 6 and configuration change (cables)

4.3.3 S15 opened

This is the expected situation when a permanent and cleared fault has been located between CB2 and S15. The lowest fault current corresponds to the minimum expected current for all the possible configurations in that network (40km, short-circuit point 17).

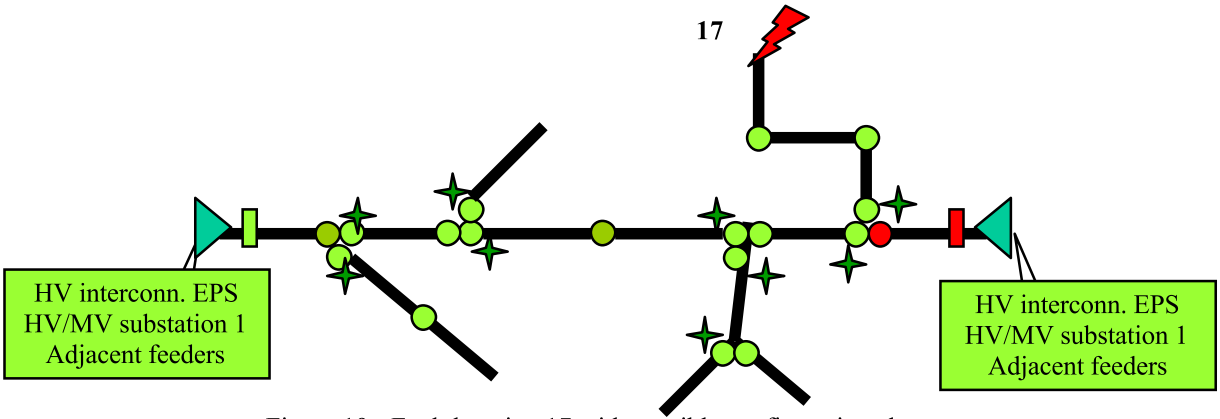

Figure.19.- Fault location 17 with possible configuration change

Case with lines for all the conductors sections:
For single-phase fault, the fault current is given with amplitude and phase

location	Distance from subst. (km)	Node name	Three-phase fault (A)	Two-phase fault (A)	Single-phase fault (A) (Rf = 0ohms) A / rd	Single-phase fault (A) (Rf = 20ohms) A / rd
17	40	45	713	617	232 / 1.11	188 / 0.81

Table.6.- Expected current for fault 17 and configuration change (lines)

Case with cables for all the conductors sections:
For single-phase fault, the fault current amplitude (I_M) is given and the imaginary component of current in the parallel resistance of the neutral impedance (Ir_I) is given.

location	Distance from subst. (km)	Node name	Three-phase fault (A)	Two-phase fault (A)	Single-phase fault (A) (Rf = 0ohms) I_M / Ir_I	Single-phase fault (A) (Rf = 20ohms) I_M / Ir_I
17	40	45	1069	926	57.62 / 0.71	58.44 / 0.66

Table.7.- Expected current for fault 17 and configuration change (cables)

4.4 Scenarios for the tool simulation

Generally, each scenario is composed of three cases:
1/ Three-phase fault,
2/ two-phase fault,
3/ single-phase fault

Some cases are not relevant in the study: a simple sentence will inform the reader in the associated chapter, and will indicate the obvious result. Only selected and relevant scenarios will be selected for the future experiment for testing ICT architecture and components.

The following table summarizes the 8 selected scenarios:

Scenario	Fault location	DR	Lines Impedance grounded neutral	Cables Compensated neutral
1	4		X	
2	4	X	X	
3	4			X
4	4	X		X

5	1 then 6		X	
6	1 then 6	X	X	
7	1 then 6			X
8	1 then 6	X		X

Table.8.- Presentation of scenarios

4.4.1 Scenario 1

All the conductors sections are MV lines. There is no DR in the network.
The neutral is grounded with impedance in order to limit the single-phase fault current.
A fault occurs in a derivation. No reconfiguration is expected in the MV cell, the EPS switch S7 should open.

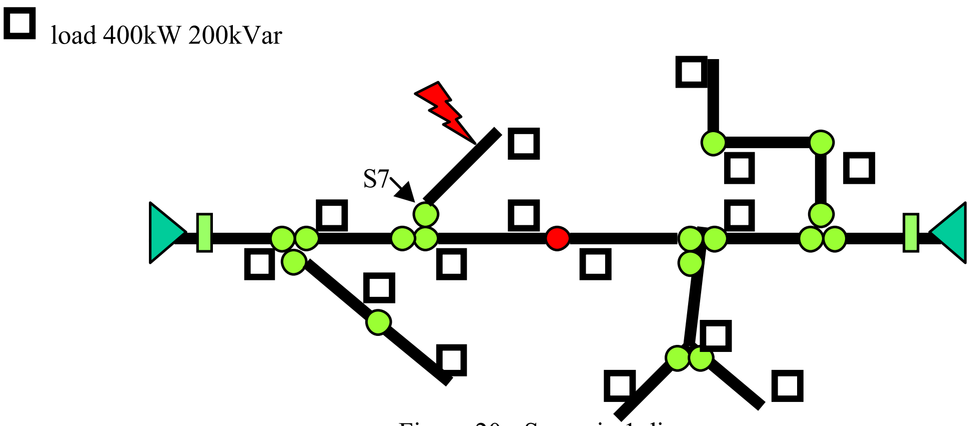

Figure.20.- Scenario 1 diagram

4.4.2 Scenario 2

The same condition as in the scenario 1 but with DR connected in the studied feeders and in the adjacent feeders.
All the conductors sections are MV lines.
The neutral is grounded with impedance in order to limit the single-phase fault current.
A fault occurs in a derivation. No reconfiguration is expected in the MV cell, the EPS switch S7 should open.

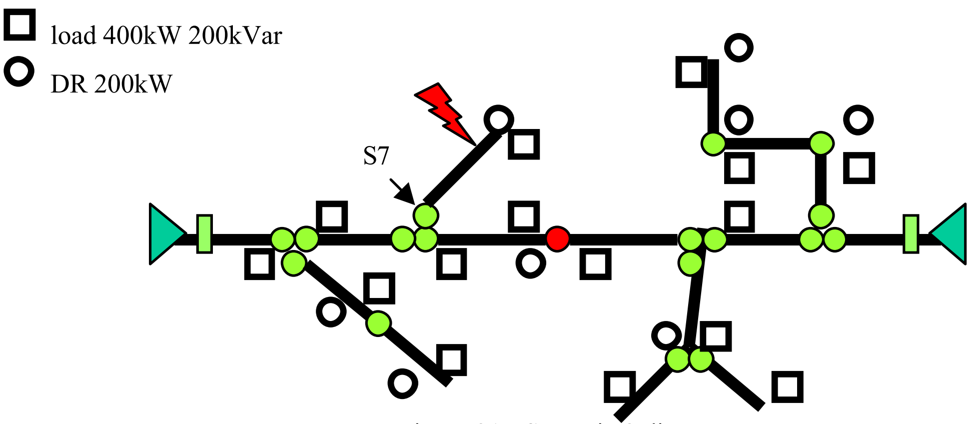

Figure.21.- Scenario 2 diagram

4.4.3 Scenario 3

The same condition as in the scenario 1 but with cables conductors only, compensated neutral and no DR in the network.

The Petersen coil is set to reduce drastically the current (a few amps maximum) caused by the capacitance between the conductors and earth. The current in the fault is mainly circulating in the (parallel) resistance of the neutral grounding system.

4.4.4 Scenario 4

The same condition as in the scenario 3 but with DR inside the local network.

4.4.5 Scenario 5

From the chosen initial situation this scenario describes two steps corresponding to two successive faults. This scenario has no distributed resource (DR) inside the simulated MV cell. The diagnosis tool must be adapted to update the configuration of the network (topology purpose).
All the conductors sections are MV lines.
The neutral is grounded with impedance in order to limit the single-phase fault current.
A fault occurs in the main feeder. A reconfiguration is expected in the MV cell.

4.4.5.1 Step 1: a fault occurs between CB1 and S1

The HTFD located in substation 1 should propose to open CB1 and to open switch S1 to clear the permanent fault. Then it should propose an appropriate sequence to close the switch S8 in order to supply as best as possible the level 1 cell (the appropriate sequence may be in this case : open CB2 – close S8 – close CB2, allowing CB2 to control a possible closing on fault).

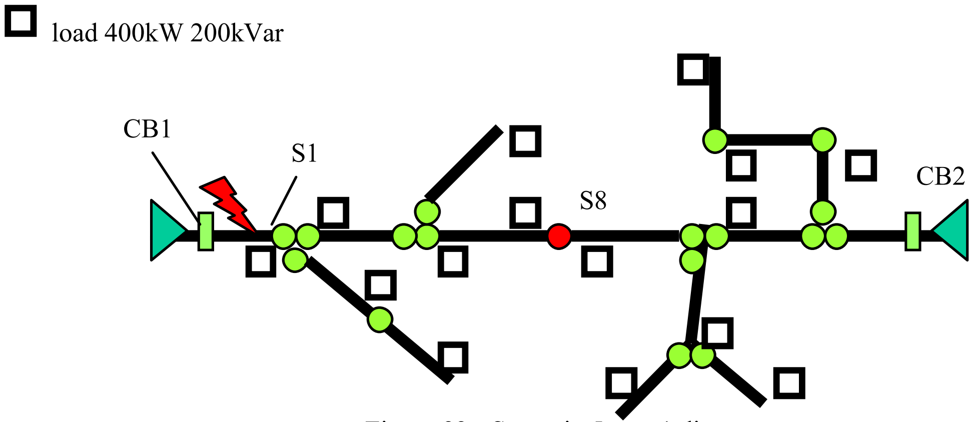

Figure.22.- Scenario 5 step 1 diagram

4.4.5.2 Step 2: a fault occurs after reconfiguration

The cleared section of the network remains not supplied during a while: the new configuration is maintained up to the next fault occurrence. A new fault appears in the network at fault location 6.
The HTFD located in substation 2 should propose to open CB2 and then to open switch S4 in order to clear the permanent fault.

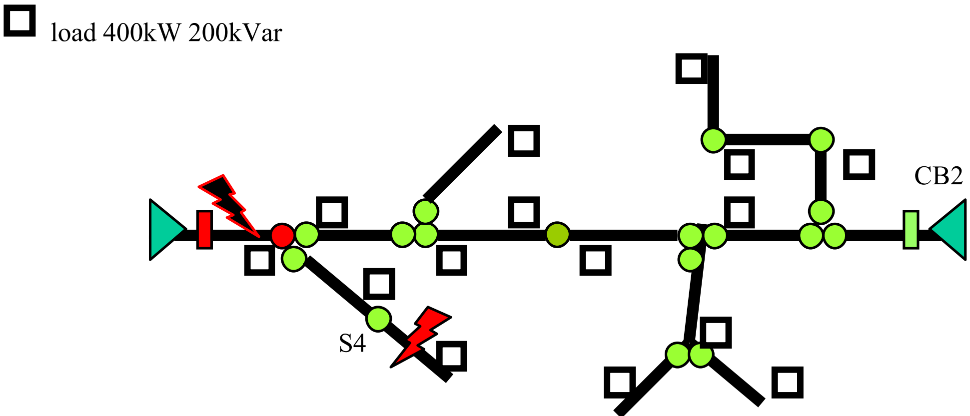

Figure.23.- Scenario 5 step 2 diagram

4.4.6 Scenario 6

The same case as in the scenario 5 is studied but including DR in the simulated network.
All the conductors sections are MV lines. The neutral is grounded with impedance.
A fault occurs in the main feeder. A reconfiguration is expected in the MV cell.
The DR tripped during step1 fault is assumed to be reconnected before the occurrence of the second fault (step2).

4.4.6.1 Step 1: a fault occurs between CB1 and S1

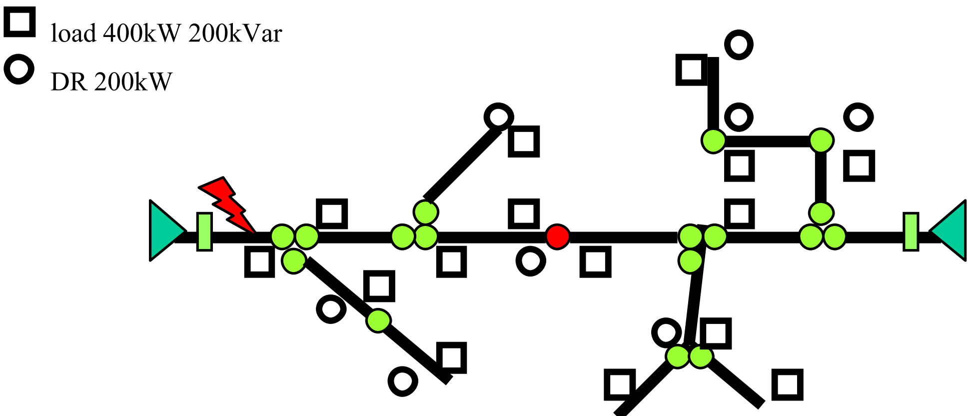

Figure.24.- Scenario 6 step 1 diagram

4.4.6.2 Step 2: : a fault occurs after reconfiguration

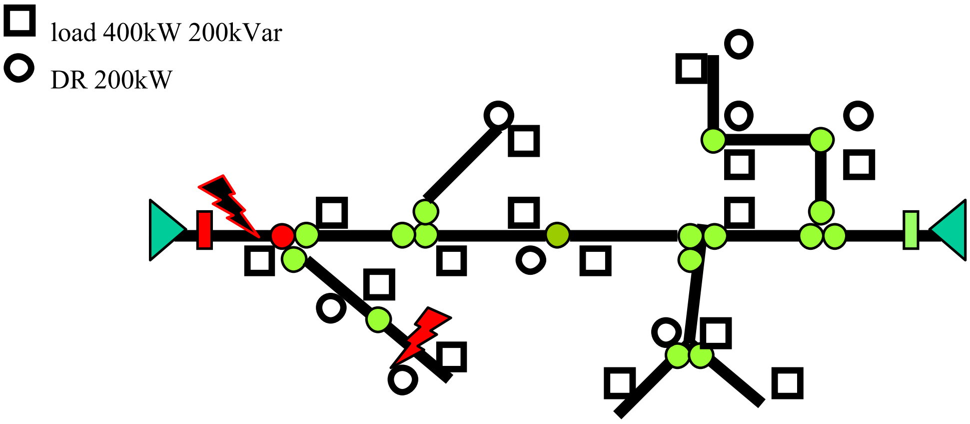

Figure.25.- Scenario 6 step 2 diagram

4.4.7 Scenario 7

The same condition as in the scenario 5 is studied but with cables conductors and compensated neutral. All the conductors sections are MV cables. There is no DR in the network.

4.4.8 Scenario 8

The same condition as in the scenario 6 is studied but with cables conductors and compensated neutral. All the conductors sections are MV cables. Distributed Resources are installed in the MV EPS.

5. Simulation results

The aim of this part is to describe the resulting sequences of the simulation tool for the given scenarios. To keep a simple form of description, very few comments are added and the direct high level information exchange is shown. The detailed description of the conversion of parameters into transmitted format will be given in the document about experiment description (deliverables D3.1 and D3.2). The simulation tool gives the main information exchanged and the local analysis of signals and collected information.
Because some scenarios are more interesting than others, a selection is proposed in chapter 6 to keep the relevant ones for the experiment.

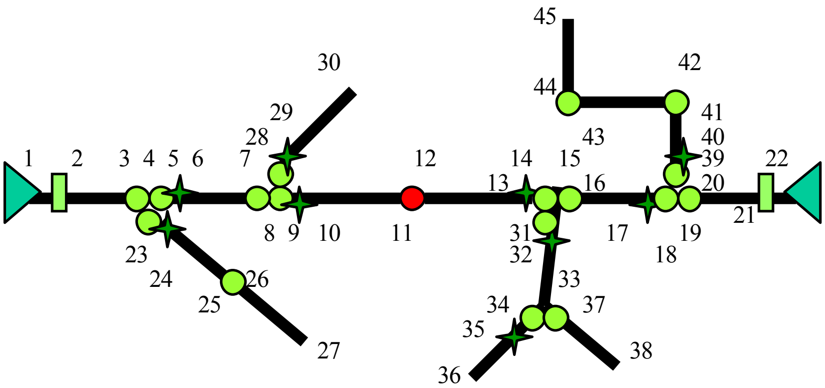

Figure.26.- Nodes names and locations

5.1 Scenario 1

Scenario	Fault location	DR	Lines Impedance grounded neutral	Cables Compensated neutral
1	4		X	

Table.9.- Scenario 1 summary

The type of fault is indicated by the protection system or by the fault recorder.
For the EVATEM evaluation and the process termination,
The reference criteria corresponding to 5% of conductor section impedance is 0.16 for 5km line for three-phase fault and two-phase fault.
The reference criteria corresponding to 5% of conductor section impedance is 0.60 for 5km line for single-phase fault.

5.1.1 Three-phase fault

Case FPI and distance evaluation in normal operation
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7

1596A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 30: -0.03 (||<0.16)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7
The main central ICT component is informed of distance evaluation failure

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure known
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable not identified, after I1>> wait for distance evaluation information

1596A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 7: -22.5 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 30: -0.03 (||<0.16) >> possible location in 30
EVA_TEM3 evaluated at location 11: -0.03 (||<0.16) >> possible location in 11 (meaning FPI I4 in failure)
>> expected location at location 30 (operator informed)

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure unknown
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified, between 6 and 7>> OPEN S2 and S5

1596A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 7: -22.5 (<0 and ||>0.16)
>> WARNING MESSAGE TO TOOL: possible FPI failure
EVA_TEM3 evaluated at location 30: -0.03 (||<0.16) >> possible location in 30 (meaning FPI I3 in failure)
EVA_TEM3 evaluated at location 11: -0.03 (||<0.16) >> possible location in 11 (meaning FPI I4 in failure)
>> expected location at location 30 or 11 (operator informed)

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

1596A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 3: -38.5 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 7: -22.5 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 30: -0.03 (||<0.16) >> possible location in 30
EVA_TEM3 evaluated at location 11: -0.03 (||<0.16) >> possible location in 11
EVA_TEM3 evaluated at location 25: -22.5 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 27: -0.03 (||<0.16) >> possible location in 27

>> expected location at location 30 or 11 or 27 (operator informed)

5.1.2 Two-phase fault

Case FPI and distance evaluation in normal operation
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7

1382A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 30: -0.043 (||<0.16)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7
The main central ICT component is informed of distance evaluation failure

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure known
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable not identified, after I1>> wait for distance evaluation information

1382A is observed at CB1 during fault and value is sent to the main central ICT component

EVA_TEM2 evaluated at location 7: -22.5 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 30: -0.043 (||<0.16) >> possible location in 30
EVA_TEM2 evaluated at location 11: -0.043 (||<0.16) >> possible location in 11 (meaning FPI I4 in failure)
>> expected location at location 30 (operator informed)

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure unknown
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified, between 6 and 7>> OPEN S2 and S5

1382A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 7: -22.5 (<0 and ||>0.16)
>> WARNING MESSAGE TO TOOL: possible FPI failure
EVA_TEM2 evaluated at location 30: -0.043 (||<0.16) >> possible location in 30 (meaning FPI I3 in failure)
EVA_TEM2 evaluated at location 11: -0.043 (||<0.16) >> possible location in 11 (meaning FPI I4 in failure)
>> expected location at location 30 or 11 (operator informed)

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

1382A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 3: -38.6 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 7: -22.5 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 30: -0.043 (||<0.16) >> possible location in 30
EVA_TEM2 evaluated at location 11: -0.043 (||<0.16) >> possible location in 11
EVA_TEM2 evaluated at location 25: -22.5 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 27: -0.043 (||<0.16) >> possible location in 27

>> expected location at location 30 or 11 or 27 (operator informed)

5.1.3 Single-phase fault

Case FPI and distance evaluation in normal operation
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7

266A / 0.6rd is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 30: 0.13 (||<0.6)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7
The main central ICT component is informed of distance evaluation failure

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure known
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable not identified, after I1>> wait for distance evaluation information

266A / 0.6rd is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 7: -11.87 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 30: 0.13 (||<0.6) >> possible location in 30
EVA_TEM1 evaluated at location 11: 0.13 (||<0.6) >> possible location in 11 (meaning FPI I4 in failure also)
>> expected location at location 30 (operator informed)

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure unknown
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified, between 6 and 7>> OPEN S2 and S5

266A / 0.6rd is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 7: -11.87 (<0 and ||>0.6)

>> WARNING MESSAGE TO TOOL: possible FPI failure in the network
EVA_TEM1 evaluated at location 30: 0.13 (||<0.6) >> possible location in 30 (meaning FPI I3 in failure)
EVA_TEM1 evaluated at location 11: 0.13 (||<0.6) >> possible location in 11 (meaning FPI I4 in failure)
>> expected location at location 30 or 11 (operator informed)

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

266A / 0.6rd is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 3: -23.87 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 7: -11.87 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 30: 0.13 (||<0.6) >> possible location in 30
EVA_TEM1 evaluated at location 11: 0.13 (||<0.6) >> possible location in 11
EVA_TEM1 evaluated at location 25: -11.87 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 27: 0.13 (||<0.6) >> possible location in 27

>> expected location at location 30 or 11 or 27 (operator informed)

5.2 Scenario 2

Scenario	Fault location	DR	Lines Impedance grounded neutral	Cables Compensated neutral
2	4	X	X	

Table.10.- Scenario 2 summary

5.2.1 Three-phase fault

DR_30 (located on node 30) faces a solid short-circuit, the voltage being nearly zero at the connection.
DR_11 observes a deep voltage drop, nearly 25% of nominal voltage during the fault.
DR_25 and DR_27 observe a voltage drop, nearly 50% of nominal voltage during the fault.
The voltage at the substation is nearly 75% of nominal voltage during the fault.
The current resulting in the lines due to DR units (nominal current of 6A under 20kV) is too low to entail an indication by the distributed FPI dedicated for phase current measurement: nearly 11A by DR_30 and 9A by DR_25 and DR_27, to compare with possible settings of the FPI thresholds at 490A.

The local DR units in the feeder contribute very few to the short-circuit current (nearly 1600A coming from the interconnected EPS for a fault in node 30). It is quite the same case for the DR located in the adjacent feeders, which contribute to the response at the local drop of voltage at the substation (75% of the nominal voltage). The local balance of power is modified also because of the load response to the voltage drop. The total resulting values on load flow does not change a lot through the adjacent feeders.

As a consequence, the simulation leads to the same results as in scenario 1 for the ICT network exchanges.
>> SEE 5.1.1 scenario 1 three-phase fault

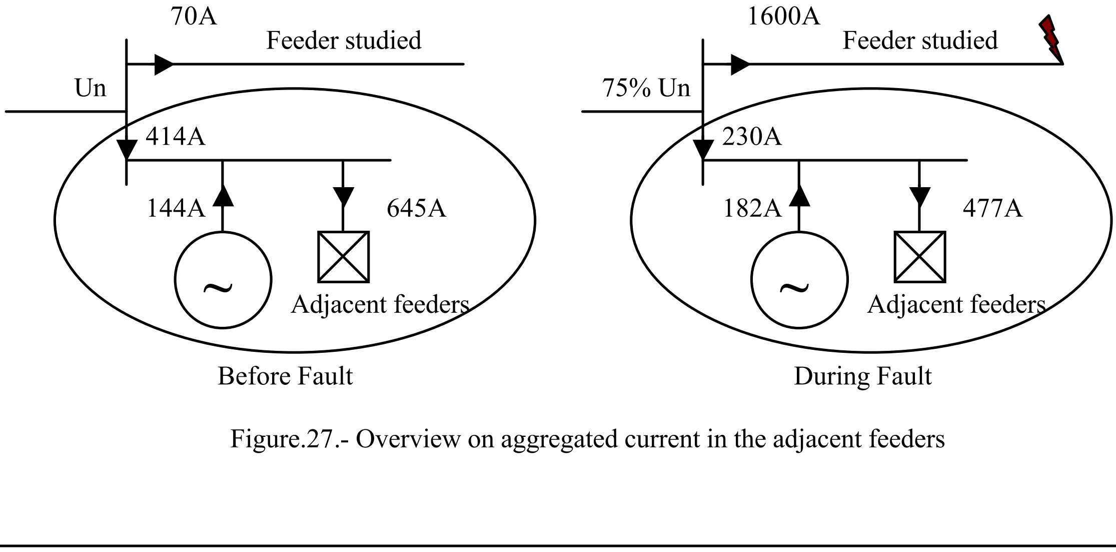

Figure.27.- Overview on aggregated current in the adjacent feeders

5.2.2 Two-phase fault

As for three-phase fault in 5.2.2, the simulation results show a low DR contribution to the fault current compared with the current injected by the interconnected network. The information exchanges in the network is as described in the scenario 1 two-phase fault (SEE 5.1.2).

5.2.3 Single-phase fault

No contribution of the DR to the MV single-phase fault: same results as in the scenario 1 (SEE 5.1.3)

5.3 Scenario 3

Scenario	Fault location	DR	Lines Impedance grounded neutral	Cables Compensated neutral
3	4			X

Table.11.- Scenario 3 summary

The reference criteria corresponding to 5% of conductor section impedance is 0.06 for 5km cable for three-phase fault and two-phase fault.
The reference criteria corresponding to 5% of conductor section impedance is 0.29 for 5km cable for single-phase fault.

5.3.1 Three-phase fault

Case FPI and distance evaluation in normal operation
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7

2306A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 30: 0.006 (||<0.06)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7
The main central ICT component is informed of distance evaluation failure

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure known
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable not identified, after I1>> wait for distance evaluation information

2306A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 7: -9.78 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 30: 0.006 (||<0.06) >> possible location in 30
EVA_TEM3 evaluated at location 11: 0.006 (||<0.06) >> possible location in 11 (meaning FPI I4 in failure)
>> expected location at location 30 (operator informed)

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure unknown
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified, between 6 and 7>> OPEN S2 and S5

2306A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 7: -9.78 (<0 and ||>0.06)
>> WARNING MESSAGE TO TOOL: possible FPI failure
EVA_TEM3 evaluated at location 30: 0.006 (||<0.06) >> possible location in 30 (meaning FPI I3 in failure)
EVA_TEM3 evaluated at location 11: 0.006 (||<0.06) >> possible location in 11 (meaning FPI I4 in failure)
>> expected location at location 30 or 11 (operator informed)

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

1596A is observed at CB1 during fault and value is sent to the main central ICT component

EVA_TEM3 evaluated at location 3: -16.7 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 7: -9.78 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 30: 0.006 (||<0.06) >> possible location in 30
EVA_TEM3 evaluated at location 11: 0.006 (||<0.06) >> possible location in 11
EVA_TEM3 evaluated at location 25: -9.78 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 27: 0.006 (||<0.06) >> possible location in 27

>> expected location at location 30 or 11 or 27 (operator informed)

5.3.2 Two-phase fault

Case FPI and distance evaluation in normal operation
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7

1997A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 30: -0.0045 (||<0.06)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7
The main central ICT component is informed of distance evaluation failure

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure known
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable not identified, after I1>> wait for distance evaluation information

1997A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 7: -9.78 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 30: -0.0045 (||<0.06) >> possible location in 30
EVA_TEM2 evaluated at location 11: -0.0045 (||<0.06) >> possible location in 11 (meaning FPI I4 in failure)
>> expected location at location 30 (operator informed)

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure unknown
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified, between 6 and 7>> OPEN S2 and S5

1997A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 7: -9.78 (<0 and ||>0.06)
>> WARNING MESSAGE TO TOOL: possible FPI failure
EVA_TEM2 evaluated at location 30: -0.0045 (||<0.06) >> possible location in 30 (meaning FPI I3 in failure)
EVA_TEM2 evaluated at location 11: -0.0045 (||<0.06) >> possible location in 11 (meaning FPI I4 in failure)
>> expected location at location 30 or 11 (operator informed)

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

1997A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 3: -16.7 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 7: -9.78 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 30: -0.045 (||<0.06) >> possible location in 30
EVA_TEM2 evaluated at location 11: -0.045 (||<0.06) >> possible location in 11
EVA_TEM2 evaluated at location 25: -9.78 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 27: -0.045 (||<0.06) >> possible location in 27

>> expected location at location 30 or 11 or 27 (operator informed)

5.3.3 Single-phase fault

Case FPI and distance evaluation in normal operation

I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7

22A / 0.012rd is observed in R_PCN during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 30: 0.01 (||<0.29)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure
I1 and I3 sense the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified >> OPEN S7
The main central ICT component is informed of distance evaluation failure

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure known
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable not identified, after I1>> wait for distance evaluation information

22A / 0.012rd is observed in R_PCN during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 7: -5.74 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 30: 0.01 (||<0.29) >> possible location in 30
EVA_TEM1 evaluated at location 11: 0.01 (||<0.29) >> possible location in 11 (meaning FPI I4 in failure also)
>> expected location at location 30 (operator informed)

Case FPI I3 in failure and distance evaluation in normal operation, FPI I3 failure unknown
I1 senses the fault current passage and send information to the main central ICT component
>> elementary faulty cable identified, between 6 and 7>> OPEN S2 and S5

22A / 0.012rd is observed in R_PCN during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 7: -5.74 (<0 and ||>0.29)
>> WARNING MESSAGE TO TOOL: possible FPI failure in the network
EVA_TEM1 evaluated at location 30: 0.01 (||<0.29) >> possible location in 30 (meaning FPI I3 in failure)
EVA_TEM1 evaluated at location 11: 0.01 (||<0.29) >> possible location in 11 (meaning FPI I4 in failure)
>> expected location at location 30 or 11 (operator informed)

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

266A / 0.6rd is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 3: -11.48 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 7: -5.74 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 30: 0.01 (||<0.29) >> possible location in 30
EVA_TEM1 evaluated at location 11: 0.01 (||<0.29) >> possible location in 11
EVA_TEM1 evaluated at location 25: -5.74 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 27: 0.01 (||<0.29) >> possible location in 27

>> expected location at location 30 or 11 or 27 (operator informed)

5.4 Scenario 4

Scenario	Fault location	DR	Lines Impedance grounded neutral	Cables Compensated neutral
4	4	X		X

Table.12.- Scenario 4 summary

5.4.1 Three-phase fault

Simulation results similar to scenario 3 three-phase fault: same ICT process for information exchanges (SEE 5.3.1)

5.4.2 Two-phase fault

Simulation results similar to scenario 3 three-phase fault: same ICT process for information exchanges (SEE 5.3.2)

5.4.3 Single-phase fault

No contribution of the DR to the MV single-phase fault: same results as in the scenario 3 for exchanges between ICT components (SEE 5.3.3)

5.5 Scenario 5

Scenario	Fault location	DR	Lines Impedance grounded neutral	Cables Compensated neutral
5	1, 6		X	

Table.13.- Scenario 5 summary

The reference criteria corresponding to 5% of conductor section impedance is 0.16 for 5km line for three-phase fault and two-phase fault.
The reference criteria corresponding to 5% of conductor section impedance is 0.60 for 5km line for single-phase fault.

5.5.1 Three-phase fault

5.5.1.1Step 1

Case FPI and distance evaluation in normal operation
No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)

3110A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 3: -0.00086 (||<0.16)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure
No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)
The main central ICT component is informed of distance evaluation failure

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

3110A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 3: -0.00086 (||<0.16)
>> expected location at location 3 or very close
>> OPEN S1 and try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8

OK for the current test, the remaining process in the algorithm should be:
2/ if fault is not observed >> OPEN CB1, CLOSE S1, OPEN S3,
>> try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> OPEN S2, OPEN S5, CLOSE S3, CLOSE S8, CLOSE CB1 (CB2 assumed closed)
(elementary fault location identified)
2/ if fault is not observed >> elementary fault detected, expected location near 24

5.5.1.2Step 2

The reference criteria corresponding to 5% of conductor section impedance is 0.16 for 5km line.
New configuration in the MV cell is updated by the support to decision tool (in the main central ICT component)

Case FPI and distance evaluation in normal operation
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
    >> fault between nodes 24 and 27, elementary faulty cable not identified

802A is observed at CB2 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 25: -48.4 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 27: 0.079 (||<0.16)
>> expected location at receiving end of the faulty identified cable (operator informed) : node 27
    >> OPEN S4 and close CB2

Case FPI in normal operation and distance evaluation in failure
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
    >> fault between nodes 24 and 27, elementary faulty cable not identified : (24-25) or (26-27)

The main central ICT component is informed of distance evaluation failure
    >> OPEN S4 and close CB2
    >> if fault still remains with same FPI information, elementary faulty cable identified: (24-25)
        >> OPEN S3 and close CB2

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

802A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 20: -193.5 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 41: -177.5 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 43: -155. (<0 and ||>0.16)
EVA_TEM3 evaluated at location 45: -126. (<0 and ||>0.16)
EVA_TEM3 evaluated at location 16: -177.5 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 33: -155. (<0 and ||>0.16)
EVA_TEM3 evaluated at location 36: -126. (<0 and ||>0.16)
EVA_TEM3 evaluated at location 38: -126. (<0 and ||>0.16)
EVA_TEM3 evaluated at location 12: -155. (<0 and ||>0.16)
EVA_TEM3 evaluated at location 10: -126. (<0 and ||>0.16)
EVA_TEM3 evaluated at location 30: -90.5 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 6: -90.5 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 25: -48.4 (<0 and ||>0.16)
EVA_TEM3 evaluated at location 27: 0.079 (||<0.16)
>> expected location at location 27 or very close (elementary faulty cable identified)
>> OPEN S4 and reclose CB2

5.5.2 Two-phase fault

5.5.2.1Step 1

Case FPI and distance evaluation in normal operation
No information from FPI sent to the main central ICT component
    >> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)

2693A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 3: -0.0043 (||<0.16)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure

No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)
The main central ICT component is informed of distance evaluation failure

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

2693A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 3: -0.0043 (||<0.16)
>> expected location at location 3 or very close
>> OPEN S1 and try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8

OK for the current test, the remaining process in the algorithm should be:
2/ if fault is not observed >> OPEN CB1, CLOSE S1, OPEN S3,
>> try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> OPEN S2, OPEN S5, CLOSE S3, CLOSE S8, CLOSE CB1 (CB2 assumed closed)
(elementary fault location identified)
2/ if fault is not observed >> elementary fault detected, expected location near 24

5.5.2.2Step 2

New configuration in the MV cell is updated by the support to decision tool (in the main central ICT component)
The reference criteria corresponding to 5% of conductor section impedance is 0.16 for 5km line.

Case FPI and distance evaluation in normal operation
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
>> fault between nodes 24 and 27, elementary faulty cable not identified

694A is observed at CB2 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 25: -48.8 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 27: -0.25 (<0 and ||>0.16)
>> WARNING: the node 27 is the most remote point (electrical meaning)… result corresponds to 8% section
>> expected location at receiving end of the faulty identified cable (operator informed) : node 27
>> OPEN S4 and close CB2

Case FPI in normal operation and distance evaluation in failure
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
>> fault between nodes 24 and 27, elementary faulty cable not identified : (24-25) or (26-27)

The main central ICT component is informed of distance evaluation failure
>> OPEN S4 and close CB2
>> if fault still remains with same FPI information, elementary faulty cable identified: (24-25)
>> OPEN S3 and close CB2

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

694A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 20: -193.8 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 41: -177.8 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 43: -155.3 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 45: -126.3 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 16: -177.8 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 33: -155.3 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 36: -126.3 (<0 and ||>0.16)

EVA_TEM2 evaluated at location 38: -126.3 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 12: -155.3 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 10: -126.3 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 30: -90.8 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 6: -90.8 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 25: -48.8 (<0 and ||>0.16)
EVA_TEM2 evaluated at location 27: 0.25 (<0 and ||>0.16)
>> WARNING: the node 27 is the most remote point (electrical meaning)… result corresponds to 8% section
>> expected location at location 27 or very close (elementary faulty cable identified)
>> OPEN S4 and reclose CB2

5.5.3 Single-phase fault

5.5.3.1Step 1

Case FPI and distance evaluation in normal operation
No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)

311A / 0.46rd is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 3: 0.22 (||<0.6)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure
No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)
The main central ICT component is informed of distance evaluation failure

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

311A / 0.46rd is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 3: 0.22 (||<0.6)
>> expected location at location 3 or very close
>> OPEN S1 and try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8

OK for the current test, the remaining process in the algorithm should be:
2/ if fault is not observed >> OPEN CB1, CLOSE S1, OPEN S3,
>> try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> OPEN S2, OPEN S5, CLOSE S3, CLOSE S8, CLOSE CB1 (CB2 assumed closed)
(elementary fault location identified)
2/ if fault is not observed >> elementary fault detected, expected location near 24

5.5.3.2Step 2

The reference criteria corresponding to 5% of conductor section impedance is 0.6 for 5km line.
New configuration in the MV cell is updated by the support to decision tool (in the main central ICT component)

Case FPI and distance evaluation in normal operation
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
>> fault between nodes 24 and 27, elementary faulty cable not identified

200A / 0.78rd is observed at CB2 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 25: -12.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 27: -0.15 (||<0.6)
>> expected location at receiving end of the faulty identified cable (operator informed) : node 27
>> OPEN S4 and close CB2

Case FPI in normal operation and distance evaluation in failure
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
>> fault between nodes 24 and 27, elementary faulty cable not identified : (24-25) or (26-27)

The main central ICT component is informed of distance evaluation failure
>> OPEN S4 and close CB2
>> if fault still remains with same FPI information, elementary faulty cable identified: (24-25)
>> OPEN S3 and close CB2

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

200A / 0.78rd is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 20: -72.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 41: -60.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 43: -48.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 45: -36.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 16: -60.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 33: -48.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 36: -36.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 38: -36.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 12: -48.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 10: -36.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 30: -24.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 6: -24.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 25: -12.15 (<0 and ||>0.6)
EVA_TEM1 evaluated at location 27: -0.15 (||<0.6)
>> expected location at location 27 or very close (elementary faulty cable identified)
>> OPEN S4 and reclose CB2

5.6 Scenario 6

Scenario	Fault location	DR	Lines Impedance grounded neutral	Cables Compensated neutral
6	1, 6	X	X	

Table.14.- Scenario 6 summary

The reference criteria corresponding to 5% of conductor section impedance is 0.16 for 5km line for three-phase fault and two-phase fault.
The reference criteria corresponding to 5% of conductor section impedance is 0.60 for 5km line for single-phase fault.

5.6.1 Three-phase fault

5.6.1.1Step 1

DR_30 (located on node 30), DR_11, DR_25 and DR_27 face a solid short-circuit, the voltage being nearly zero at the connection: the fault located in 3 has a high impact on the voltage of all the nodes of the feeder.
The voltage at the substation is nearly 48% of nominal voltage during the fault.
The current resulting in the lines due to DR units (nominal current of 6A under 20kV) depends on the excitation of the generators if they are synchronous machines (neglected fault current contribution in case of inverter or induction machine connected to the network). An extreme case is to assume a current of 6 times the nominal

value, it means a 36A by generating unit. Comparing with the possible settings of the FPI thresholds (490A for instance), there is no possible wrong indication due to the distributed DR.

The local DR units in the feeder contribute very few to the short-circuit current (nearly 3100A coming from the interconnected EPS for a fault at node 3). It is quite the same case for the DR located in the adjacent feeders, which contribute to the response at the local drop of voltage at the substation (48% of the nominal voltage). The local balance of power is modified also because of the load response to the voltage drop, as described in 5.2.1.

As a consequence, the simulation leads to the same results as in scenario 5 for the ICT network exchanges.
>> SEE 5.5.1 step 1

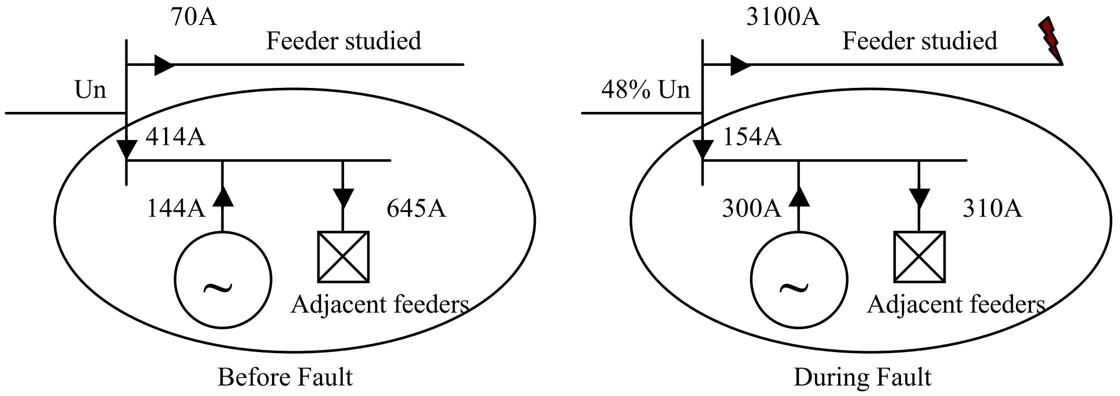

Figure.28.- Overview on aggregated current in the adjacent feeders

5.6.1.2Step 2

New configuration in the MV cell is updated by the support to decision tool (in the main central ICT component) The reference criteria corresponding to 5% of conductor section impedance is 0.16 for 5km line.

The fault entails a new voltage distribution in the network, the distributed DR of the network being impacted differently depending on the location of the connection. During the fault the distribution expected is:

node	Voltage (% nominal)
27	0
25	12.5
6	25
10	37.5
12	50
16	62.5
20	75
22	87.5

The DR located in nodes 25 and 27 are the most impacted due to the deep voltage drop. The contribution to the short-circuit current does not change the indication of the FPI in the studied case. In any case, if the DR units may indicate a fault in a branch not faulted, the power direction given by the device allows the software to treat correctly the indication.

So this scenario leads to the same result for the ICT exchanges as presented in same case without DR: SEE chapter 5.5.1

5.6.2 Two-phase fault

As for three-phase fault described in 5.6.1, there is no additional information exchanged by the ICT components. For the simulation results, SEE chapter 5.5.2

5.6.3 Single-phase fault

No contribution of the DR to the MV single-phase fault: same results as in the scenario 5

5.7 Scenario 7

Scenario	Fault location	DR	Lines Impedance grounded neutral	Cables Compensated neutral
7	1,6			X

Table.15.- Scenario 7 summary

The reference criteria corresponding to 5% of conductor section impedance is 0.06 for 5km line for three-phase fault and two-phase fault.
The reference criteria corresponding to 5% of conductor section impedance is 0.29 for 5km line for single-phase fault.

5.7.1 Three-phase fault

5.7.1.1Step 1

Case FPI and distance evaluation in normal operation
No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)

3994A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 3: -0.0014 (||<0.06)
>> expected location at receiving end of the faulty identified cable (operator informed) : near node 3

Case FPI in normal operation and distance evaluation in failure
No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified : (2-3)

The main central ICT component is informed of distance evaluation failure

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

3994A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 3: -0.0014 (||<0.06)
>> expected location at location 3 (or near)
>> OPEN S1 and try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8

OK for the current test, the remaining process in the algorithm should be:
2/ if fault is not observed >> OPEN CB1, CLOSE S1, OPEN S3,
>> try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> OPEN S2, OPEN S5, CLOSE S3, CLOSE S8, CLOSE CB1 (CB2 assumed closed)
(elementary fault location identified)
2/ if fault is not observed >> elementary fault detected, expected location near 24

5.7.1.2Step 2

New configuration in the MV cell is updated by the support to decision tool (in the main central ICT component)
The reference criteria corresponding to 5% of conductor section impedance is 0.06 for 5km line.

Case FPI and distance evaluation in normal operation
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
>> fault between nodes 24 and 27, elementary faulty cable not identified

1199A is observed at CB2 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 25: -21.2 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 27: -0.031 (||<0.06)
>> expected location at receiving end of the faulty identified cable (operator informed) : node 27
>> OPEN S4 and close CB2

Case FPI in normal operation and distance evaluation in failure
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
>> fault between nodes 24 and 27, elementary faulty cable not identified : (24-25) or (26-27)

The main central ICT component is informed of distance evaluation failure
>> OPEN S4 and close CB2
>> if fault still remains with same FPI information, elementary faulty cable identified: (24-25)
>> OPEN S3 and close CB2

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

1199A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM3 evaluated at location 20: -84.4 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 41: -77.4 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 43: -67.7 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 45: -55. (<0 and ||>0.06)
EVA_TEM3 evaluated at location 16: -77.4 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 33: -67.7 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 36: -55. (<0 and ||>0.06)
EVA_TEM3 evaluated at location 38: -55. (<0 and ||>0.06)
EVA_TEM3 evaluated at location 12: -67.7 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 10: -55. (<0 and ||>0.06)
EVA_TEM3 evaluated at location 30: -39.5 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 6: -39.5 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 25: -21.2 (<0 and ||>0.06)
EVA_TEM3 evaluated at location 27: 0.031 (||<0.06)
>> expected location at location 27 or very close (elementary faulty cable identified)
>> OPEN S4 and reclose CB2

5.7.2 Two-phase fault

5.7.2.1Step 1

Case FPI and distance evaluation in normal operation
No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)

3459A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 3: -0.00094 (||<0.06)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure
No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)
The main central ICT component is informed of distance evaluation failure

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

3459A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 3: -0.00094 (||<0.06)
>> expected location at location 3 or very close
>> OPEN S1 and try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8

OK for the current test, the remaining process in the algorithm should be:
2/ if fault is not observed >> OPEN CB1, CLOSE S1, OPEN S3,
>> try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> OPEN S2, OPEN S5, CLOSE S3, CLOSE S8, CLOSE CB1 (CB2 assumed closed)
(elementary fault location identified)
2/ if fault is not observed >> elementary fault detected, expected location near 24

5.7.2.2Step 2

New configuration in the MV cell is updated by the support to decision tool (in the main central ICT component)
The reference criteria corresponding to 5% of conductor section impedance is 0.06 for 5km cable.

Case FPI and distance evaluation in normal operation
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
>> fault between nodes 24 and 27, elementary faulty cable not identified

1038A is observed at CB2 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 25: -21.3 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 27: -0.0965 (<0 and ||>0.06)
>> WARNING: the node 27 is the most remote point (electrical meaning)… result corresponds to 8% section
>> expected location at receiving end of the faulty identified cable (operator informed) : node 27
>> OPEN S4 and close CB2

Case FPI in normal operation and distance evaluation in failure
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
>> fault between nodes 24 and 27, elementary faulty cable not identified : (24-25) or (26-27)

The main central ICT component is informed of distance evaluation failure
>> OPEN S4 and close CB2
>> if fault still remains with same FPI information, elementary faulty cable identified: (24-25)
>> OPEN S3 and close CB2

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

1038A is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM2 evaluated at location 20: -84.4 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 41: -77.5 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 43: -67.7 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 45: -55.1 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 16: -77.5 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 33: -67.7 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 36: -55.1 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 38: -55.1 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 12: -155.3 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 10: -55.1 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 30: -39.6 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 6: -39.6 (<0 and ||>0.06)

EVA_TEM2 evaluated at location 25: -21.3 (<0 and ||>0.06)
EVA_TEM2 evaluated at location 27: -0.0965 (<0 and ||>0.06)
>> WARNING: the node 27 is the most remote point (electrical meaning)… result corresponds to 8% section
>> expected location at location 27 or very close (elementary faulty cable identified)
>> OPEN S4 and reclose CB2

5.7.3 Single-phase fault

5.7.3.1Step 1

Case FPI and distance evaluation in normal operation
No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)

22A / 0.0047rd is observed in R_PCN during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 3: 0.01 (||<0.29)
>> expected location at receiving end of the faulty identified cable (operator informed)

Case FPI in normal operation and distance evaluation in failure
No information from FPI sent to the main central ICT component
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8
(elementary faulty cable identified)
The main central ICT component is informed of distance evaluation failure

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

22A / 0.0047rd is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 3: 0.01 (||<0.29)
>> expected location at location 3 or very close
>> OPEN S1 and try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> CB1 assigned OPEN, S1 assigned OPEN, CLOSE S8

OK for the current test, the remaining process in the algorithm should be:
2/ if fault is not observed >> OPEN CB1, CLOSE S1, OPEN S3,
>> try reclosing CB1:
1/ if fault is still observed, protection makes trip CB1
>> OPEN S2, OPEN S5, CLOSE S3, CLOSE S8, CLOSE CB1 (CB2 assumed closed)
(elementary fault location identified)
2/ if fault is not observed >> elementary fault detected, expected location near 24

5.7.3.2Step 2

New configuration in the MV cell is updated by the support to decision tool (in the main central ICT component)
The reference criteria corresponding to 5% of conductor section impedance is 0.29 for 5km cable.

Case FPI and distance evaluation in normal operation
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
>> fault between nodes 24 and 27, elementary faulty cable not identified

21.9A / 0.027rd is observed at CB2 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 25: -6.56 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 27: -0.81 (<0 and ||>0.29)
>> WARNING value out of 5% range for the longest section, evaluation with node 27: 14%
>> expected location at receiving end of the faulty identified cable (operator informed) : node 27
>> OPEN S4 and close CB2

Case FPI in normal operation and distance evaluation in failure
Fault indication from FPI I2, I1, I4, I5, I8 sent to the main central ICT component
>> fault between nodes 24 and 27, elementary faulty cable not identified : (24-25) or (26-27)

The main central ICT component is informed of distance evaluation failure
>> OPEN S4 and close CB2
>> if fault still remains with same FPI information, elementary faulty cable identified: (24-25)
>> OPEN S3 and close CB2

Case all FPI in failure and distance evaluation in normal operation,
No information from FPI

21.9A / 0.027rd is observed at CB1 during fault and value is sent to the main central ICT component
EVA_TEM1 evaluated at location 20: -35.29 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 41: -29.54 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 43: -23.8 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 45: -18.05 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 16: -29.54 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 33: -23.8 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 36: -18.05 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 38: -18.05 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 12: -23.8 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 10: -18.05 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 30: -12.31 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 6: -12.31 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 25: -6.56 (<0 and ||>0.29)
EVA_TEM1 evaluated at location 27: -0.81 (<0 and ||>0.29)
>> WARNING value out of 5% range for the longest section, evaluation with node 27: 14%
>> expected location at location 27 or very close (elementary faulty cable identified)
>> OPEN S4 and reclose CB2

5.8 Scenario 8

Scenario	Fault location	DR	Lines Impedance grounded neutral	Cables Compensated neutral
8	1,6	X		X

Table.16.- Scenario 8 summary

The reference criteria corresponding to 5% of conductor section impedance is 0.06 for 5km cable for three-phase fault and two-phase fault.
The reference criteria corresponding to 5% of conductor section impedance is 0.29 for 5km cable for single-phase fault.

5.8.1 Three-phase fault

5.8.1.1Step 1

The results of simulation are quite similar to results of chapter 5.6.1
DR_30 (located on node 30), DR_11, DR_25 and DR_27 face a solid short-circuit, the voltage being nearly zero at the connection: the fault located in 3 has a high impact on the voltage of all the nodes of the feeder.
The voltage at the substation is nearly 48% of nominal voltage during the fault.
The current resulting in the lines due to DR units (nominal current of 6A under 20kV) depends on the excitation of the generators if they are synchronous machines (neglected fault current contribution in case of inverter or induction machine connected to the network). An extreme case is to assume a current of 6 times the nominal value, it means a 36A by generating unit. Comparing with the possible settings of the FPI thresholds (490A for instance), there is no possible wrong indication due to the distributed DR.

The local DR units in the feeder contribute very few to the short-circuit current (nearly 3970A coming from the interconnected EPS for a fault at node 3). It is quite the same case for the DR located in the adjacent feeders, which contribute to the response at the local drop of voltage at the substation (48% of the nominal voltage). The local balance of power is modified also because of the load response to the voltage drop, as described in 5.2.1.

As a consequence, the simulation leads to the same results as in scenario 5 for the ICT network exchanges.
>> SEE 5.5.1 step 1

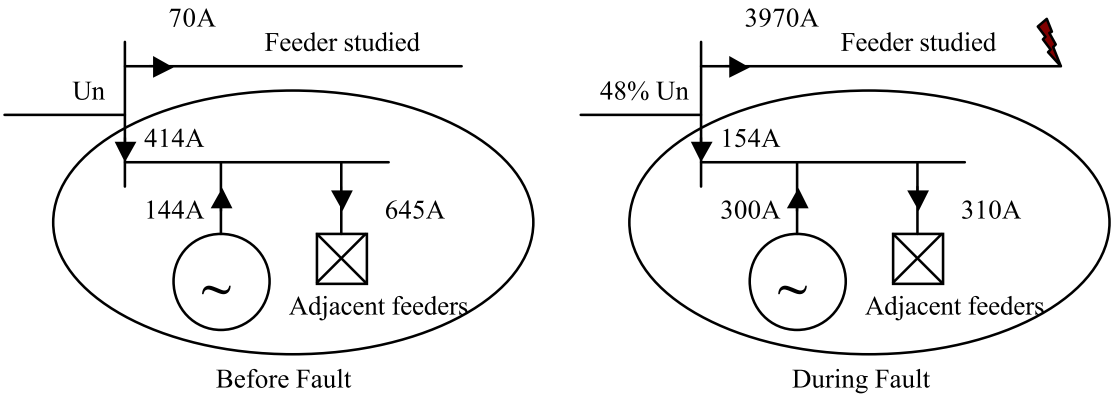

Figure.29.- Overview on aggregated current in the adjacent feeders

5.8.1.2Step 2

New configuration in the MV cell is updated by the support to decision tool (in the main central ICT component) The reference criteria corresponding to 5% of conductor section impedance is 0.29 for 5km cable.

The fault entails a new voltage distribution in the network, the distributed DR of the network being impacted differently depending on the location of the connection. During the fault the distribution expected is:

node	Voltage (% nominal)
27	0
25	12.4
6	24.7
10	37.
12	49.4
16	61.8
20	74
22	86.5

Table.17.- Voltage profile during fault

The DR located in nodes 25 and 27 are the most impacted due to the deep voltage drop. The contribution to the short-circuit current does not change the indication of the FPI in the studied case. In any case, if the DR units may indicate a fault in a branch not faulted, the power direction given by the device allows the software to treat correctly the indication.

So this scenario leads to the same result for the ICT exchanges as presented in same case without DR: SEE chapter 5.6.1

5.8.2 Two-phase fault

As for three-phase fault described in 5.8.1, there is no additional information exchanged by the ICT components compared with simulation described in 5.7.2. For the simulation results, SEE chapter 5.7.2

5.8.3 Single-phase fault

No contribution of the DR to the MV single-phase fault: same results for ICT components exchanges as in the scenario 7 (SEE 5.7.3)

6. Selection of the scenarios for experiment

This chapter gives the main scenarios (taken into the previous 8 scenarios) which are expected to be used in order to test the real ICT. During tests additional tests will be produced depending on the observed and analysed results.

The 8 scenarios show some various kinds of results depending on conductors types, grounding systems and insertion or not with distributed resources. The main characteristics investigated during experiments for ICT components may be derived from scenarios 1 and 5.

A more detailed description is needed for the time sequences at the ICT components inputs. This description is described in the document associated to the experiment. The following table gives a summary of scenario 1 with an activity diagram. The four ICT components involved in the experiment are underlined.

Event	FPI	FR	SW	CB1	Protection system	HTFD	Operator
Fault 4							
	*(I3,				*>open		Warning
	* I1)			*open CB	CB	* (I3)	Warning
	*	*(files_input)				* (I1) (CB op.)	*
	*	*				*	*
		*				*	*
		*(files_output)				* (FR)	*
						*	*
						* >open S7	*
						*	*>open S7
			*open S7			*	*
						*(S7 op.)	*(S7 op.)
						*>new topo.	*>closeCB
				*close CB		*	*
						*	*fault cleared
						*>history	

Table.18.- Activity diagram for scenario 1

7. Conclusion

A description of a fault localization tool for MV network has been presented. This tool is intended to use intensively ICT capabilities in terms of analysis and communication. The main aspect described in this document is about the electro technical part of the solution: topology description, electrical assumption in a typical given MV network, grid description for the simulation tool and experimental purpose, description and principle of the algorithm of localization.
The different existing neutral connections make difficult the achievement of a general method for any distribution EPS. The aim of this document is to bring some relevant information about the limitation of this kind of method, depending on the accuracy of the measurements and the associated computed analysis.

An interest of the simulation produced is to take into account reconfiguration aspects, making more relevant the use of a IP information network to share properly the information among a given part of power system.

When going through the experiment phase, this simulation tool allows us to define an expected time schedule for ICT components inputs/outputs, gives us information about the expected accuracy for the values sent and analysed, and gives also the expected accuracy of the localization tool results (depending also on the errors accumulated in the assumptions associated to the chosen calculation and the difference between the electrical assumptions and the actual components in the network).

The main achievement is to present the expected information exchanges between the different ICT components for a given application and for typical scenarios. A systematic approach has been followed for the proposed scenarios, showing that several cases have similar expectations in term of data exchanges and localization process.

This deliverable is useful to enter in the detailed description of the requirements for the real ICT components needed for the application.