MAKING FAULTS TO PROTECT POWER NETWORKS

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ABSTRACT

Today, distribution networks are supposed to be reliable enough to prevent major power disruptions, but is this true? How can we be sure that distribution networks really are correctly protected? How can we be sure that faults are correctly isolated and service restored in a minimum time?

Standardization and testing would be the normal answer to that question for network components under strictly controlled laboratory environments. However, the problem arises when we wish to "type test" complete networks, including increasingly complex digital devices, their associated software and communication systems, to verify the correct performance of the whole protection system.

Traditionally, these functional tests are carried out through simulation or on real networks when the operator allows it. For this, we decided to build a 'laboratory', called Demonstration and Experimentation Unit (UDEX), a real grid designed as a platform for the research, development and verification of new technologies, products, services and systems. It permits the reproduction of normal conditions and anomalous situations such as network failures.

To highlight the methodology, capabilities and benefits of such infrastructures, we present one particular case study dealing with aspects of the distribution automation application, FLISR (Fault Location Isolation and Service Restoration).

INTRODUCTION

Type testing is mandatory to assess the performance of single components or functionality. In essence it splits real-life problems down into a sequence of "easier-to-solve" simplifications. This 'necessary' simplification is normally studied by scientific experts and agreed within technical committees of standardization institutions who issue the corresponding standards. It is to be noted that these simplifications are strongly conditioned by the state of the art of testing laboratories and techniques. The type testing is consequently carried out in strictly controlled laboratory conditions.

Here we address the problem of functional testing under real network conditions which traditionally are carried out on real networks only when the operator allows it and only after the equipment has passed its individual type test, where applicable.

Typically, these functional tests are complicated, performed under difficult to control conditions and not very operational, requiring the installation and removal of equipment, performing the tests, and finally restoring the grid to its original state. For this, we decided to build a 'laboratory', called Demonstration and Experimentation Unit (UDEX), a real grid designed as a platform for the research, development and verification of new technologies, products, services and systems. It permits the reproduction of normal conditions and anomalous situations such as network failures, e.g. a short circuit, by connecting with our High Power Laboratory (HPL), powered by a short circuit generator (SCG) of 2500 MVA, providing the power needed to produce real medium voltage operating conditions, in a non-risk environment.

We present one particular case study dealing with protection aspects of the distribution automation application FLISR (Fault Location Isolation and Service Restoration). This is a key application for optimising the deployment of maintenance teams in the field, so reducing maintenance costs and times, and subsequently leading to significant reductions in outage time for end users. This is a well-known application and much has been published related to verification of algorithms, components, and systems. However, these deal principally with simulation, co-simulation, hardware-in-the-loop (HIL), etc. [1-3] and there is little or no information related to real network verification testing of this application. Here we present results of performing real faults on a MV grid highlighting the benefits of this type of infrastructure for development and validation testing prior to field application.

BACKGROUND

Actual test practices

Type testing of single components is the typical way to prove the performance of power systems. For high power testing a very special installation [4] is required, including a short circuit generator able to provide the test circuit with the severest possible conditions that can occur in an electrical network, and with the required regulation of being capable of reproducing the nominal and short circuit conditions of a medium voltage electrical network on the DUT (Device Under Test).

Two independent systems are used for the control of the laboratory and for the test measurements:

(1) Laboratory Management System (LMS)

The LMS prevents any dangerous use of the installation, ensuring the integrity of the laboratory through trips and alarms coming from the different sensors transmitting the pressure, temperature, oil level, vibration, arc presence, etc.

(2) Measuring system.

This system gathers all specified information, including the test data in order to report the test results. The signals captured by the various sensors are transformed into optical signals and transmitted to the control room by means of fibre optic cables.

Brief Description of UDEX

The main purpose of the UDEX is to make experiments in a real MV network (Figure 1) having a high degree of flexibility, independent of the utility network, for the development and testing of new technologies. It is able to reproduce normal conditions of existing worldwide MV networks as well as anomalous situations, such as network failures.

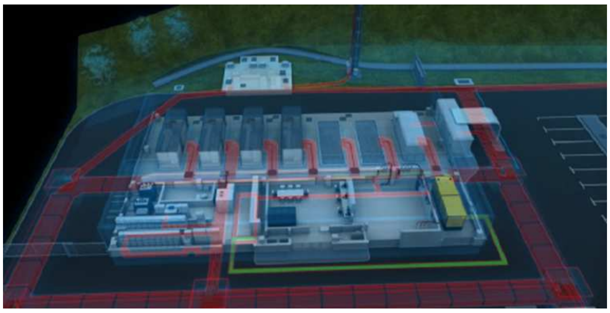

Figure 1 Image of UDEX showing network component and cable infrastructure which provides configuration flexibility.

This concept of a highly configurable medium voltage network for development and testing of new technologies not only contemplates equipment testing, as with standard laboratory testing, but also embraces solutions and applications for network infrastructures, e.g. [5]. These include, in particular for this application, electrical protections and automation performance validation during fault conditions.

In the same way as in the HPL, for the control of the installation, and measuring of the test results the following two systems were installed:
(1) UDEX Management System (UMS)
(2) Data Acquisition System (DAS)

The UMS monitors and manages all the equipment and components in the UDEX laboratory, in a safe and efficient way. Information of all laboratory systems is available for the operator in the Control Room and/or in the Remote Operation Centre (ROC), according to the Figure 2.

In the UDEX several locations to place new equipment or components are distinguished:
- Primary substations CS1, CS2
- Transformer substations CT1, CT2, CT3, CT4, CT5
- Spare test bays for new Transformer substations
- Test bay

Test bay and Transformer substations are operated and monitored from the same operator console.
From the UMS it is possible to program settings in all subsystems such as DAS and any other control system.

While the UDEX is energized from the HPL, the HPL test sequence is however not controlled by the UMS. For protection and safety reasons, alarms from UDEX components and analogue values during a test sequence are transmitted to the LMS of the High Power Lab.

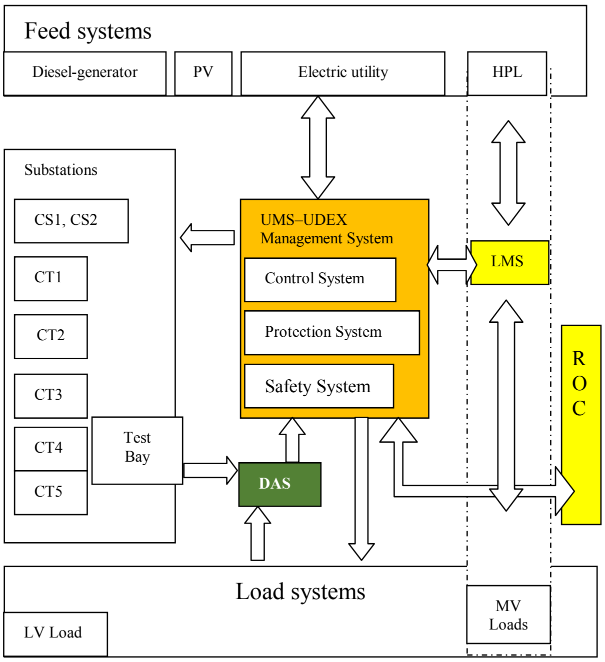

Figure 2 Schematic illustrating interconnectivity between UMS and LMS systems.

FLISR CASE STUDY

The FLISR use case is very well known in Distribution Automation. Its main purpose is fault location, isolation and automatic service restoration. However, this simple functionality is totally dependent on the correct performance of all the elements of the system. The main difference between this automatic use case and the manual operation of the network is the RELIABILITY of the information. Automatic systems take decisions based on information, and therefore an incorrect signal or a wrong detection could lead the automatic system to a critical or risky operation. Thus, the main aim of the test is to verify that all the elements involved in a system works properly. Here we addressed the correct functioning of the protection elements of a system for the FLISR application.

Description of test

The UDEX circuit was chosen so as to include a short section with the fault and a longer and extensible section (to incorporate larger capacitive loads) without the fault. Both sections passed through the test bay as shown in Figure 3. The details of lengths and capacitances of each cable section are shown in Table 1.

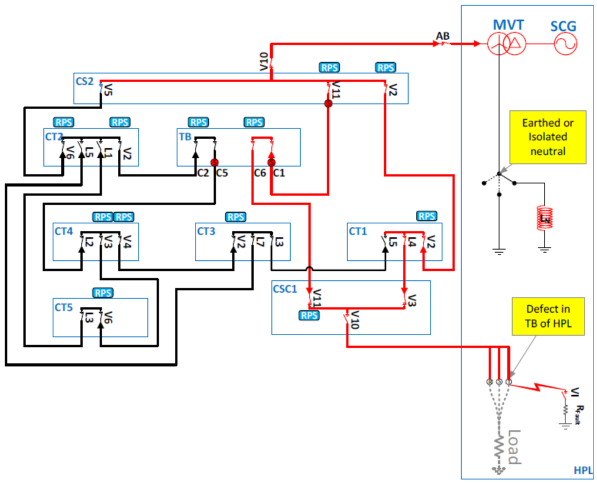

Figure 3 UDEX Test circuit used for functional validation test

Table 1 UDEX circuit cable parameters

Connection	Line Length (m)	Capacitance (nF)
CS2-CT2	40	11.6
CT2-CT3	1153	334.37
CT2-CT5	1189	344.81
CT2-TB	48	13.92
TB-CT4	42	12.18
CT4-CT5	287	83.23
CT4-CT3	443	128.47
CT3-CT1	613	177.77
CS2-TB	51	14.79
TB-CS1	49	14.21
CS1-CT1	44	12.76
CT1-CS2	32	9.28

To perform the protection elements functional validation test we chose a closed loop circuit between the HPL supply and MV Loads, considering the UDEX network as a DUT (Figure 3)

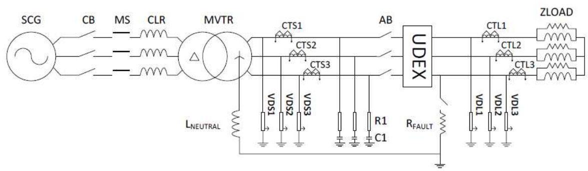

Figure 4 HPL Test circuit

The pre-fault conditions are shown given in Table 2.

Table 2 HPL Testing Parameters

Test	Neutral (mH)	Fault (Ω)	Prefault Conditions		
			Voltage (kV)	Current (A)	Power Factor
(a)	Isolated	800	20	200	0.7
(b)	33.5	2	20	200	0.7
(c)	76.5	2	20	200	0.7

Different faults were performed trying to emulate typical faults under normal working conditions in a cable network.

Three faults are presented here using one isolated and two earthed neutral configurations. The earthed neutral was configured with two different impedance values representative of aerial and subterranean lines.

Results and discussion

The oscillograms of the faults with the different neutral configurations are shown in Figure 5, and the corresponding data presented in Table 3.

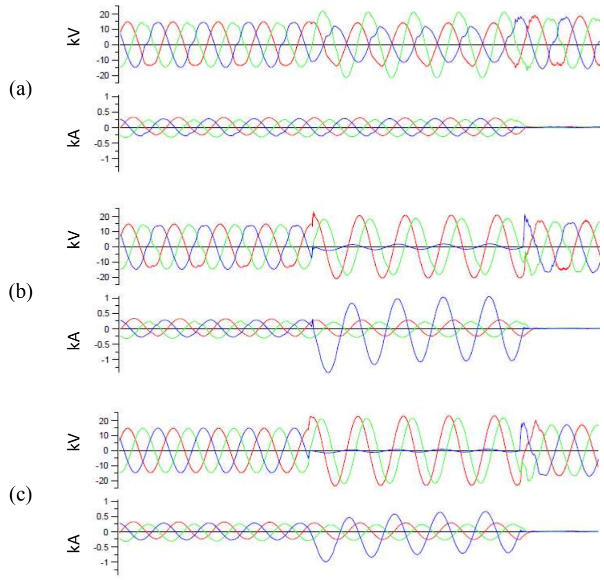

Figure 5 Oscillograms of the three neutral configurations tested: Isolated (a), and Earthed (b), (c)

Table 3 Measurements from fault to earth tests

Test	Neutral Impedance (mH)	I fault (A)	Fault Duration (ms)
(a)	Isolated	-	96.2
(b)	33.5	679	92.8
(c)	76.5	408	96.3

The five fully automated transformer substations located at various points in the MV network correctly detected the faults, the direction, and the values (module and argument). The complete information was sent, in real time, to the SCADA system. An automatic restoration algorithm run properly identifying the location of the faults, sending commands to the MV switches for network reconfiguration, and finally restoring service to the maximum number of cables, optimizing quality of service. The result of the tests shows that RELIABLE information on time is the key factor for the correct performance of the system. In order to achieve this, the following main points should be taken into account:

Reliable Fault Detection. The phase-to-phase and phase-to-earth fault detectors can present problems of incorrect indication depending on the characteristics of the MV network. Many of these kinds of device were developed for local indication, lighting a lamp when a short-circuit current was detected. Incorrect operations were not critical since local indication was reset after a period of time and did not have any influence in the network operation procedure. For MV/LV automated substations no incorrect operation is allowed since the indication will be directly reported to the SCADA and will lead to wrong operations in the network to locate the fault and delaying service restoration. The main problems found in traditional fault indicators are:

Capacitive currents. A phase-to-earth fault in a network yields a zero sequence capacitive current in all lines and cables. The fault indicator has to discriminate between the fault current and the capacitive current. The more cable a network has, the more capacitive current will appear in the case of a phase-to-earth fault (e.g. underground cable 18kV/30kV x 240mm^2 $\Rightarrow$ 3A/km).

No coordination. Earth fault indicators are definite time devices where time indication is independent of the magnitude of the current (e.g. 100ms for 20A implies 100ms for 200A). So to ensure proper detection of real faults, the setting for minimum detection current should be the maximum capacitive current at the point where the earth fault detector is installed.

Inrush magnetizing current. When a feeder is closed at the primary substation, the current in the line not only corresponds to the load but also to the inrush magnetizing current of the MV/LV distribution transformers. One characteristic of this current wave is its peak value (e.g. 5 times the rated value) which phase-to-phase fault detectors detect as a fault. In order to avoid incorrect operation these devices usually include a self-reset indication if there is load current after the peak detection. However, if after the current peak there is a trip (e.g. a phase-to-earth fault previous to the MV/LV substation) the fault detector will incorrectly operate and indicate to the operator an incorrect location for the fault. This phenomenon also appears when using feeders with automatic reclosing functions.

Voltage sensors are used for MV presence indication, reset of fault indication, polarization of directional fault detectors, fault impedance estimation and continuous monitoring of the correct performance of the sensors (alarm) is necessary.

Current sensors. Current sensors are installed around the MV cable and used for phase-to-phase and phase-to-earth fault detection, load current measurement and fault impedance estimation. In order to properly detect the zero sequence current the earth screen of the cable has to pass through the sensor twice. There are 3 current sensors for each switching device and are placed in the cable compartment meaning that service has to be interrupted for installation. Continuous monitoring is necessary for the correct performance of the sensors (alarm).

Wired signals. Each switching device has several wires connecting the cubicle with the Remote Terminal Unit and sensors. Typical numbers for a load-switch feeder are 9 wires for control, 4 wires for current sensors and 4 wires for voltage sensors. It means that a MV/LV substation with 3 feeders needs more than 100 points to be connected on site. Continuous monitoring of the signals is essential.

Remote parameters setting. Every function of the MV/LV automated substation is affected by the task of parameters setting. The complexity of the settings is increasing drastically due to the new functionalities. It means that only very skilled people handling many installations are able to do the task with guarantee. To minimize labour costs fully remote access from the one location is necessary.

CONCLUSIONS

The functional testing of complete networks is complicated without the access to real networks, which is generally limited by the network operators.

UDEX has become an important tool for the research, development and evaluation of new technologies for the products and services to be applied in the electrical grids, anticipating problems, which may appear under the most difficult conditions for the development of protection and automation products and, above all, solutions that are fully proven in a real network.

The case study presented has shown the importance of this type of experimentation unit and the practicality for both manufacturers of grid components and solutions, and network operators providing a reference for a resilient distribution system and its operation.

REFERENCES

[1] G. Zhabelova and V. Vyatkin, 2012, “Multiagent Smart Grid Automation Architecture Based on IEC 61850/61499 Intelligent Logical Nodes”, *IEEE Transactions on Industrial Electronics*, vol. 59, 2351-2362

[2] Wanshui Ling, Dong Liu, Yiming Lu, Pengwei Du and Fei Pan, 2014, “IEC 61850 Model Expansion Toward Distributed Fault Localization, Isolation, and Supply Restoration”, *IEEE Transactions on Power Delivery*, vol. 29, 977-984

[3] Liu Jinsong, Liu Dong, Ling Wangshui and Li Zhibin, 2010, “Study on Simulation and Testing of FLISR”, Electricity Distribution (CICED), 2010 China International Conference on, Nanjing, 1-7.

[4] I.Orue, J.Larrieta, I.Gilbert, 2010, “Development and Requirements of a New High Power Laboratory”, IEEE PES 2010 Transmission and Distribution Conference and Exposition, IEEE PES

[5] I.Gilbert, P.Mulroy, A.Hurtado, N.Akroud, I.Orue, 2015, "Practical Experience of a Partial Discharge Monitoring Application on an Experimentation MV Distribution Network", *CIRED 2015: 23rd International Conference and Exhibition on Electricity Distribution*, IET CIRED, paper nº 0664