SHORT CIRCUITS IN 3 kV DC TRACTION SYSTEM AND FUSES - SIMULATION AND TESTING

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Abstract. This paper consider several aspects related to 3 kVdc fuses, taking into consideration short circuit simulation and testing methods. A presentation of some activities made by FS in this field is made.

The first part of this paper describes quickly standard developments and some short circuit measurements on line. Then a preliminary simulation code able to make a simulation of 3 kVdc electric feeding system during short circuits is drawn.

In the end the new FS High Voltage Test Facility at the FS Electric Substation of Empoli is described.

I CONTEST

The separation between management of the power supply system and the traction system, the interconnection between the European railway networks, and technical developments of on-board equipment, all require a series of operations for which simulation and experimentation is essential, particularly in the case of verifying the aspects governing safety and reliability.

Several factors representing a focal point today:

a) All products for railway use should be subjected to a course standardized at European level, regarding their qualification and/or homologation; the procedure **"Conformity assessment and acceptance of railway products"**, at its highest level of definition in UIC-UNIFE-UITP, foresees the instituting of test laboratories which must supply all data pertaining to test results to the Organization in charge of qualification.

b) The definition of technical specifications of railway "interoperability" foresees, in particular for the electrical part, the definition of the regulations and test specifications which rolling stock and components have to be subjected to in order to guarantee their use on all the various railway networks.

c) The evolution in the field of electrical and electronic equipment has brought to light a series of questions related to electrical and electronic interaction between the various apparatuses, and for which there is the need for systems designed to simulate as closely as possible their real conditions.

II STANDARDS

At the level of the IEC (International Electrotechnical Commission) the revision of the IEC77 "Regulations for electrical traction equipment" is currently being completed by the WG 23 of the CT9 (Traction). The updating of this document foresees the issuing of a new family of standards, illustrated in table 1, which will pertain to the general operating conditions of electrical equipment for traction, electromechanical equipment, power switches, and fuses. They will be included in European Standards.

Table 1: Several IEC Pubblications, of recent or future issuing.

IEC60077-1 : Railway applications – Electric equipment for rolling stock – Part 1: General service conditions and general rules

IEC60077-2 : Railway applications – Electric equipment for rolling stock – Part 2:Electrotechnical components – General requirements

IEC60077-3 : Railway applications – Electric equipment for rolling stock – Part 3: d.c. circuit breakers

IEC60077-4 : Railway applications – Electric equipment for rolling stock – Part 4: a.c. circuit breakers

IEC60077-5 : Railway applications – Electric equipment for rolling stock – Part 5: High Voltage fuses

- Within the frame of the UIC (Union International des Chemin de Fer) standards several "Fiches" to be considered are the 550 OR, "Installations pour l'alimentation en énergie électrique du matériel à voyageurs" and the 550-2 OR , "Installations pour l'alimentation en énergie électrique du matériel à voyageurs - Essais de types". Amongst other things, the tests involving high voltage fuses, the measurements of harmonic currents and the inlet impedance of the vehicles are described in these.

- Following FS specification define the tests pertaining to the supply of high voltages fuses the Ferrovie dello Stato S.p.A:

Spec. FS N° 309532: "General specification for the supply of HT fuses for DC circuits.;

III SHORT CIRCUIT IN DC TRACTION SYSTEM

III.1 General

Due to the severity of the extreme conditions involving short circuits, these are a critical point when it comes to dealing with railway safety and interoperability, for the aspects related to defining energetic and electrodynamic stress, and those concerning electromagnetic compatibility.

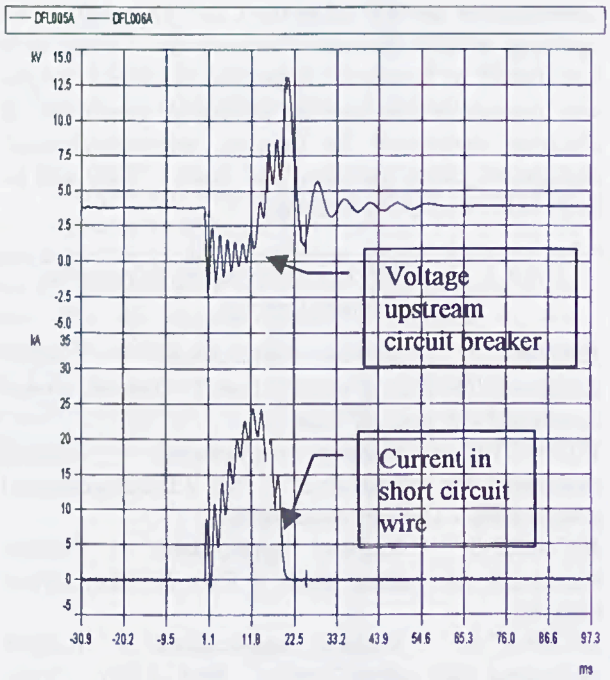

Fig. 1: voltage and current measurements during a short circuit near a substation opened by a circuit breaker

In the field of electrical experimentation of rolling stock, the following developments have evolved regarding the definition of stress deriving from short circuits:

- monitoring of test vehicles and testing of safety equipment; conducting short circuit tests on the line and on rolling stock [fig. 1 and 2];
- the developing of calculation models designed to simulate the 3 kV dc electrical system during a short circuit ;
- classification of the main stress agents caused by such transitory phenomena.

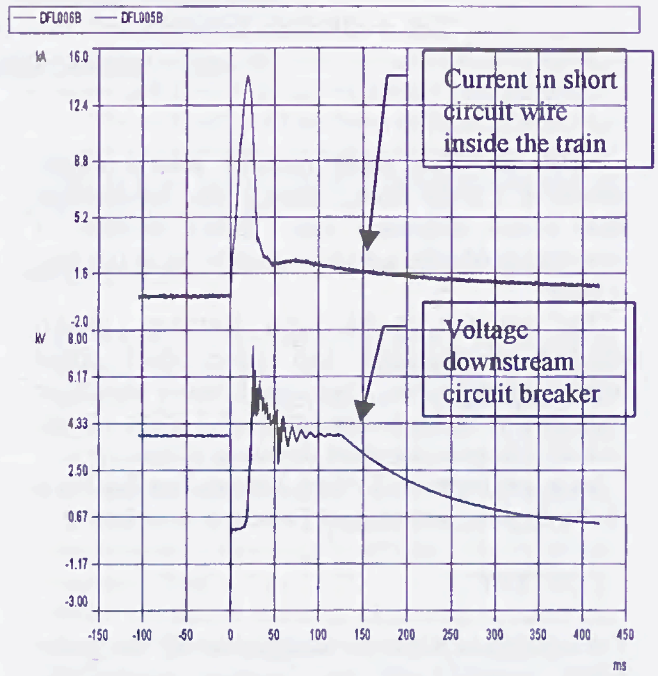

Fig. 2: measurements during a short circuit between substations opened by a circuit breaker

This paper considers 3000 Vdc systems, seeing that present day experimental and theoretical research is focalized on this type of system typology. It must be pointed out however, that these results may also have an effect on 25 kVac systems for the following reasons:

. a short circuit in this system may have dynamic elements which are in part similar to those associated with the 3000 Vdc system;
. the need to have poly-voltage rolling stock calls in any case, for compatibility between the on-board systems and the existing power supply systems.

III.2 Classification

In order to make a classification of the short circuits and to make their simulation on board rolling stock there are various points which must be taken into account.

a) The position of the rolling stock in relation to the substations, in the following situations:

- short circuit in proximity of the substation terminals;

- short circuit on the line;
- short circuit in interconnection.

Circuit-wise the elements to be defined at this point are: the substation circuits (transformers, rectifiers, inductive and capacitive filters, protections); the contact lines and the return circuits, (inductance, resistance and capacity transversal and mutual coupling between lines next to each other); the earthing system (ground, piling, strands, tracks).

b) The position of the short circuit inside the rolling stock:

- upstream from the DC circuit breaker;
- downstream from the DC circuit breaker, upstream from the filters;
- downstream from the filters;
- on the train line;
- on rolling stock in composition.

The main elements to be considered related to rolling stock are the characteristics of the DC circuit breaker, the fuses, the specifications of the overvoltage arresters, the body of the vehicle, the inductive-capacitive filters, the cable laying, the traction motors, the converters .

c) The presence of other vehicles:

- in the train composition;
- not in composition, on the same track;
- not in composition, on the next track.

The rolling stock in composition interacts by means of the DC circuit breaker, the overvoltage arresters, the inductive-capacitive filters, the motors and converters; in particular, in the case of two interconnected locomotives, as happens with the ETR500, or with interconnected machines in double traction, added oscillations of a considerable entity may be created, with the filters of the two locomotives at each end of the train and connected via the contact line and the track, also entering into oscillation with them as well.

IV SIMULATION

One of the first stress evaluation methods to use is that obtained via by simulation of the system.

For this purpose a calculation program has been developed for simulating the electrical power supply system. As inlet variables to choose from, this considers the configuration of the system, the circuital parameters of the substation (number of units, short circuit voltage, transformers, filter characteristics), the geometric characteristic of the lines, the operating curves of the overvoltage arrester, and the characteristics of the DC circuit breaker of the locomotive, with the impedance of the fault point.

As an outlet it supplies the wires of the voltages and the currents in the nodes and branches of the system, together with the energetic parameters correlated to the phenomenon. This calculation model, even if not complete, has given good match-ups, especially in assessing the current, with respect to the measurements obtained via experimentation.

In Fig. 3, as an example, a simulation of a short circuit in an interconnection point is showed: the two curves are related to an opening by a circuit breaker and by an "ideal" fuse.

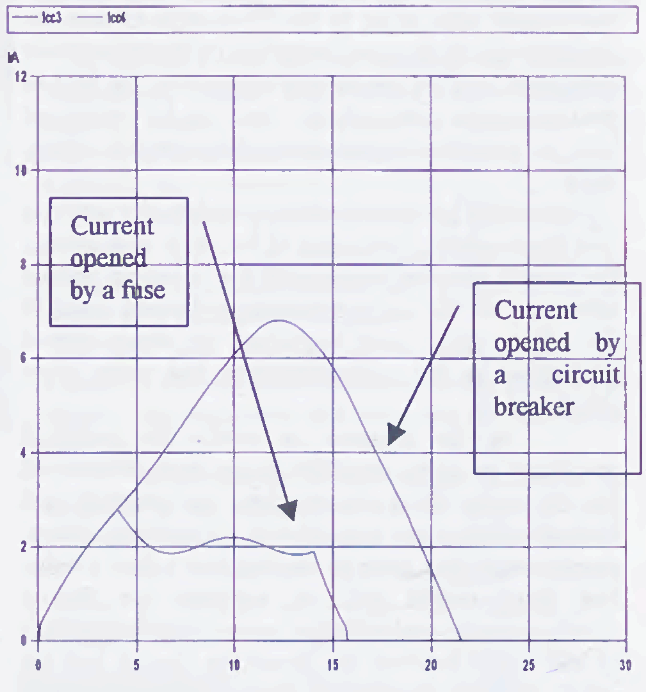

Fig. 3: simulation of short circuit currents in an interconnection point

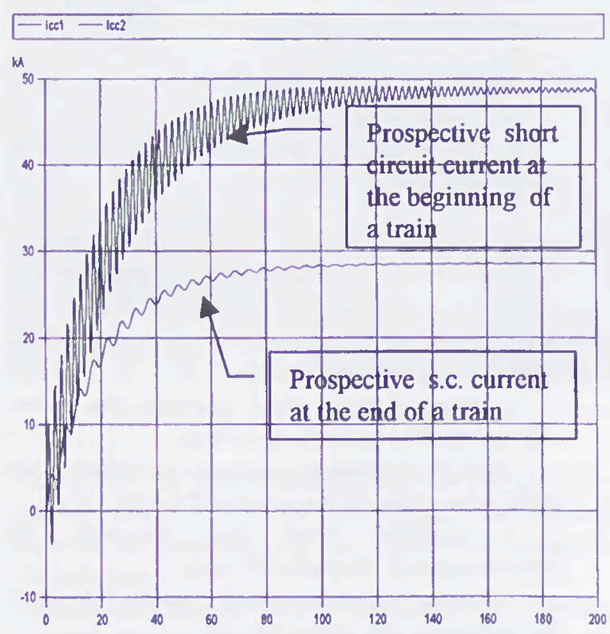

Fig. 4: prospective short circuit currents near a substation

In Fig. 4 is showed short circuit prospective current waveforms in a position of the train near a substation, with the waveform related to a short circuit at the beginning and at the end of a train.

V THE NEW TEST ROOM

V.1 General

The new High Voltage Electrical Test Room at Empoli has recently been set up by the FS in order to meet the demands related to experimentation of electrical power equipment, and for conducting research in the field of electromagnetic compatibility. Tests can be carried out both on individual apparatuses and complete rolling stock.

This system has been created to replace the previous Test Room which, at the end of the '80's after having for several decades represented the principal testing laboratory for the electrotechnical equipment used in FS rolling stock, was beginning to show evident limitations as far as performance and space were concerned.

At the moment in which the technical specifications of the new Test Room were determined (in the early 90's), apart from the renewal and intensification of the capacities of the existing system, consideration was given to the fact that a high voltage test room should also be equipped for testing electromagnetic compatibility, seeing that the problem of interaction between the signalling devices and the power systems represented one of the most critical questions for the future, and also in view of the know-how acquired in the old test room in perfecting digital instrumentation for carrying out operational surveys.

V.2 Description of the system

The test room is equipped with the following installations and systems:

- a 3000 Vdc high voltage testing system, powered by Unit C of the Electric Substation, and consisting of line and load simulators (rheostat and inductance), an electromechanical configuration system, and protection devices;
- a control system, which manages the system and controls the performing of tests ;
- 380/220 V auxiliary systems, including a no-break generating set for privileged loads;
- a shielded room and pre-room for electromagnetic compatibility tests;
- operating tracks energized from the test room, and equipped with inspection pit.

V.3 The 3 kV dc system

Fig 5 illustrates the block diagram. This system consists of the following:

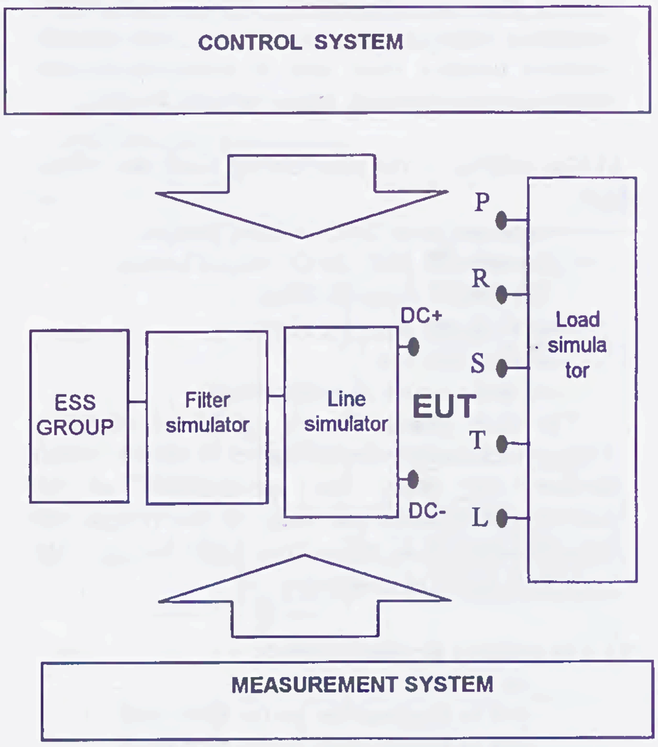

Fig. 5 HV circuit block-diagram

a) <u>Power outlet:</u> UNIT C of the ELECTRIC SUBSTATION, inlet power supply 130 kV ac, power rating 5.4 MW, outlet voltage 3600 Vdc, adjustable.

b) <u>Filter simulator</u>: inductance of network filter L= 6 mH with a 2 mH terminal also available, filter condensers, bench with 1100 μF .

c) <u>Line simulators</u>:

c.1) RX rheostat line simulator -
The resistance values are variable from 0.1 to 6.3 Ω, in steps of 0.1 Ω. This rheostat is sized to support ON/OFF cycles with current values exceeding 10 kA. Packets are also available designed specifically for short circuit testing. The line resistance is controllable via the PLC by means of the contactors.

c.2) LXA1, LXA2, LXB1, LXB2, LXB3 inductance line simulators (Fig. 6) :
Type LXA inductor : N° 2 inductors, each of 6.5 mH. The constructive features are such that the parasitic currents are minimized to approx. 1 MHz.

Type LXB inductor: N° 3 inductors, each with 13 mH.

All the inductors are located inside the building on special stainless steel frames for minimizing the dynamic actions deriving from the coils during the tests. The line resistance is controllable via the PLC by means of the contactors.

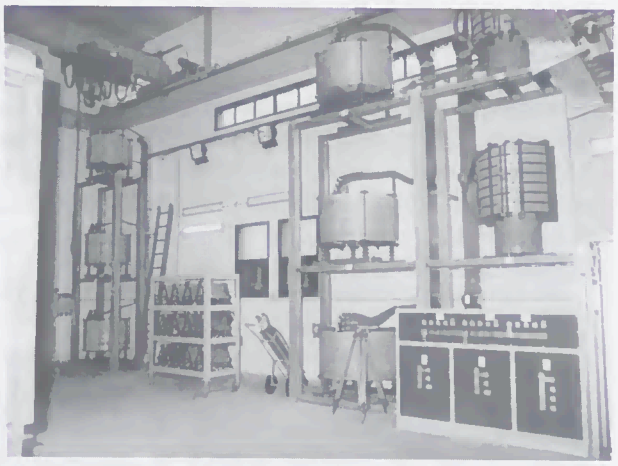

Fig. 6 : inductance simulators

d) Load-resistance Simulator:- The resistive load in configuration series, powered at 3600 V, which can absorb, on a continuous basis, a current varying from 1 up to more than 750 A, with steps adjustable up to 1 A.

- in parallel configuration , currents over 1000 A can be absorbed on a non-continuous basis.
- The load can be set in three-phase configuration, with three R S & T terminals available

The resistances are electrically divided into four benches; to each bench resistances are attributed which can instead be controlled individually via the PLC by means of the contactors

The line and load resistances have been installed in stainless steel cabinets located on the roof of the building.

This load is split up into sections with natural air ventilation and sections with forced air ventilation in order to reach higher dissipating capacities throughout the overall dimensions: a careful layout of these sections has been necessary in order to reduce to a minimum acoustic emission towards the outside, decisions which have proved correct at the end of operation.

e) Load - inductance simulator: The inductive load is composed of 3 inductors, LC1, LC2 and LC3 each with L = 13 mH.

The following intermediary terminals are also provided : 3 mH; 6.5 mH; 9 mH.

V.4 The control system

Management of the test room, the choice of network/load characteristics, and the setting of automated test sequences are all handled by means of a PC, with specifically designed software (in Fig. 7 a comprehensive image of the control room). From the very first page of the menu it is possible to set a new test, recall an already programmed and filed test, file a current test, perform the test and visualize past and present alarms.

For setting a new test the operator has numerous menu pages on hand which allow him to choose the network voltage, the insertion of the filter, the selection of inductance values and those of the network resistance, the prearrangement of the star load in case of tests with three-phase lines, or in series for tests with DC or in any case, single-phase power supply, the setting of the threshold alarms on the current and the voltage with the relative delays etc.

The four load benches can be entered from the program in various ways, totally, partially, in series, in parallel, and in parallel and star series for three-phase loads.

The prearrangement of the load is made at the beginning of the program in the configuration phase by means of motorized isolating switches.

The contactors and motorized isolating switches are installed on an open frame located on an elevated platform on the top floor of the building.

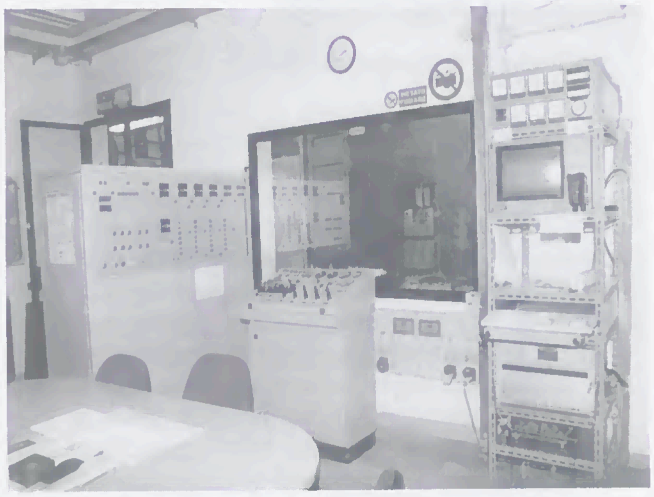

Fig. 7 – control room

Apart from the test controlling devices various other control lines and logics have been implemented between the substation and the Test Room, related to the following:

- emergency opening of the circuit breakers (130 kVac, 3 kVdc, 380 Vac), both during the tests and while the Test Room is unattended;
- adjusting of the voltage via the variations in the transformation ratio.

V.5 Experimental possibilities

The characteristics of this system allow for performing tests on electrical traction equipment in a wide variety of configurations. As an example several test typologies are listed below.

V.5.1 Tests of 3 kV dc equipment

Typologies of tests performable (both on equipment and stationary vehicles):
- performance and functional tests of new components and electronic converters;
- tests of DC circuit breakers, contactors, isolating switches, fuses, overvoltage arresters.

These tests, for example, include the following:
- performing of continuous load and overload cycles;
- switchover tests, overvoltage checks
- short circuit tests.

V.5.2 Electromagnetic compatibility

The following typologies of tests are possible:
- measuring of electromagnetic emissions of equipment and rolling stock at radio frequency and low frequency ;
- study of interaction phenomena between power devices and signal devices;
- studies of harmonic currents generated by towed rolling stock and by converters.

V.6 Aspects regarding the quality

V.6.1 Management procedures

During the phase of operative activation of the system a special management procedure has been established - "procedure for conducting tests and experimental activities in the FS High Voltage Test Room at Empoli", in order to guarantee a correct Client/Supplier rapport and to ensure conditions of impartiality and discretion in carrying out tests.

This procedure, which is put into force in the transitory phase before the final certification and accrediting, has been perfected by using as references, the standards **UNI EN ISO 9001** "Model for assuring the quality during the design, development, construction, installation, and assistance" and **UNI CEI EN 45001** "General criteria for the functioning of test laboratories".

V.6.2 Operating procedures

Specific procedures have been determined for each type of test, each of which, on the basis of the requirements of the relative standards and technical specifications, provide an exact definition of the test modalities and equipment. In this context the test procedures regarding contactors and fuses for example, have been developed.

V.6.3 Certification and accrediting of the Laboratory

The activities necessary for obtaining the certification based on the UNI EN ISO 9001 standard and the accrediting according to the UNI CEI EN 45001 standard are currently in the phase of being developed by the Experimentation Structure which supervises the laboratory. Following these procedures, the Test Room will operate in an ISO 9001 Structure, and it will request the accrediting for performing tests required by the regulations for the homologation of the equipment and vehicles under its own competence.

V.7 Future developments

This Test Room, with its capacity to recreate the electrical conditions of the railway system without having to use the systems actually in operation, is proposed as an advanced test laboratory for studying the electrical systems for traction, and is available for use by the Technical Structures of Railways, Industries, and Universities.

The development of the Test Room is foreseen contextually with the certification and accrediting process, and its objective is that of being able to offer a testing and electrical experimentation service with a laboratory which is the most complete possible and compliant to standard requirements.

It will also be possible to implement power supply systems with 25 kVac and 1.5 kVac, climatic and vibration test equipment and systems for controlling electromagnetic immunity on complete rolling stock in the future, in the aim of supplying a wide coverage of the experimentation necessary both for research, and for the homologation of the electric railway products.

VI CONCLUSIONS

The separation between line and rolling stock management, European interoperability specifications and technological development need in general an improving in simulation capability and testing procedures. In particular short circuit is a typical system phenomena, in which various elements has to be taken into consideration: for example vehicle position and configuration, feeding system parameters, components specifications. These aspects have to be taken into consideration in fuses standard, design and testing.