Disturbances affecting essential loads in high-speed railway systems

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Abstract: – A thorough analysis is given of the various phenomena responsible for the main disturbances involving essential loads in high-speed railway systems. Subsequently, a new system configuration is properly highlighted and discussed. The architecture of the proposed system replaces the already adopted architecture, which was responsible for many problems of the UPSes supplying the essential loads. The main differences between the two layouts mainly involve LV systems supplied by the UPSes. Actually, the BT system configuration changed from TN-S to IT with distributed neutral; in addition, an isolation transformer was inserted to supply the remote sensible loads. The aim of the isolating transformer was to reduce disturbances reaching the UPS through greatly exposed cables. In practice, these cables are very long and installed side by side along both the electrical MV power lines and the linear earth plate of the railway system.

Key-Words: - High-speed railway (HSR); Essential load supply; Continuity systems

1 Introduction
The auxiliary systems of the High-Speed Railway (HSR), particularly those concerning essential loads, are supplied through UPS usually installed in structures named FPP (Fixed Peripheral Point). The BT system upstream of the UPS is supplied by means of a single-phase MV/LV transformer whose terminations are connected to a pole of the 2x25kV power line (supplying the contact wires) and to the ground respectively [2], [7]. When one pole is not available, the supply is automatically transferred to the other pole. In the case of both poles being unavailable, the UPSes are automatically commuted to an LV-three-phase electric generator. The experience acquired on these originally built systems showed a number of problems on the operation of the UPSes, whose often serious consequences inevitably affected the essential loads. Subsequent studies performed on the issue allowed to identify a new system configuration for the LV electrical installations supplied by the UPS, which enabled to overcome the difficulties previously encountered. In the following, the different phenomena related to the problem are first investigated and then the new system layout is properly described.

2 A classification of the disturbances affecting UPS
A correct operation of the UPS supplying the auxiliary installations of the HSR system can be strongly affected by a number of disturbances, which are concisely classified in what follows. The origin of the disturbances can be either internal or external to the electrical auxiliary system examined. Among the possible external causes, there are phenomena involving the HV sub-transmission system, MV rail power lines, and global grounding system [9]. The events that need a more in-depth study are those linked to atmospheric or switching overvoltages. Atmospheric phenomena such as direct and indirect lightning strokes involving the supply system 2x25kV and MV feeders connected to MV/LV transformers can produce earth faults affecting the global grounding system, which in its turn transfers a voltage also to the neutral of the TN-S systems, consequently involving the UPS ground reference. The switching overvoltages can be caused by actions performed on HV and MV systems, especially during breaker operations with non-simultaneous opening (or closing) of all poles. The same kind of overvoltage can be caused by sudden, important load changes.
With reference to sensitive equipment and loads, a quantitative evaluation concerning the respect of the limits allowed for overvoltages was performed by means of the ITIC (Information Technology Industry Council) power acceptability curve for industrial loads [1], [3]. Fig. 1 shows an example on how to use these diagrams.

Fig. 1. An example of the use of a power acceptability curve.

From another point of view, disturbances that may affect the correct UPS operation can be distinguished into radiated and conducted [4]. As concerns radiated disturbances, currents on the LV feeders (even and odd) supplying the FPP induce electromotive forces (EMF) on the LV cables placed side by side along the railway system. The harmonic contributions of these voltages increase whenever overvoltages phenomena involve MT feeders. The induced voltages are particularly important in cables supplying load very faraway from the UPS since voltages increase with the line length.

In addition, the same linear earth plate of the railway system may induce EMF on the mentioned BT cables when interested by relevant currents due to either fault conditions (lightning, single-phase earth faults, etc.) or a transiting train especially when it draws high current. As far as conducted disturbances are concerned, atmospheric or switching overvoltages definitely cause a distortion on the supply voltage. Whenever amplitude and duration of a disturbance overcome certain limits, anomalies can affect such electronic devices as computers, PLC, telecommunication apparatuses and also UPS electronic cards, [8]. Actually, a disturbance can be also associated to an increase in the potential of the linear earth plate (or more generally the global ground system) and consequently of the neutral of the TN-S systems.

3 The new system architecture

As already said, depending on different phenomena the HSR global earthing system can assume anomalous voltages that may cause unacceptable disturbances to UPSes and electronic devices supplied by a TN-S system [5]. Therefore, in order to eliminate disturbances to the essential loads and to increase the supply continuity of the system, the best solution appeared to be the disconnection of the neutral from the earth, which corresponds to adopting an IT system for the BT installations supplied by the UPS. In addition, an isolation transformer (with a 1:1 ratio) was inserted upstream to the lines supplying the remote loads, which usually correspond to auxiliary equipments placed up to one km from the auxiliary switchboard installed inside the FPP.

Regarding its internal arrangement, a UPS is characterized by a galvanic insulation between the AC and DC sections represented by an H-Class transformer installed downstream to the AC/DC converter. As a matter of fact, this configuration prevents most of the disturbances from upstream but is not able to stop anomalous currents from downstream installations especially in the case of impulse-type currents. For this reason, an isolation transformer was installed upstream the BT cables particularly exposed to both conducted and radiated disturbances, such as those supplying remote loads.

In any case, it can be noted that also with a TT system apparatuses such as electronic devices requiring a ground reference can be sensitive to the anomalous voltages affecting the earthing system.

In general, an IT system is used when a great continuity level is required, since in the presence of an earth fault the circuit can be held energized, protecting at the same time operators against indirect contacts. In addition to these important advantages, the adopted IT system eliminates the problem caused to the UPS by the use of the TN-S system.

As far as the specific standards of IT systems are concerned, the installation of a measurement apparatus for a continuous check of the system insulation is particularly important; furthermore, the setting time of the protection device must also be evaluated, especially in the presence of a second earth fault. Finally, since the neutral is distributed, all device insulation must be designed for the line-to-line voltage.

The proposed system architecture was applied to electrical installations which were already built but also to constructions now in progress. This solution, in addition to the previously described advantages,
implies a good technical-economic compromise. Fig. 2 shows the layout of the old and new configurations.

4 Further considerations on the IT system
As already said, an IT system in presence of a first earth fault does not affect the supply continuity but, since a second phase-ground fault cannot be tolerated, the protection system must promptly open the circuit causing an inevitable energy interruption. Actually, since the first earth fault causes overvoltages between phases (not affected by the fault) and ground, it can be responsible for the second fault with heavy consequences on the supply continuity. For this reason, further precautionary measures must be adopted to assure supply continuity.

In the case under study, the 230/400V three-phase IT system originates downstream the UPS inverter section. The BT system is characterized by the following properties:

- The neutral conductor is distributed to supply the single-phase essential loads;
- The exposed conductive parts (frames) are connected to the global grounding system.

Fig. 2. System layouts; a) old configuration, b) new configuration.
Because the neutral is distributed, the second fault can also occur between a single-phase and the neutral; in this case, the fault circuit is supplied by the $U_0$ line-to-neutral voltage. In that situation the fault current may be too small for the protection devices to trip with an acceptable delay so as to adequately protect the operators. In this case the requirements imposed by the standards, which must be verified, are the following:

$$Z_s' \leq \frac{U_0}{2 \times I_a}$$

where:

- $I_a$ is the current that causes the protection device to trip before 0.8s for terminal circuits supplying mobile apparatuses and 5s for the other circuits; the rated voltages of the system are 230/400V and the environment is assumed to be of the normal kind.

- $Z_s'$ the impedance of the fault circuit represented by neutral and protective conductors;

- $U_0 = 230$ V is the line-to-neutral voltage.

Generally speaking, it is imprudent to distribute the neutral in IT systems, since in this case the insulation must be designed for the line-to-line voltage for both the electrical installation and devices. In addition, the neutral is easier to be kept insulated from the ground if it is non-distributed. In the case under study, assuming this recommendation cannot be satisfied, all necessary precautions must be adopted during the system construction.

5 The continuous isolation monitoring

The IT system does not assure safety conditions in presence of an electrical contact with a system having higher nominal voltage (e.g. MV systems). For this reason standards prescribe the installation of a surge arrester between the LV star point of the MT/BT transformer and the earth system. In the case under study, the surge arresters are installed upstream to the UPS. In this condition, it is not necessary to repeat their installation downstream the UPS where the IT system originated. Nevertheless, in IT systems it is necessary to install an isolation monitoring device, considering that high reliability of an IT system is guaranteed by a continuous isolation check [6]. The adopted isolation monitoring system is based on the Adaptive Measurement Principle (AMP); it uses a low-frequency square voltage wave whose period is adjusted in accordance with the network capacitance. The isolation-monitoring device recognizes insulation faults as they develop, and immediately reports any falls below the minimum, which prevents an interruption of the power set point that would be caused by a second, more severe insulation fault.

As to the choice of the device, it is important to remember that the current to be checked is of the capacitive kind, being similar to the typical current generated in systems where rectifiers and inverters supply electronic circuits. In general, every network or circuit is characterized by distributed line-to-ground capacitances; in addition, capacitive filters installed between energized conductors and ground can be taken into account. The total capacitance is the sum of all line-to-ground capacitances of the system. The monitoring device must evaluate only the resistive earth-leakage current due to fault or insulation degradation. In this case, the measurement device must omit all capacitive currents.

In the previous evaluations, the possible evolution of the electrical installations must also be considered since further loads may be added in the future.

6 The isolation transformer

Isolation transformers are generally used for safety reasons, but can also be used to avoid common-mode transient overvoltages between primary and secondary windings. The common-mode disturbance depends on the voltages between different points connected to the ground. In the case under study, the isolation transformer contributes to solve the problem evidenced in the UPS, because it reduces both radiated and conducted common-mode disturbances (depending on capacitive and inductive couplings) transferred to LV cables placed side by side of the supply feeders, contact lines and the linear earth plate. The main feature of the adopted isolation transformer corresponds to the galvanic separation between the previous mentioned long LV cables and the UPS, installed upstream and representing the actual victim of the disturbance.

Despite their advantages in the case of common-mode disturbances, isolation transformers do not affect differential-mode overvoltages transferred to the secondary by inductive effects. Nevertheless, the common-mode overvoltages can reach the secondary by means of the capacitive coupling between the two transformer windings, which increases with the value of the disturbance frequency. In order to reduce the winding coupling capacitances, a metal shield connected to ground can be inserted between the transformer windings; the addition of metal shields (one, two, even three) can strongly reduce common-mode overvoltages transferred to the secondary winding. The positive effect of the shields is therefore to drastically reduce the transmission of capacitive common-mode disturbances. In practice, when connected to ground these shields introduce an additional way for disturbances, which corresponds to a reduction on the pulse transferred to the secondary. Moreover, in order to control common-mode voltages,
also windings with a middle point connected to the ground can be adopted [8].
The introduction of the isolation transformer is not the only solution that may be adopted; as a matter of fact, also shielded cables may be used to solve the problem, but this solution implies removing the existing cables that must be replaced by new ones, with heavy economic impact.

7 Conclusions

The system architecture here proposed and adopted to supply essential loads in the Italian HSR system was mainly developed in order to minimize off-duty times in dedicated electrical installations.
The adoption of an IT system with distributed neutral instead of the TN-S system and of an isolation transformer allowed a substantial increase in the continuity level of the essential load supply.
Furthermore, the continuous isolation monitoring device required for IT systems can optimize the maintenance planning of electrical installations, which can be scheduled on the basis of a real knowledge of the system isolation level.
The adopted choices meet also other important requirements, such as high safety level for operators, the plant conceptual linearity, high reliability and availability levels.

REFERENCES


