Innovations in the automation of the electric power railway substations

S. Cosmi¹, G. Alessandro², A. Luzi¹ & G. Veca²
¹RFI S.p.A. – Maintenance Direction, Italy
²Department Electrical Engineering, “La Sapienza” University, Italy

Abstract

In this paper the authors highlight the main problems connected to the technological renovation of infrastructures applied for electrical supply of the contact line. This paper has been developed in co-operation with RFI (the Italian Railway Network), addressing with particular attention the railway electrical substations (ESS).

The purpose of this study consists of the identification of some innovative technical solutions for the realization of 3kVdc ESS. In fact, to satisfy the increase of market demand for railway transport during the next 10 years, the whole Italian electrical railway network has to be radically improved.

The authors briefly analyse the actual status of the RFI ESS structures, and point out the limitations of the traditional technologies.

From this study, it is evident that there is a need to critically analyse two crucial aspects of the modernization: some strategies of interventions are proposed, with the purpose of achieving a convenient technical-economic management for the infrastructures.

Keywords: railway electrical infrastructures modernization, railway electrical substation, railway electrical station, railway automation, railway PLC system.

1 Introduction

For what concerns the renewal of the electrical energy distribution and transformation infrastructures for Italian Railways, the authors suggest major improvements to the actual conversion 3kVdc ESS and to the Electrical Stations (ES). This study suggests solutions and methodologies that could improve the quality handling of the electrical railways systems.
The result of the analysis of the possible improvements to the majority of the 450 plants powering over 22,000 km railway is that the renewal process, through constant action, has to start as a block of systems, ways and procedures to effectively, and in a standard way, grant the infrastructures control and protection.

With this purpose an analysis of the modern automation and protection systems possibly used for railway applications has been made. In particular, the feeder units at 3kV dc powering single railway section have been discussed and important results have been reached in terms of innovative characteristics.

The analysis has highlighted that the use of innovative technologies and new methodologies in the ESS construction could improve the safety of the operators, the maintenance, the flexibility and the speed for the installation, in addition to increment their performance and reliability during their whole life cycle.

However, the achievement of the above-mentioned goals, though, depends on the normal use of digital technologies as a replacement of the electro mechanic ones.

It has been learnt that this implementation, even though it represents a mandatory step in the renewal process, has to be carefully handled because of the inevitable related issues. As specified after, a non-appropriate adoption of digital technologies could solve some temporary needs of the ESS, but could give some problems of manageability in the future, mostly due to the automation software's intrinsic characteristics.

2 Main characteristics of the railways ESS improvable through the renewal process

The analysis of the actual electric power Italian railway substations identified some quality issues that can be improved. The main issues are listed below:

- The necessity of increasing the ESS performances. In particular, it will be necessary to increment the power supplied to the contact lines granting that the safety levels already achieved will not decrease.
- The continuance of the service supply and the reliability of the different components of the ESS. The reliability of an ESS has to be evaluated on the basis of the continuance of the service supply; the continuance is conditional either on the components reliability or on the design of the plant. In the future the design will play an always increasing strategic role.
- The safety of the operators. This is a fundamental aspect of the renewal process. In order to achieve higher safety levels, in case of malfunctioning or mistakes in steering, it will be necessary to increase the safety standards of the tools and the existing devices inside the ESS.
- The maintenance. This is another issue that can be improved by reducing the fixing times after a fault. This result could also be reached by introducing devices that can diagnostic the working status of the different parts of the ESS.

Based on above considerations, the authors believe that the actions advised in order to improve the quality of the plants should be related, first of all, to the
automation and control systems and help the introduction of standard ready-mode units.

3 Analysis of the automation and control systems

The problems related to the electro mechanic solutions (relays) can be faced by using the latest technologies, just like in other industrial sectors. They can be used to implement fundamental functions like diagnostic, monitoring, and control to better manage the various apparatus of the plant.

While doing the present job, though, it has been noticed that it’s not granted that such a change of technology in the railway field could lead to the expected results. In fact, the possible use of PLC (Programmable Logic Controller) technologies could generate new peculiar critic elements: one of the most critic is the software!

The most important capability of the PLC technology is the possibility of performing different functions by realizing more efficient and updatable algorithm without having to modify the equipment of the ESS or ES. In such way the problem moves from the hardware to the software that allows a larger number of achievable functions. It has to be noticed, though, that increasing the complexity of software necessarily increases the probability of mistakes in the code. In fact, the error rate in the industrial automation software development is never null, and it is higher either at the starting point or after the probable modifications or updates to a previous version. To summarize these concepts figure 1 shows the trend during the life cycle of Mean Time Between Failure (MTBF) of software. Therefore, the usage of not fully reliable software could create problems.

![Figure 1: A software MTBF trend compared to the utilization time.](image)

To success in this technologic change, it is fundamental to use both quality and reliable software and experienced organizations to maintain and improve the reliability. The MTBF growth shown in figure 1 is due to the maintenance activities of such structures.

The introduction of new technologies to computerize both maintenance and activity workflows can be the solution: anyway, they have to be implemented
without causing any failures to the existing infrastructures. Often, the monitoring systems used until now are based on home made solutions physically split from the control system, not allowing therefore a complete communication and integration with the system being developed separately in different modes and times. The restricted communication capability makes difficult to achieve the reliability, availability and continuance expected from the ESS. Therefore, monitoring systems should be chosen among standard solutions and communication protocols.

One of the main limits of the supervising, monitoring and controlling technologies used to date in the railway system is the effectiveness of the auto-diagnostic functions, due to both components and system. In fact, it has been learnt that the auto-diagnostic active systems, i.e. structured in such a way to give precise information on what action to take rather than just detecting a malfunctioning, can improve the ESS handling.

According to the above-mentioned technological needing and infrastructures renewal issues, a possible configuration of a governance system, based on control, monitoring and diagnostic functions, has been proposed.

3.1 Automation, monitoring and control systems performance: parameters and main functions

The performance parameters to be introduced in the ESS and ES are the following:

- Safety in Plant handling;
- Modularity and flexibility;
- Maintenance and configuration ease;
- Reliability;
- Minimization of the impact on the actual plant configuration;
- Use of standard technologies regardless of the supplier.

In particular, the control function should be equally usable either from on site operators or from remote, through a global control Centre.

The diagnostic function should detect the actions needed to keep the ESS and ES infrastructures efficient.

The monitoring function makes possible the diagnostic: it has to allow any operator (either on site or from remote) to make the fully check of the ESS or ES operating systems in order to detect and correct any malfunctioning or quickly act in case of fault.

From an operative point of view, any ESS or ES can be managed by splitting it in many sections: each one is locally drivable through one or more peripherals able to perform all foreseeable automation and protection functions. An example of such model is provided in the following.

Each ESS section, whose monitoring systems are spread on site, can acquire and send a series of signals processed by the control and supervision system on field!

A possible solution that can be adopted either in the most modern ESS or in the eldest ones could be to set up “Operating Units” (O.U.), constituted by PLC systems, able to autonomously manage one or more sections activities.
Therefore, through specific software, these O.U. could acquire and process the signals sent by the system. In this way each O.U. would be constituted by a block of PLC able to operate either on site or from remote.

To apply this kind of supervision and control it necessary means to introduce new concepts in the handling of RFI.

As a matter of fact, the ESS and ES local control system that processes the input and output signals originated from the various O.U. spread in the field, could perform the following functions:

- Local Command and Control;
- Monitoring and diagnostic command;
- Interface to a remote global system control.

The actual technologies allow develop hardware systems that minimize the unavailability of the control process in case of fault or malfunctioning: the “strategic” signals originated from different sections could be duplicated, sent and processed from more O.U. linked together. In this case, each O.U. should be programmed with specific management software to command the relevant compartment, leaving the action on more sections only in case of malfunctioning of the linked O.U. During this study we referred to the characteristics of some new 3kVdc ESS that are completely new or being renewed in order to standardize the electric network in terms of control and automation.

Based on the previous analysis, the ESS or ES governance system is composed of SW and HW modules integrated and linked so that the main four functions, i.e. tele-control, automation, monitoring and diagnostic, are performed.

The proposed governance system architecture estimates three main subsystems: a Local Control System, a Communication Network and a series of O.U., as shown in figure 2.

The Local Control System should be composed of SW/HW integrated modules and linked to perform the following functions:

- Man/machine interface (for all the following functions)
- Remote control, meant as command and centralized control of all SSE systems
- Remote-signal, Remote-alarm and Remote-measure
- All ESS systems diagnostic
- Central governance auto-diagnostic
- Interface to the compartmental Tele-control and diagnostic systems belonging to a higher hierarchy
- O.U. configuration and calibration
- Remote-control inclusion/exclusion

The Communication Network should be composed by a block of software/hardware modules and devices integrated and linked to make possible those functions needed to interconnect the Local Control System to the O.U. and to start all those functions pertinent to the SSE governance system. These technologies can be realized with standard market products and with unified open protocols (IEC).
The duty of a O.U. is generally to protect and control the single compartment that composes a normal ESS. In particular, the governance system could imply the following types of O.U.:

- AT/MT service arrival;
- AT/MT transformer;
- Auxiliary services transformer;
- Rectifier compartment;
- DC circuit breaker compartment
- Measure compartment;
- DC auxiliary services;
- AC auxiliary services;
- Common services.

Figure 3 shows the general electric scheme of a railway Substation where the application of the above mentioned solutions could be feasible.

4 The prefabricated 3kVdc functional units: the evolution of the performance

The authors believe that the prefabricated 3kVdc functional units are strategically important for both renewal and future production.

In case of either the masonry structure (built until 90’s) or the new proposed prefabricated structures, the main improvable aspects are:

- Adoption of automation and control methodologies by dropping the electro-mechanical technologies;
- Maintenance improvement;
- Modularity optimisation;
- Possible further increase of the operator’s safety.
In this study, the authors reserved special attention to the functional feeder units, whose complexity combines all kind of functional units elements. The proposed actions may answer (also through slow steps) to the railway transportation growing demand. These actions could either optimise the existing plants capabilities or simplify the installation of new plants along the railway.
network, by reducing the environmental impact: i.e. through medium voltage (MT) feeding plants.

In the authors’ opinion, the prefabricated structures represent the possible solutions that could contemporaneously allow one to achieve above targets, for what concerns direct current.

During the recent past, many actions have been taken to improve some characteristics of the previous solutions. Nevertheless, these experiments aimed to solve those local named problems rather than to define the global solution. In previous years this strategy caused the failure of the infrastructures harmonization.

This study aims to propose a possible evolution path for what concerns the critical and/or improvable aspects.

Even though the probability of electrical accidents is nowadays very low, it is important to further lower it, mainly when technicians are present in the plant for maintenance or repairs. This can be achieved by rising up the direct contacts protection levels (IP index increase), by introducing opportune sections among the different parts of the plant and by adopting evolved diagnostic and command systems.

During the normal activity the most dangerous event that can occur inside a functional unit is the development of an electric arch caused by faults, presence of small animals, dust in unprotected plants, etc. The thermal wave and the consequent pressure wave connected to the arch naturally become a real danger for closer things and people.

This analysis shows that not much has been done till today to mitigate the effects of the internal arch in the railway environment: for this reason it would be good to introduce some specific remedies, just like in the AC electric power distribution field.

4.1 Description of the proposed improvements to the functional units: detailed analysis of the newly designed 3kV_{dc} power pack

During the last decade, some plants feeding the railway electrical contact line with increasing train traffic have been partially renewed or completely remodelled by adopting those technical solutions analyzed and developed during this study.

The need to take in the new monitoring, diagnostic and control technologies is also valid for all plant components that follows the six pole disconnector (see Figure 3); keeping in mind other industrial areas new designs, where PLC technologies allowed a generation jump in terms of performance, optimization and maintenance ease.

It is believed that it would be necessary to improve the following main elements:

- The highest degree of total protection from direct contacts for IP3X in sections containing medium voltage equipments and IP2X in compartment conducting bus bar omnibus;
- Partitioning and grounding of the bar pre-emptively connected to the negative pole at the input of each U.O.;
Assembly of the cumbersome MT equipments (extra fast switch, earth proof resistance, filter capacitors, etc.) through systems allowing their easy extraction;

Layout design to fit MT equipments from different providers;

Partitioning and visible grounding of the sections that can be checked and maintained from the operators;

Electrical segregation among sections in which the prefabricated structures are separated (omnibus bars, MT equipments, BT equipments – command and control);

Design and proofs of immunity against internal arches to be autonomously carried out in each section;

Automatic re-establishment of ESS functionalities following a fault (total opening, internal arch, insulation loss and so on) with detection and partitioning of the generating functional unit;

Utilization of disconnecting switches realized with energy storage systems (for opening manoeuvre) to grant the partitioning of the units, even without auxiliary power.

For what concerns the functional units internal components layout, it came up that a further reduction of the necessary space and the optimisation of the equipment installation is possible. This is especially true for the masonry-built technical solutions built, for instance, the extra fast switch is placed about two meter high from the floor, the other equipments and the energy transportation bars are attached to the walls in a way that can ease the energy loss (due to possible presence of small animals or dust or faults). Furthermore the service operations done by the operators must be simplified: they are actually very complicated, especially for the heaviest equipments replacement. It has been assessed that a simplification of the maintenance activities is obtainable through the introduction of appropriate motorizations of some components, e.g. the disconnecting switches. The realization of a mechanic and automatic manoeuvre system would allow to automatically repair ESS functionalities, following a total opening event except the fault of O.U. Regarding the safety of the operators, the introduction of well visible partitioning instead of the outdated security systems is proposed. An example: the need of connecting the negative pole to the earth in case of faults; this is normally done by using different kind of devices that do not give the operator the possibility to internally see the functional unit. The need of finding modular and compact solutions comes from the necessity of cutting down all the following complications occurring since the installation phase:

Long time for the on site constructions by engaging the RFI personnel;

Difficult testing and working operations: since all wiring are done during the installation, the testing has to be necessarily done after complete installation;

High cost for buying and to be put into operation.

To improve the safety, the authors propose to integrate the entry system to the functional unit: to date electromechanical interlock devices allow the metal door opening only if the DC disconnector of functional unit is open. Since these devices could be out of order, the utilization of more simple and reliable mechanic interlocks systems, where both the disconnecting switch and the door
belong to the functional unit open/lock device, is suggested. The authors believe that the proposed actions can be considered as a starting point of a structured renewal development process, keeping in mind both the needing of standardization and the affordable prices.

5 Conclusion

The main problems of the railway infrastructures renovation is related to the technological change favoring the use of PLC technologies substituting the traditional electro mechanic technologies. Through these fundamental functions could be implemented for an improved management of the ESS instruments, like diagnostics, monitoring, and control. In the current work it has emerged that it is not at all granted that a change in technology of this kind in the railway context allows one to reach the expected results. A critical element relies in the software, to be realized according to the specific needs of the ESS instruments: all technical solution must be oriented to the standardisation of railway technologies and to the simplification of the ESS control processes.

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