

Study for the Integrated Automation of the São Paulo Subway System Rectifier Substations

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Abstract – This article shows a proposal for the integrated automation of the São Paulo subway system rectifier substations, supported on the gains of reliability which may be obtained in case it is implemented, and in the improvement of the efficiency of operation of the system open to question. To quantify these profits of reliability there is presented the development of the model of reliability of Markov devoted to the system of automation of rectifying substations. The used methodology proceeded to the lifting and analysis of the incidents when they were opened in the years of 2006, 2007 and 2008 in the rectifier substations of the subway of Sao Paulo, calculating HIS MTBF (Mean Time Between Failures). The study ends that the profit of reliability is significant in what it refers to the improvement of public transport with the application of the integration of the automation of the rectifying substations.

Keywords: Automation, Integrated automation system; rectifier substation; rectifier protection system.

1 Introduction

1.1 Need for expansion or modernization projects

Population growth and economy development have generated constant increase in the demand for public transportation passengers. Today, Brazil accounts for 15 urban railroad transportation systems. All these systems either need or already have expansion or modernization projects. Most of all subway systems employ electric traction systems. Therefore, the study on the integration of automation system in rectifier substations of the subway system is a must to minimize the effects resulting from the increase in demand, and to ensure the increase in reliability for the electrical power supply system.

1.2 The integration of the Automation as an Improvement Tool for the operation of the railroad system

Figure 1 exemplifies the Supervision and Control System, as identified by the “SSC” acronym, what, constitutes the system through which all services related to the operation of the line and shunting yard are supervised and controlled, involving the traffic, power, and auxiliary systems. The SSC is formed by a set of control subsystems. This system includes three operational subsets that work in an integrated manner.

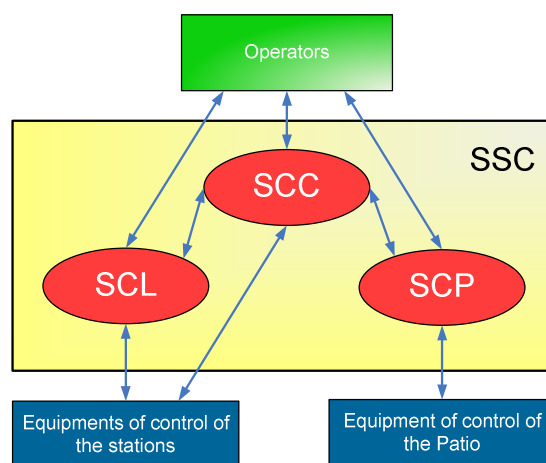


Fig. 1. Integration of the SSC - Source: Companhia de Companhia do Metropolitano do Estado de São Paulo - Metrô (2008)

- Centralized Control Subsystem – SCC – composed of control equipment and operating capabilities installed in the Operating Control Center (CCO) environment;
- The Local Control Subsystem – SCL – composed of operational control and capability equipment that is installed in both the stations that make up the line and the primary substations;
- Yard Control Station – PCP – composed of operational control and capability equipment installed in the Yard.

2 Description of the subway system automation

2.1 Integrated Service Control

It is an integrated control system that offers capabilities to the control and supervision of other services normally related to the operation of subway lines, such as:

- Electrical power systems, including rectifier and auxiliary substations and traction power distribution networks;
- Auxiliary station equipment;
- Communication equipment (CFTV, sound reinforcement, radio and others);
- System for the collection of tickets and control of passengers.

All these types of systems are integrated to the SSC allowing for all line operations to be concentrated in one single location. This architecture provides a great deal of efficiency due to the global information access in real time by all system operators and supervisors.

2.2 Architecture of the SCC, SCL, and SCP

The network architecture of the SCC, SCL, and SCP consists of a joint operation of the three separate local networks which interconnect to each other by means of dedicated equipment, called switches, and operate in a integrated manner as if it was one single network. This integrated form of actuation allows for the three networks to exchange data among each other whenever necessary. With all readiness and sophistications inherent to the client/server scheme, and to the concept of network interconnection.

- The first network, called Local Traffic Ethernet Network, composes a subsystem dedicated to the centralized traffic control.
- The second network, called Local Ethernet Network SCADA (Supervisory, Control, and Data Acquisition System), corresponds to the centralized control subsystem of functions type SCADA where all further line functions such as power and auxiliary distribution control and auxiliary and interfaces with the communication equipment will be processed.
- The third network, called the Common Local Ethernet Network, aggregates all SCC elements common to the two first networks, enabling the communication of these elements with the servers and the clients of traffic and SCADA.

2.3 Subsystems that are interfaced with the SCC, SCL, and SCP

The Supervision and Control System is characterized by its diversity of services associated with the line operation. In the SSC, all of them, the SCC, SCL, and the PCP, contribute in a well defined form of coexistence to the administration of all these interfaces, being SCC responsible for the centralization of actions. Therefore, the SCC constitutes a system type ICC (Integrated Control Center), that permits its operators the control of all these "peripheral systems" in a rational and integrated form from the SCC Control Room, also called herein Control Center or CCO.

Physically, all of them, the SCC, SCL and the PCP, in the case of the Yard, have communication channels dedicated with the equipment located in the stations, following a hierarchic process defined for a organized system operation administration.

The following systems and equipment, located in the stations and substations are interfaced with the SCC/SCL and SCC/PCP, as illustrated in Figure 2.

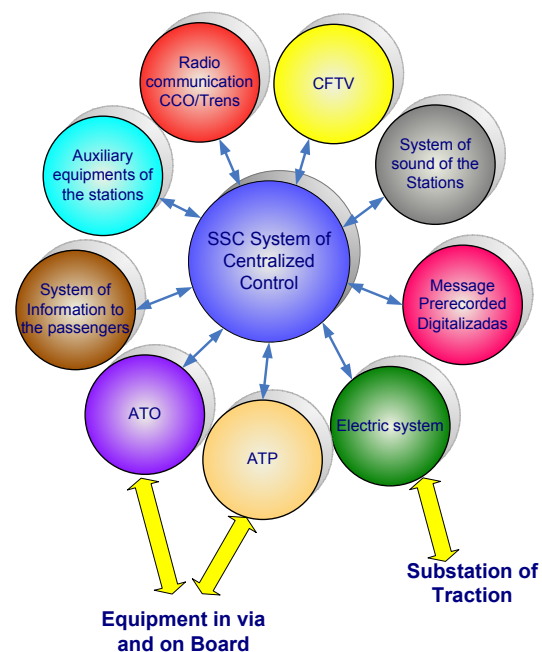


Fig. 2. Subsystems that are interfaced with the SCC

The SCC application functions are grouped in a manner that each group includes a service performed by the Operation personnel.

- Traffic Control Operation Services;
- Electrical Power control Operation Services;
- Auxiliary Equipment Control Operation Services
- Passenger Flow Control Services
- Ticket Collection Control Services

- Maintenance Support Services
- Planning Support Services

Figure 3 illustrates, in a simplified manner the basic needs for the exchange of updated data between the

various systems. A more detailed illustration of the data flow between the services may appropriately demonstrate the importance of fully integrated conception of the SCC.

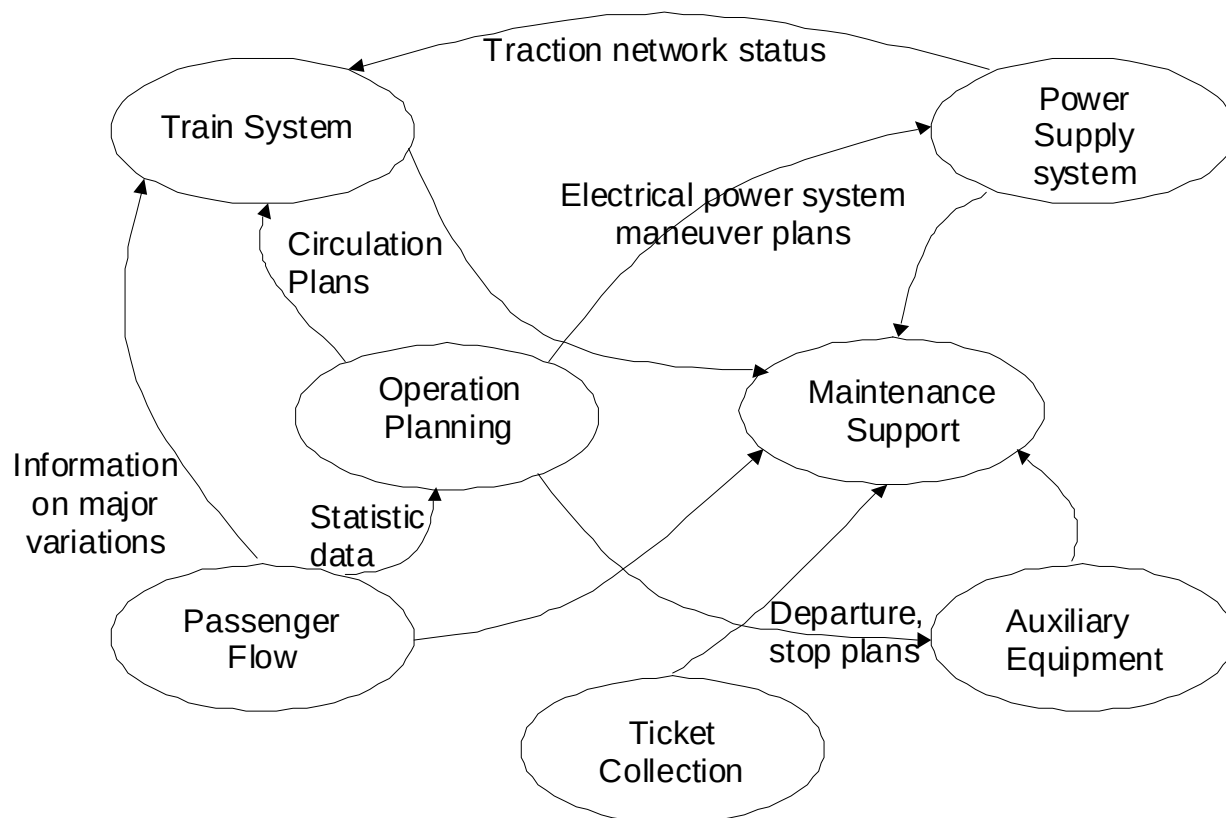


Fig. 3. SCC Service Interaction

The data flow shown in the previous Figure without a legend refers to the indications of diagnoses and failures that all system equipment sends to the Maintenance Support service.

3 Proposal for the Integration of the automation of subway system rectifier substations

Currently, there is a set of functions to meet the operation needs. However, one can note that it is possible to add more functions to the substation automation to increase the levels of reliability and flexibility of rectifier substations that operate in the Brazilian subway system. These are the results from the fact that today there are no corporate positions

that automate the decisions under system degraded conditions.

The integrated automation system in the subway system rectifier substations will integrate the protection, supervision, and control functions of the subway system rectifier substations. This system should cover the following characteristics.

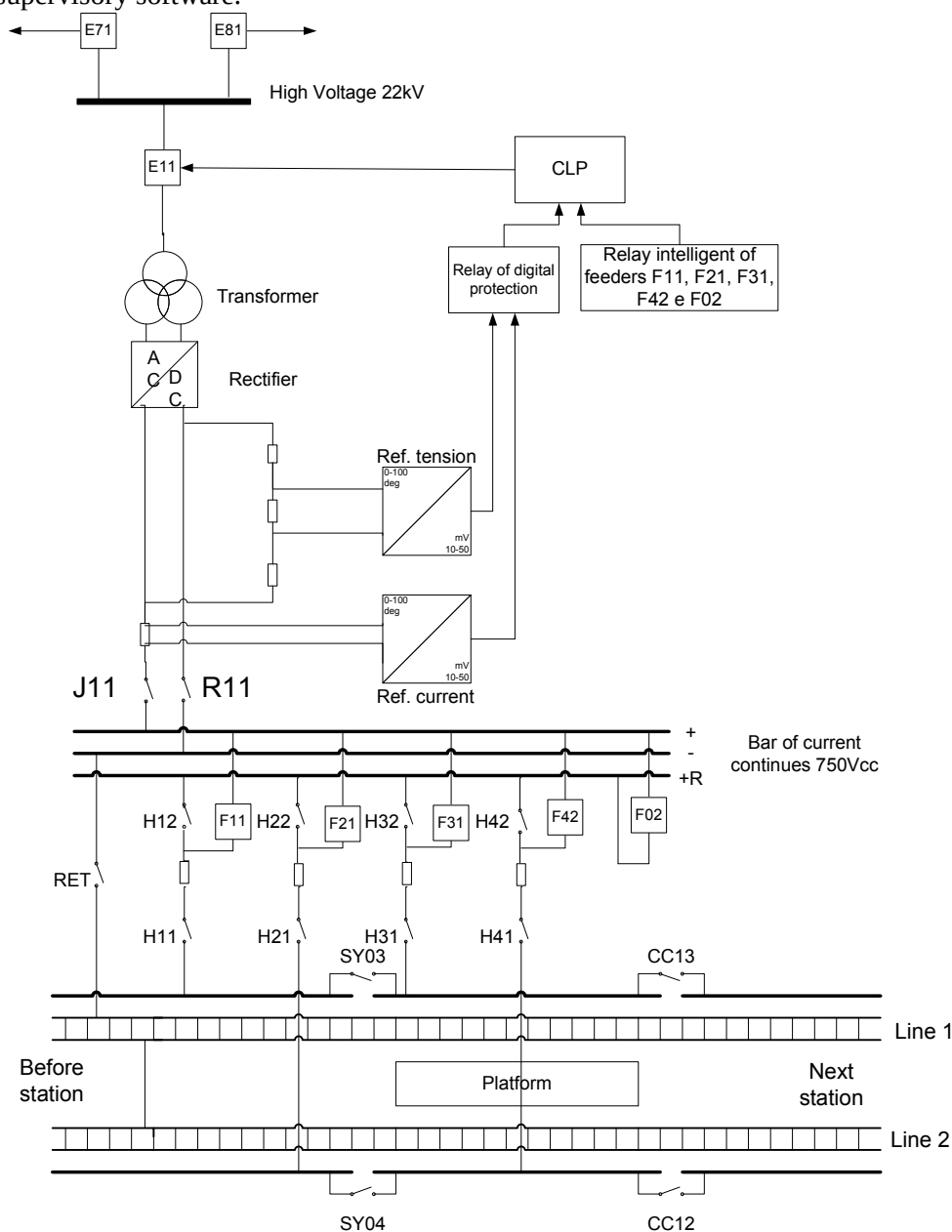
- Meet standard IEC-61970 related to the exchange of information between the control centers, and standard IEC-61850 related to the exchange of data in the substations;
- Be able to operate in the automatic and manual modes;
- Synchronize the digital protection relays through the GPS (Global Positioning System).

3.1 Hardware architectures for the Automation and Control of rectifier substations

The SER proposed architecture for the subway system is based on Technologies applied to the industrial automation. The technologies taking into consideration in this article will be:

- Microprocessed multifunction relays;
- Programmable Logic Controller;
- GPS antenna and receptor for the synchronization of the protection devices;
- Modbus RTU field networks, physical standard (RS-232 and RS-485);
- Synchronization network for the protection devices standard IRIG-B; and
- Market supervisory software.

The algorithm proposed in this article é based on the digital protection relays. All digital protection relays are networked. Each of the devices is connected to a data control and acquisition network, to a parameterization network, and to a synchronization network. In this study the Modbus RTU communication standard will be used for the control and acquisition network, and for the relay parameterization network. The synchronization of each device will be through the IRIG-B standard network connected to a receptor, and to an antenna obtaining the exact time through the Global Positioning System (GPS). Figure 4 shows the single-line diagram for the subway system rectifier substation.



Observation: CC13 e CC12 normally closed

Fig. 4. Single-line diagram for the subway system rectifier substation.

The operation and remote monitoring of all SER electrical devices are performed by a programmable logic controller that is responsible for the interconnection of the digital relays, thyristor triggering control, control network and data acquisition, and for the implementation of the control algorithm. Figure 5 shows the architecture of the SER automation system.

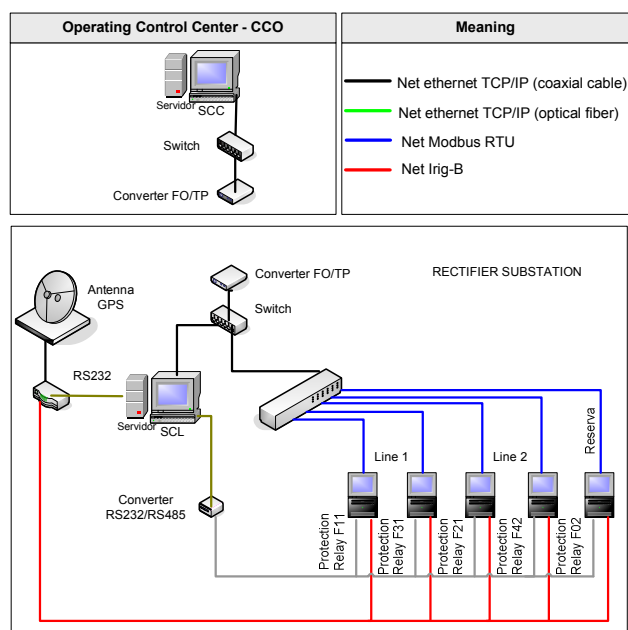


Fig. 5. SER automation system architecture

3.2 SER Automation and Control Software Architectures

The integration architecture to be implemented is based in the client/server model for the Exchange of information between the rectifier substation and the control Center. The same server will be able to receive data simultaneously from various clients. This allows for various rectifier substations to transmit information to the same corporate environment.

Figure 6 illustrates this situation where the rectifier substations are connected to the same server through the client.

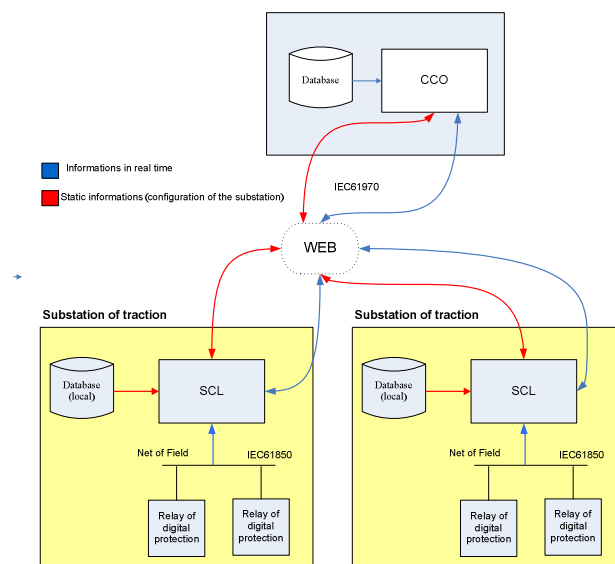


Fig. 6. Implementation of the client/server environment

Figure 7 shows a general view of how the data integration will take place in the rectifier substation with the subway railroad power supply system.

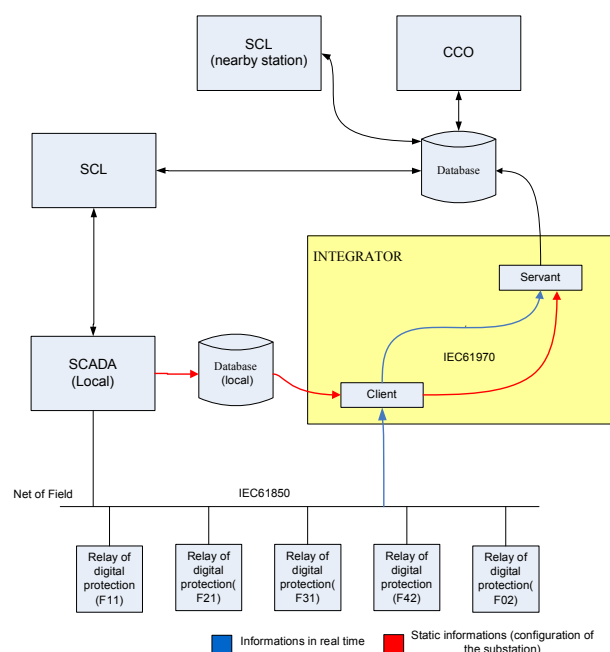


Fig. 7. Proposal for data integration.

3.3 Proposal for the Rectifier Substation Automation Control Algorithm

This new proposal for the integration of the rectifier substation, the architecture will show a control algorithm based on the current scientific and technologic developments for the digital protection relays, supervisory systems, and field networks. The purpose of the control algorithm is to replace the manual control for the automatic control, increasing

the reliability of the electrical traction power system. Figure 8 illustrates the algorithm for digital

protection Di/Dt actuations analysis in the subway system rectifier substations.

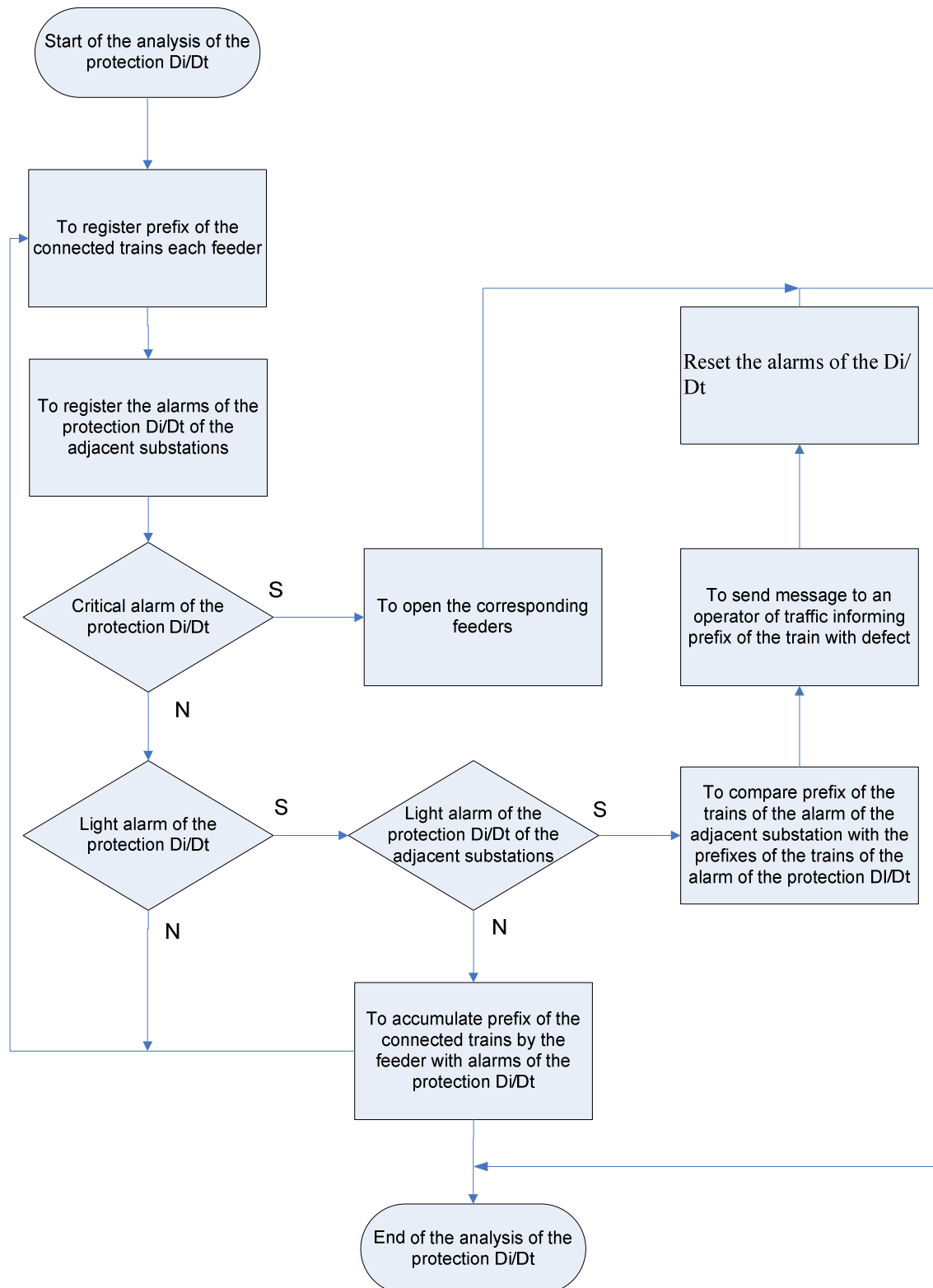


Fig. 8. Algorithm flowchart for Di/Dt digital protection actuations analysis.

4 Analysis and considerations for the use of the automation integration in rectifier substations

The rectifier substation automation integration, as existing in the power distribution companies (carriers), contributes to the management, reliability increase, and operation flexibility.

In order to enable the comparison between improvements and application of the automation integration, this article shows the results of failure cause researches in the rectifier substations of São Paulo city subway system. Based on the main requirements of standard IEC62278, employed worldwide in railroad industry for the management of reliability. A special attention was given to the technical specifications of standard IEC62278, RAMS (Reliability, Availability, Maintainability and Safety), taking it into consideration for the failure rating. Furthermore, theoretical and practical aspects were covered regarding the main RAMS tools and methods analysis employed, such as allocation of goals, prediction of reliability, block diagrams, FMECA, FTA, monitoring of field reliability, etc.

4.1 Main systems of rectifier substations - SERs

The rectifier substations (SER) are composed of systems with specific functions such as the rectifier group that converts alternating to direct current. They are provided with systems designed for protection in addition to systems for SER control, failure signaling, and communication, among others.

4.2 Study for obtaining the model of reliability from the subway system rectifier substations

The model, as shown in Figure 9, is the representation of the status in which a rectifier substation may be found, according to the vision of reliability, when the maintenance technique is applied based on the use conditions. In this figure it is possible of observing two statuses: status "1" the SER is operating normally and without signs of degradation; nonetheless, status "2" shows a failure in the rectifier substation.

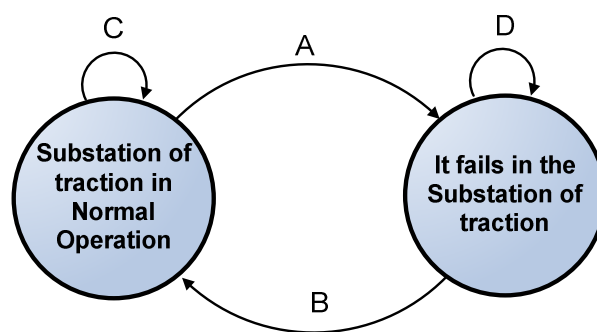


Fig. 9. Rectifier Substation Reliability Model using a Maintenance Technique Based on the Use Condition.

Table 1 shows transitions “A”, “B”, “C”, and “D” for this model, including their probabilities of occurrences.

Table 1: Transitions for the Rectifier Substation Reliability Model

TRANSITION	DESCRIPTION	PROBABILITY
“A”	SER failure	$A = \frac{1}{MTTF_{SER}} \cdot \Delta t$
“B”	SER corrective maintenance	$B = \frac{1}{MTTR_{SER}} \cdot \Delta t$
“C”	SER operating normally	$C = 1 - \frac{1}{MTTF_{SER}} \cdot \Delta t$
“D”	SER failure	$D = 1 - \frac{1}{MTTR_{SER}} \cdot \Delta t$

4.3 Analysis of the current reliability of SERs in the subway system

For the development of the work the occurrences opened in 2006, 2007, and 2008 in São Paulo subway rectifier substations were used. The methodology adopted was to survey the occurrences per line, calculate the SER MTBF by taking into consideration only the occurrences that were rated as failures. Furthermore, the influence of opened occurrences was analyzed, but from those which were not caused by failures in the rectifier substation, and to calculate the MTTR of line 3 rectifier substation.

In the São Paulo subway occurrences are opened for deviations detected in the operation of the equipment, and the corrective maintenance team is the one responsible for analyzing the occurrence rated as:

A – Failure
 C – Consequence of another failure
 E – Not identified
 F - Improper operation
 G – Vandalism
 H – Resulting from another equipment
 I – Natural fortuitousness
 L – Improper maintenance

P – Inadequate technical parameter
 W – External agent

Figure 10 shows the percentage of diagnostics from the occurrences of 2006 – 2008 – in SERs of SP subway.

Diagnoses of the incidents in the substations 2006 – 2008 – Metrô SP

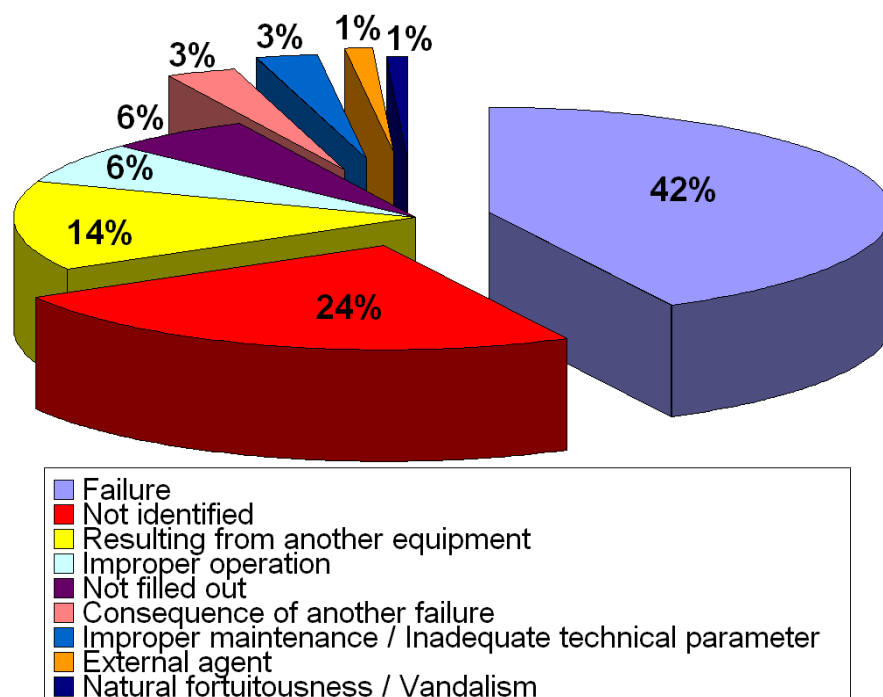


Fig. 10. Diagnostics of 2006 – 2008 – in SERs of SP subway

The automation integration provides, as one of its benefits, the reduction of the interferences in the system due to manual interventions. The values shown in graph of Figure 11 were calculated based

on the data from European subways which use train traffic system automation integration (CBTC – Communication Based Train Control).

Graphic of the diagnoses of the incidents in the substation with the integration of the automation

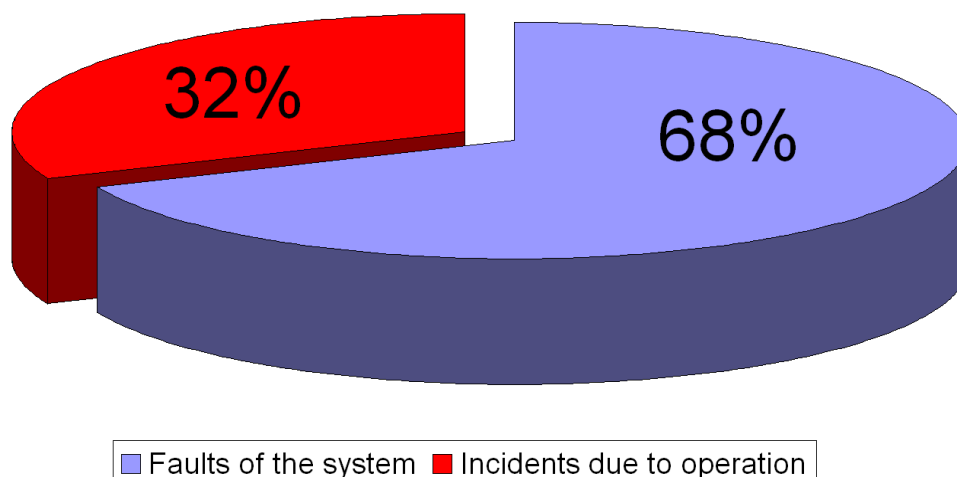


Fig. 11. Graph of the diagnostics of occurrences in SERs with the automation integration.

You can note that when compared with the graph of Figure 10, there is a significant reduction in the occurrences due to the manual interventions.

4.4 Automation integration performance analysis in the subway system SER

Figure 12 shows the result of the rectifying substation reliability calculations obtained by means of the

simulation of the reliability mathematic model run in the MATLAB software. In the graph, the red curve shows the current system reliability, and the blue curve illustrates the results obtained by means of simulating the model with the use of parameters from a system with the proposed rectifier substation automation integration.

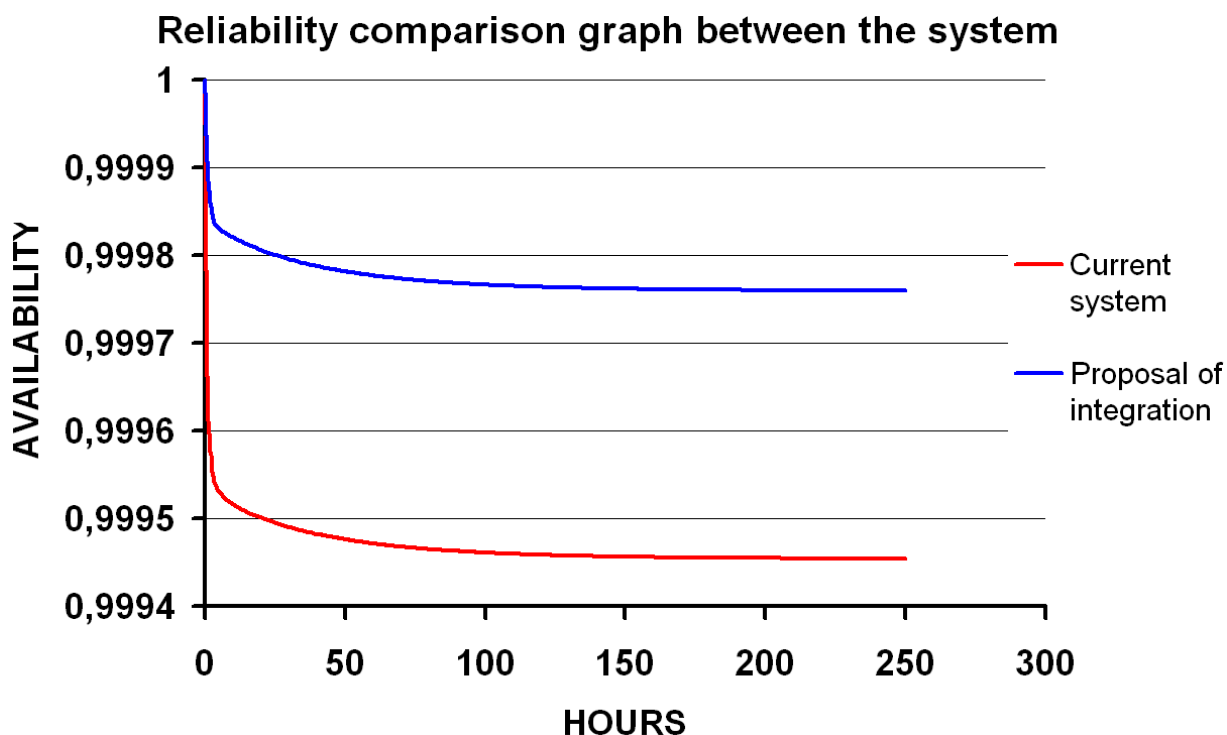


Fig. 12. Reliability comparison graph between the system without the integration and the integrated system.

5 Conclusions

As shown in this article, the Brazilian subway system rectifier substation automation system integration contributes to the increase in operational reliability. In the studied case, line 3 of São Paulo subway, the increase ranged from 0.9995 to 0.9998, even though this increase may not seem a great amount it is worth mentioning that the system will operate 210 minutes more without operational interferences. By taking into consideration the impact onto the global quality of life and collective transportation provided by São Paulo subway which, today, transports 2,310,503 passengers per day, the total gain over the reliability is significant.

Among the possibilities of continuing this work, there is the increment of the Markov model for the entire traction power system with the addition of failure rates from other components present in the system, i.e. fuses, switches, etc.

Another possibility of continuing this study is the improvement of the proposed integration model,

preparing a new control algorithm to increase the synchronization of stops and departures of trains in order to increase the regenerated power produced by the electrical traction power system.

Furthermore, it is also possible to carry out an economic study on the financial feasibility of the implementation of these techniques versus the benefits to be achieved, applied to a Brazilian scenario.

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