Automation proposal applied to Trolleybus current collector

Proposta de automação aplicada em coletor de corrente para Trólebus

Propuesta de automatización aplicada al colector de corriente de Trolebús

Evandro Rostirolla Bortoloto 1
Francisco Carlos Parquet Bizarria 2
José Walter Parquet Bizarria 3

Abstract

This work presents the main steps performed in the development of a system proposal to automate the operation of the current collector that is used in trolleybuses, aiming, mainly, to continuously monitor the contact with the overhead electric wire and also to provide the coordinated movement of collection in situations of circuit disconnection, in order to reduce the incident of collisions between the collector and the mechanical structure of this wire. These improvements are aimed at contributing to the quality of the public transport service, a factor that corroborates the expansion of new routes of mass public transport that use renewable sources of energy, replacing the traditional vehicles powered by combustion with fossil fuel. The method employed and the details contained in this proposal allow the use of an expressive part of the traditional design of the current collector, being suggested the substitution of parts, adequacy of the mechanical structure related to the fixation points of the components, installation of sensor elements, actuating elements, and programmable controller with dedicated algorithm for this application. The positive results observed in the computational evaluations of the electronic and pneumatic circuit, which are managed by a dedicated control algorithm for these systems, suggest that the resources and components proposed in this work when effectively integrated in trolleybuses will be able to meet the purposes for which they

1PhD in Space Sciences and Technologies, University of Basilia (UNB), Brasília, Brazil. E-mail: evandrobor@gmail.com Orcid: https://orcid.org/0000-0002-6355-6060
2PhD in Electrical Engineering, University of Taubaté (UNITAU), Brazil. E-mail: fcpbiz@gmail.com Orcid: https://orcid.org/0000-0003-2329-0883
3PhD in Electrical Engineering, University of Taubaté (UNITAU), Brazil. E-mail: jwpbiz@gmail.com Orcid: https://orcid.org/0000-0001-6167-2829
are intended.

**Keywords:** Automation. Current Collector. Public Transport. Trolleybus.

**Resumo**
Este trabalho apresenta as principais etapas realizadas no desenvolvimento de uma proposta de sistema para automatizar a operação do coletor de corrente que é utilizado em Trólebus, visando, principalmente, monitorar continuamente o contato com rede elétrica aérea e, também, prover o movimento coordenado de recolhimento em situações de desconexão do circuito, a fim de reduzir a incidência de colisões entre coletor e a estrutura mecânica dessa rede. Essas melhorias são direcionadas para contribuir com a qualidade no serviço de transporte coletivo, fator que corrobora para ampliar novas rotas de transporte coletivo em massa que utilizem fontes renováveis de energia, em substituição aos tradicionais veículos movidos a combustão com combustível fósil. O método empregado e os detalhes contidos nessa proposta permitem utilizar uma parte expressiva do projeto tradicional do coletor de corrente, sendo sugerida a substituição de partes, adequação da estrutura mecânica relacionada aos pontos de fixação dos componentes, instalação de elementos sensores, elementos atuadores e controlador programável com algoritmo dedicado para essa aplicação. Os resultados positivos observados nas avaliações computacionais do circuito eletrônico e pneumático, os quais são gerenciados por algoritmo de controle dedicado para esses sistemas, sugerem que os recursos e componentes propostos neste trabalho quando forem efetivamente integrados em Trólebus serão capazes de atenderem as finalidades para as quais se destinam.


**Resumen**
Este trabajo presenta los principales pasos llevados a cabo en el desarrollo de una propuesta de sistema para automatizar el funcionamiento del colector de corriente que se utiliza en Trolebuses, teniendo como objetivo, principalmente, monitorear continuamente el contacto con la red eléctrica aérea y, además, proporcionar la movilidad coordinado del captador en situaciones de desconexión del circuito, con el fin de reducir la incidencia de colisiones entre el captador y la estructura mecánica de esta red. Estas mejoras tienen como objetivo contribuir a la calidad del servicio de transporte público, factor que apoya la expansión de nuevas rutas de transporte público masivo que utilizan fuentes de energía renovables, reemplazando a los vehículos tradicionales propulsados por combustión de combustibles fósiles. El método utilizado y los detalles contenidos en esta propuesta permiten utilizar una parte importante del
diseño tradicional del colector de corriente, con la sugerencia de reemplazar piezas, adaptar la estructura mecánica en relación con los puntos de fijación de los componentes, instalar elementos sensores, elementos actuatorados y Controlador programable con un algoritmo dedicado para esta aplicación. Los resultados positivos observados en las evaluaciones computacionales del circuito electrónico y neumático, que son administrados por un algoritmo de control dedicado para estos sistemas, sugieren que los recursos y componentes propuestos en este trabajo, cuando se integren efectivamente en los Trolebuses, serán capaces de cumplir con los fines a los que están destinados.

**Palabras clave:** Automatización. Colector de Corriente. Transporte Público. Trolebús.

**Introduction**

The main measures developed by the countries members of United Nations was to reduce harmful gases emissions to the ozone layer, also to minimize other impacts related to the greenhouse effect. They are contained in the Kyoto Protocol (1997). These measures are highlighted in this Protocol, measures from fossil fuel burning, to provide for the growing need for urban mobility (Barczak; Duarte, 2012).

Several strategies are used in order to mitigate these gases emissions and contribute to the sustainable growth of the planet. In particular the use of clean technologies coming from renewable sources; the development of more energy efficient on-board systems and the encouragement of adhesion of non-polluting vehicles for mass public transport in urban areas (Silva; Sousa, 2005).

Among the different large motor vehicles that are applied to public transport on conventional public roads in large urban centers; those that use electric traction systems can be highlighted for this application, that is, equipped with motors and other devices that have the ability to convert electric energy into mechanics to provide the vehicle´s displacement (Magagnin, 2008).

In Brazil, the predominant type of vehicle used to meet the mentioned characteristics is called Trólebus (Trolleybus). This vehicle uses two current collectors installed on the roof and in its mechanical structure to connect to an overhead electric wire which has as its main purpose the supply of energy for several vehicles in the same line (Ferreira, 1995).

Nowadays, these collectors are mechanically driven by springs, and the vertical displacement is restricted by the contact with the overhead electric wire. In general, the
stability of this contact is affected mainly by the structural condition of the wire, the drivers’ ability to keep the vehicles within the tolerable operating lanes, and the maintenance condition of the carriageway bed of the circulation routes (Macedo, 2017).

Neglect to observe these conditions can contribute to the disconnection of the circuit, allowing the extremity of the current collector to exceed the upper level of the overhead electric wire. That may result in the collision with the support structure of this wire, damaging the collector, de-energizing the circuit that serves the trolleybus (Ferreira, 2015).

Incidents of this nature may occur due to incorrect operation of the mechanism that is designed to identify the sudden vertical acceleration of the current collector which comes from the disconnection with the overhead electrical wire supply, and this carry out the collection of this collector to the resting position (Grigorieva; Nikulshin, 2023).

With the goal of presenting measures to minimize the mentioned collision between the current collector and the overhead electrical wire support structure, this work presents the main stages of the development of a system proposal to automate the operation of the trolleybus current collector, aiming in this way to contribute to reduce incidents of this nature and provide better quality in the public transportation service.

**Objectives**

The main objectives of this work are: i) to propose basic sequence of steps to develop an automatic integrated application system to the standard current collector that is used in trolleybus, ii) present the most relevant benefits that can be obtained by implementing this system, iii) present a comparison between the technical, functional, and operational characteristics of the traditional system and the proposed automated system.

**Methodology**

The procedures established within the system, and which were applied in the development of the aforementioned automation proposal of the current collector is presented below:

- Carry out bibliographic research, mainly focused on identifying works whose concepts are based on the elements used to make the connection of trolleybus with the overhead electric wire.
• Define the functional and constructive requirements for the components of the proposed system.
• Elaborate an electronic, pneumatic, and mechanical circuit proposal, to compose an automatic and specialized system applied to the monitoring and control of the current collector set used to connect the trolleybus to the overhead electric wire.
• Establish the minimum characteristics that must be met for the main components of this automated system.
• Present control structure and high-level operation of current collectors.
• Elaborate text explaining the steps and expected results with the use of this proposal.

Theoretical Reference

According to Crosley (1960), the first experiments involving a vehicle with electric propulsion supplied by means of overhead wires were carried out by Werner Von Siemens in April 1882, in Germany. However, only at the Universal Exhibition in Paris in 1900, the Frenchman Lombard Gérin conducted an experimental line of trolleybuses, followed after two years by the German Max Shiemann, responsible for the first successful trolleybus installation.

The trolleybus can circulate on normal public roads and among other vehicles, and it has installed on the roof and its mechanical structure two collectors that have independent horizontal and vertical movements, both traditionally driven by springs to provide electrical contact with the overhead electric wire (Wolek et al., 2021). The main elements related to this type of transport are presented in Figure 1.
In Brazil, several lines were implemented between 1950 and 1960, mainly in the cities of São Paulo, Rio de Janeiro, Belo Horizonte, Niterói, Porto Alegre, Salvador, and Fortaleza. The main advantages and disadvantages of this type of vehicle when compared to public transportation buses, which use the burning of fossil fuel to propel the vehicle, are presented in Figure 2.

Figure 2

*Operational Characteristics*

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>High rate of energy efficiency.</td>
<td>Routes depends on overhead electric wire.</td>
</tr>
<tr>
<td>Reliability and durability of electric motors.</td>
<td>Power supply failure.</td>
</tr>
<tr>
<td>Silent operation.</td>
<td>Break in the overhead wire.</td>
</tr>
<tr>
<td>Less exposure to heat.</td>
<td>Higher cost of implementation.</td>
</tr>
<tr>
<td>Continuous acceleration and no bumps.</td>
<td>Exhaust of the current collector from the overhead wire.</td>
</tr>
<tr>
<td>Less environmental footprint.</td>
<td>Specialized labor for maintenance.</td>
</tr>
<tr>
<td>Zero emission of pollutants.</td>
<td></td>
</tr>
<tr>
<td>Absence of transmission.</td>
<td></td>
</tr>
<tr>
<td>Better drivability.</td>
<td></td>
</tr>
<tr>
<td>Lower maintenance cost.</td>
<td></td>
</tr>
</tbody>
</table>
4.1 Conventional Current Collector

The current collectors are used to establish contact and conduct the energy from the overhead electric wire to the control and operation systems of the trolleybus. These collectors are commonly installed on a support made of hardened metal profiles and fixed to the roof and mechanical structure of this vehicle.

Two current collectors are installed in each trolleybus, as shown in Figure 3. They have independent horizontal and vertical movement in order to guarantee the continuous connection to the overhead electric wire, during displacement of the vehicle on public roads (Hołyszko; Filipek, 2016).

Figure 3
*Trolleybus’ current collector*

4.1.1 Vertical Displacement

The vertical displacement of the current collector makes it possible to compensate for the variation in the height of the overhead electric wire in relation to the vehicle level during its displacement on public roads.

This movement is possible due to the degree of freedom existing in the joint located at the base of the cannon, as shown in Figure 4 (a), and by the force applied by means of the
set of tension springs. The limits of the vertical movement of the current collector are established through the restrictions indicated in Figure 4 (b).

**Figure 4**
*Vertical Movement*

These tension springs are sized and calibrated in the reference position to exert contact force, typically between 10 and 12 kgf of pole shoe with overhead electric wire. However, due to variations in wire height, situations may occur in which the contact force is outside this range, causing a reduction in the useful life of the electrical contact components located in the pole shoe.

4.1.2 **Horizontal Displacement**

The horizontal displacement of the current collector makes it possible to compensate the lateral misalignment of the trolleybus in relation to the position of the overhead electric wire during the displacement of the vehicle, allowing the driver to deviate from obstacles, perform maneuvers and turns. This movement is possible due to the degree of freedom existing in the center of the base of the cannon as shown in Figure 5 (a).

The limits of the horizontal movement, represented in Figure 5 (b), of the current collector are established by means of a restriction imposed by a flexible pole rope that interconnects the retractor to the upper end of the collector, as indicated in Figure 5 (a).
4.2 Retractor

It is an item similar to a reel installed in the back of the vehicle. Its internal mechanism is composed of two torsion springs each with different intensity of force and independent operation. The retractor’s main objective is to perform the following actions:

- Limit collector stroke: restriction that is due to the length established by the flexible pole rope that connects the retractor to the collector.
- Maintaining the tension of the pole rope: the condition is guaranteed by means of the force exerted by one of the torsion springs, regardless of the position of the collector allowing less response time when the retractor system is activated.
- Collecting the current collector: the mechanism provides the displacement of the collector to the rest position located in the central and upper part of the vehicle.

In situations where the contact shoe escapes from the overhead electric wire, there is a sudden vertical acceleration of the current collector due to the force exerted by the set of torsion springs located at the base of the cannon. In this condition, a trigger is activated in the retractor mechanism causing the second torsion spring to trip and releasing the contained energy, which has a higher intensity than the set of tension springs, providing the displacement of the collector to a support located in the rest position, as shown in Figure 6.
As a result of the activation of this mechanism, the vehicle is disconnected from the overhead electric wire and the power supply to the electronic and power system of the trolleybus is interrupted, causing the vehicle to stop, and interrupting the flow of buses at this point of the line. In this condition, it is necessary to act manually by a duly qualified and trained professional to carry out the sequence of steps that consist of:

i) Perform a visual verification in order to identify the integrity or existence of damage to the current collector and the overhead electric wire.

ii) In the event of any damage being identified communicate to the related department to carry out the relevant actions.

iii) If there is no damage, manipulate the current collector by means of the flexible pole rope to reestablish the connection to the overhead electric wire.

iv) Rearm the second torsion spring and drive the retraction mechanism.

v) Restart the electronic and power system of the vehicle.

The main elements related to the collection of the trolleybus current collectors are presented in Figure 7.
In some situations, it has been observed that the power collector retractors operate incorrectly. In these cases, the acceleration of the flexible pole rope is not identified or occurs with delay, allowing the upper end of the collector to go beyond the level of the overhead electric wire and this cause a collision with elements of the physical structure installed over the trolleybus circulation routes, which are used to provide the electrical energy to be captured and transferred to the vehicle.

Development

The development stage covers the definition of requirements and presentation of a system design proposal to automate the operation of the trolleybus current collectors as explained in the following sub items.

5.1 Requirements

The basic requirements that must be met for the development of the automation system to be integrated in the current collector that is addressed in this work are divided into functional and constructive and are described in Figure 8.
Figure 8

Requirements

<table>
<thead>
<tr>
<th>Functional</th>
<th>Constructive</th>
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<tbody>
<tr>
<td>RF 1 - Continuously monitors the contact with the overhead electric wire.</td>
<td>RC 1 - Allow integration to conventional current collector.</td>
</tr>
<tr>
<td>RF 2 - Each current collector must act independently.</td>
<td>RC 2 - Supply the control system with 24 Vcc.</td>
</tr>
<tr>
<td>RF 3 - Be able to use two stages of vertical movement.</td>
<td>RC 3 - Operate pneumatic system with maximum pressure of 10 bar.</td>
</tr>
<tr>
<td>RF 4 - Pose a horizontal movement stage.</td>
<td>RC 4 - Be easy to install.</td>
</tr>
<tr>
<td>RF 5 - Maintain the contact force with overhead electric wire compatible with conventional mechanism.</td>
<td>RC 5 - Use components of nature applied to the vehicle.</td>
</tr>
<tr>
<td>RF 6 - Simple operation and easy maintenance.</td>
<td>RC 6 - Have resistance to weathering and external environment.</td>
</tr>
<tr>
<td>RF 7 - Limit horizontal movement in +/- 45°.</td>
<td>RC 7 - Have interface for functionality configuration.</td>
</tr>
<tr>
<td>RF 8 - Display three points for emergency drives.</td>
<td>RC 8 - Reconnection equivalent to the traditional method.</td>
</tr>
<tr>
<td>RF 9 - To have reconnection drive of the collectors to the independent overhead electric wire.</td>
<td>RC 9 - Have emergency drives located next to the retractors, current collectors and driver.</td>
</tr>
</tbody>
</table>

5.2 Automation of Vertical Displacement

To meet this application in accordance with the RF 2, 3, 5, 6 and RC 1, 2, 3, 4, 5, 6, 8 requirements established in Figure 8, it is proposed in this work to replace the set of tension springs that exercises permanent lifting force on the chain collector, which is shown in Figure 9 (a) by two pneumatic actuators assisted by sensor elements and with dedicated control, allowing the coordinated movement of the collectors collection, whenever the overhead electric wire exhaust is identified or if this action is carried out through the activation of specific commands.

The main steps that must be followed to meet this proposed change are presented in Figure 8 and described below:

Figure 9 (a): this configuration is considered to initiate the proposed changes.
Figure 9 (b): Remove set of tension springs and related components.
Figure 9 (c): Remove spring tensioning support.
Figure 9 (d): Install base to fix the actuators support.
Figure 9 (e): to have a set of pneumatic actuators named “A” and “B”.
Figure 9 (f): to integrate the set of actuators in the chain collector.
5.3 Automation of Horizontal Displacement

To meet this application in accordance with the RF 2, 4, 6, 7 and RC 1, 2, 3, 4, 5, 6, 8 requirements established in Figure 8, it is proposed in this work to change the restriction of horizontal movement imposed by the length of the pole rope by a pneumatic actuator of specific length and stroke assisted by sensor elements and with dedicated control, which should be fixed in the area located at the base of the cannon, as shown in Figure 10 (a), which must operate depressurized so as not to generate resistance in the displacement, being activated only to allow the coordinated movement during the collectors collection.

The main steps that must be followed to meet this change are presented in Figure 10 and described below:

Figure 10 (a): This setting is considered to initiate the proposed changes.
Figure 10 (b): to have pneumatic actuators entitled “C” and brackets for fixing.
Figure 10 (c): Integrating actuator and supports to the current collector.
Figure 10 (d): Automation of horizontal displacement.
5.4 Monitoring Contact with Overhead Wire

In order to meet RF 1, 2, 6 and RC 1, 2, 3, 4, 5, 6, 8 requirements in accordance with Figure 8, it is proposed in this work to replace the support of the contact shoe located at the upper end of the current collector, which is shown in Figure 11 (a) with a support equipped with a position sensor, making it possible to identify the contact with the overhead wire in a situation where the voltage level supplied by the monitoring system is zero. This condition comes from the power outage or discontinuities caused by elements that make up the overhead wire.

The main steps that must be followed to meet this change are presented in Figure 11 and described below:

Figure 11 (a): This configuration is considered to initiate the proposed changes.
Figure 11 (b): Remove support from the contact shoe and its related components.
Figure 11 (c): to have support equipped with position sensor.
Figure 11 (d): to integrate a set called position detector in the current collector.
The support proposed in this application is composed of two parts, one fixed and equipped with photoelectric tubular sensor and the other articulated and equipped with photoelectric tubular receiver, as shown in Figure 12 (a). The movement between the parts is possible due to the existing degree of freedom and applied force.

The command signal from the sensor is altered due to the light beam generated by the sensor, i.e., in situations where the collector is disconnected from the overhead electric wire, the nominal light beam is not captured by the receiver, as shown in Figure 12 (b), a condition that is altered after connecting the collector to the overhead electric wire, causing alignment of the elements and detection of the nominal light beam, as shown in Figure 12 (c).

**Figure 12**

*Position sensor activation*

5.5 Drive and Control Circuit

To meet the modification proposed in this work in accordance with the RF1, 2, 6, 8, 9 and RC 1, 3, 4, 6, 7, 9, 10 requirements established in Figure 8, it is necessary to integrate a control system containing a dedicated programming, sensor elements to monitor the signals required for control, means of command to enable external agents to act on the system and pneumatic actuators to provide the necessary force to the current collector.

The integration of these elements has the objective of providing the adequate decision making of the system due to the events related to the vehicle operation, being the main items that compose these systems presented in
Figure 13, in which the simplified diagram represents the items assigned to the two current collectors.
5.6 Algorithm

Among the various functions that can be programmed with the resources contained in the Programmable Logic Controller (PLC) proposed for this application, those necessary to define the logical sequence of instructions designed to carry out the automation of the trolleybus current collector were considered.

The algorithm elaborated establishes the orderly sequence of actions to be executed in order to manage the system, which uses as a basis, mainly, the previously defined data arrangement and information that are constantly supplied through sensor devices and command elements, which will determine the signals that will be generated by the control to meet each task.

In this sense, a specific sequence of actions foreseen for this algorithm is represented in Figure 14, by means of a synthetic flowchart that portrays the main steps of the programming proposed in this work.
5.7 Dimensioning of Pneumatic Actuators

Currently, the trolleybus fleet in operation is composed of vehicles of different models and manufacturers, each containing particular constructive characteristics that can influence the main variables to be considered in the design of pneumatic actuators.

Based on these characteristics and the RF 5, 6 and RC 3 requirements established in Figure 8, numerical models were developed with the goal of assisting in the execution of the calculations to be used in the proposed application.

The free body diagram presented in Figure 15 contains the information used to establish the numerical model referring to the vertical displacement of current collector.
From the information contained in this figure and the relevant mathematical definitions, it is possible to dimension the force exerted by means of equation (1) for the pneumatic actuators presented in Figure 9 (e), being the distance defined by $\overline{AGp}$ for actuator “A” and the distance defined by $\overline{GpC}$ for actuator “B”.

$$F_p = m_p \cdot g \cdot \frac{L_a \cdot h_p - r_a \cdot h}{L_a + L_r} \cdot \frac{d_p \cdot h_p^2 \cdot \left(1 - \frac{h}{L_a}\right)^2 + d_a \cdot m_a + L_a \cdot m_r}{r_a \cdot h_p \cdot \sqrt{h_p^2 + r_a^2 - 2h_p \cdot r_a \cdot \frac{h}{L_a}}}$$

The nomenclatures contained in this equation have the following meanings:

- $F_p$: force of the pneumatic actuators A and B [N].
- $m_p$: mass of the pneumatic actuators A and B [kg].
- $g$: gravitational acceleration [m/s²].
- $L_a$: length of the current collector [m].
- $h_p$: distance from the articulated point to the attachment of the pneumatic actuator B [m].
- $r_a$: distance from the articulated point to the attachment of pneumatic actuator A [m].
- $h$: distance from the articulated point to the end of the current collector [m].
\( d_p \): actuator length B [m].

\( d_o \): distance from the articulated point to the center of mass of the current collector [m].

\( m_o \): mass of the current collector [kg].

\( m_r \): mass related to the counted with overhead electric wire [kg].

To dimension the actuator assigned to the horizontal movement it is necessary to make the particular considerations of this application, in this sense, it is presented in Figure 16 (a) the free body diagram with the main points of the set proposed for the current collector, being presented in Figure 16 (b) the most relevant for this application.

**Figure 16**

_Free body diagram – (a) Lateral view and (b) Top view_

Using the points considered in Figure 16 (b) and relevant nomenclatures, the free body diagram presented in Figure 17 contains the information used to establish the numerical model regarding the vertical displacement of the current collector.
From the information contained in this figure and relevant mathematical definitions, it is possible to dimension the force exerted by means of equation (2), for the pneumatic actuator presented in Figure 10 (c) being the distance defined by $\overline{DE}$ referring to the actuator “C”:

$$F_{p2} = (m_a + m_p) \cdot g \cdot \frac{L_g}{L_d} \cdot \frac{\cos \varphi \sin \varphi}{\sin (\varphi + \varphi_2)} \cdot \cos \varphi = \arcsin \frac{w}{\sqrt{L_a^2 - h^2}} \quad \text{e} \quad \varphi_2 = \arctan \frac{L_d w}{L_{p2} \sin \sqrt{L_a^2 - h^2}}$$

The nomenclatures contained in this equation have the following meanings:

- $F_{p2}$: force of the pneumatic actuator C [N].
- $m_a$: mass of the current collector [kg].
- $m_p$: mass of the pneumatic actuator C [kg].
- $g$: gravitational acceleration [m/s²].
- $L_g$: distance from the articulated point to the center of mass of the current collector [m].
- $L_d$: distance from the articulated point to the clamp of the pneumatic actuator C [m].
- $w$: distance from the articulated point to the end of the current collector [m].
- $L_a$: length of current collector [m].
- $h$: distance from the articulated point to the end of current collector [m].
- $L_{p2}$: length of the pneumatic actuator C [m].
- $\varphi$: angle between the side of the vehicle and the current collector [°].
- $\varphi_2$: angle between the side of the vehicle and pneumatic actuator C [°].
5.8 Difficulties encountered

To make possible the development proposed in this work, some previous steps were necessary among them, field activities together with public transportation companies in São Paulo City to evaluate, mainly, the operation of the vehicle, the procedures adopted for reconnection, characteristics of the overhead electric wire, differences between the vehicles used, definitions of requirements, among other particularities related to the use of trolleybuses.

Among the steps performed in the field, the characterization of the current collector required more time and resource, due to the unavailability of technical documentation for this item, requiring reverse engineering of the mechanism.

For this activity, a current collector was disassembled being its parts and pieces analyzed by a qualified team in order to reproduce them electronically with resources contained in the virtual development environment called SolidWorks®, of the manufacturer Dassault Systèmes S.A., which uses parametric computing from elementary geometric operations to elaborate three-dimensional shapes (Shih; Schilling, 2020).

Results

The automation proposal of the current collector presented in this work allows adapting the legacy through the replacement of parts, adaptation of the mechanical structure related to the fixation points of the components, installation of sensor elements, actuator elements and programmable controller containing dedicated algorithm.

The main functionalities established in the controller and elements contained in the diagram presented in
Figure 13, were validated through computational simulation that represents the limit of the considered requests, showing that they are adequate for the proposed application and superior in the safety criteria, response time and failure rate, when compared to the traditional mechanism of the current collector.

In this context, the main differences between the mechanically driven current collector by springs and the model containing components that allow its automation, which is proposed in this work, are presented in

Figure 18.

Figure 18
Conventional and automated current collector

The signal provided by the electronic position detector allows the controller to identify the exhaust of the current collector from the overhead wire and to send in adequate time the relevant commands to the actuators that perform the vertical and horizontal movement, providing the sequence of steps foreseen for the displacement of the collector to the rest position.

The logical sequence of operations of the system can be interfered by means of manual command carried out by the operators, in buttons arranged in specific locations allowing the reconnection of the current collector to the overhead electric wire or placing the system in
emergency mode, condition in which the electronic control and sensing system is kept energized and inactive, while the pneumatic energy circuit is depressurized which makes possible the manual movement of the collector.

The numerical models presented in equations (1) and (2) allow determining the necessary force of the pneumatic actuators according to the characteristics of each vehicle and overhead electric wire, because these models take into account the main variables related in the proposed system.

**Conclusion**

The positive results observed in the computational evaluations of the electronic and pneumatic circuit integrated to the algorithm, which are proposed in this work; suggest that the resources and components established to automate the current collector for trolleybus will allow operators to perform the operation and maintenance of the system in an intuitive and safe way.

The resources provided with the automation integration aim at: i) continuously monitoring the contact with the overhead electric wire; ii) identifying the current collector’s exhaust; iii) performing coordinated collection movement; iv) maintaining constant wire contact force, and v) reducing the incidence of collisions of the current collector with the overhead electric wire structure.

The possibility of automating the traditional mechanism seeks to contribute to the implementation of this system in the trolleybus fleet in operation, improving the quality of the collective transportation service provided by this type of vehicle, a factor that corroborates the expansion of new routes using renewable energy sources, replacing the traditional vehicles powered by fossil fuel combustion.

The expressiveness and details contained on the system proposed to automate the trolleybus current collector provide users with simple and intuitive operation, and these conditions minimize possible misunderstandings and facilitate the use of the system.

This proposal of automation of the current collector was presented to the trolleybus operators, maintenance teams and related people, being observed interest in the implementation of the system for functional tests resulting from the operational benefits, reduction of the damages to the overhead electric wire and lower downtime of vehicles, factors that contribute to the return of the investment.
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