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SELF-CONFIGURABLE AND SELF-STEERING ROBOTIC STRUCTURE FOR INSPECTION OF ELECTRIC POWER DISTRIBUTION LINES

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Abstract. *Electricity distribution companies seek a way to improve the inspection process of its power distribution lines that currently is not efficient. There are several researches aimed at developing methods for automated inspection, but these focus on transmission lines. The characteristics of the transmission lines are usually very different compared to distribution lines. For this reason, this paper proposes a new robotic structure capable of running along the three cables of an aerial primary distribution line. It has as important features: i) three motorized wheels, each one running over one phase of the primary line; ii) self-steering wheels i.e., wheels capable of aligning to the cable direction; iii) a self-configurable structure that, besides supporting the three wheels, is capable of adjusts the wheel position according to the distance among distribution line cables and; iv) electric isolation compatible with the primary line voltage. This structure can be equipped with a variety of sensors to allow automated inspection of distribution line components. The electrician controls and proceeds the inspection from the ground level. The robot structure is presented, a prototype is constructed and by field tests, the effectiveness of this structure demonstrated.*

Keywords: *distribution line, robotic structure, automated inspection, adaptable.*

1. INTRODUCTION

The electricity system is composed of several subsystems. Power plants, transmission lines, substations and distribution lines are some of those subsystems. Each one must work correctly for a non-interrupt power supply and for a good energy quality. To avoid system failure and consequent interruption in the power supply, inspections are carried out to detect devices that show some indicatives of abnormality. It is often possible to predict a failure by analyzing device conditions and plan a preventive maintenance.

Inspection of distribution power lines is done on components like: insulators, jumpers, cables, crossarms, poles and the surrounding vegetation. Nowadays, the inspection process is done manually by visual inspection, using for example thermo-camera for identifying hot spots. Thus, the inspection procedure is time consuming requiring that the electrician go along the line, doing the inspection pole by pole. In addition, such manual inspection presents lack of accuracy since many times the judgment is subjective and most of failures may be unnoticed by the electrician.

With the increasing complexity of the energy distribution system, the automated inspection is nowadays a clear need. In response to this need, many projects are being developed concerning inspection of electric power networks, but most of them focus on the transmission lines.

The aim of this work is to propose a robotic structure for inspection of electric power distribution networks. Such robotic structure should take advantage of the conditions of distribution network to minimize the difficulties of movement and facilitate the implementation of a system with an algorithm for identifying the conditions of the network elements.

2. CHARACTERISTICS OF THE DISTRIBUTION POWER LINE

On conceiving a robotic structure for inspection, some considerations are made concerning power distribution network. This work considers a traditional aerial distribution network adopted in Brazil, which is responsible for conducting electricity from substation to distribution points or straight to the consumer. Generally, these distribution lines are composed of a primary line with a voltage of 13.8 kV and a secondary line with a voltage of 110/220V (Elektro, 2009a; Elektro 2010). The primary line consists of three conductors that run on the highest portion of a pole. The secondary line is set at lower height. The secondary line presents a large variety of configurations including larger types of components compared with the primary line. Below the secondary line, the problem increases since these portions are used for telephone, cable TV or cables for public illumination systems. Therefore, at this point, this work defines that the robot will run the primary line.

The conductors of the primary line are bare made of copper or aluminum. The conductors are anchored to the cross arms through ceramic insulators. And the cross arms are firmly bolted to poles (Elektro, 2008). The cross arms can be made by wood, steel, fiberglass or polymeric materials and have a length, which vary between 2 meters to 6 meters. Figure 1 shows an example of cross arm. The poles are set at intervals of 80m for systems in which there is only primary network (13.8kV) and 40m for networks that have both primary and secondary (110/220V). The poles are generally made with concrete circular profile or H-profile and, although not usual, can also have wood circular profile (Short, 2004).

The distances between conductors of the primary network may vary between 0.6 meters to 1.2 meters. In some cases, these distances are not uniform and the conductor at the middle is a little closer to one of the external conductors. This may cause a difference between 0.1m to 0.6m. In those cases, the arrangement of the conductors in the cross arms is alternated at each pole so as to keep the load on the poles balanced.

When considering a robot running along the primary line, some obstacles should be considered. The most common obstacles in the primary network are curves, insulators, cross arms, pole top and jumpers. It is assumed that the robot should transpose these obstacles. However, networks also have other types of obstacles such as bifurcations (Fig.1(b)), junctions at different levels and line terminations. Since these obstacles are less usual, they are not considered to design the robot.

(a) (b)

Figure 1. Usual electrical distribution lines. (a) Simple path, (b) Complex path.

3. CURRENT INSPECTION METHODS

Currently, electric companies use basically two methods for inspection of distribution power lines. These methods are completely manual, dependent of the direct activity of employees. Those methods are classified into two groups: visual and by contact. In the visual method, the electrician travels along the line watching carefully the occurrence of damage, from the ground level (Elektro, 2009b). For this, electrician can make use of the following types of instruments: binoculars, infrared cameras (Fig.2), ultrasound detectors and radio interference equipment.

Infrared cameras, ultrasound sensors and radio interference equipment are considered auxiliary and allow observing heating points in the network (Short, 2004, Sheppard, 2011, Elektro, 2011). Another method makes use of an instrument called a pyrometer. The measurement is made through the contact of the instrument with the object to be inspected (CENF *et al*., 2004). The temperature checking with the pyrometer is made in order to determine devices with abnormal temperature. These devices are inspected to check for an imminent failure.

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Figure 2. Inspection of elements aided by IR camera.
Source: http://irisbuildingsciences.com

4. RELATED WORKS

There are many studies concerning robots for automatic inspection of electric power lines. However, most of those studies deal with robots for inspection of transmission power lines. Despite this, the way to overcome obstacles and perform movements in some cases can be adapted to the inspection task of distribution power lines.

These researches deals with flying robots or climbing robots. Perhaps the use of flying robots has been inspired by the current use of helicopters for inspection of transmission power lines. Recent researches on flying robots deal with autonomous flying robots, i.e., those that are not controlled by human operators. In this case, the robot should follow a power line while keeping a safe distance. The navigation of the robot can be done in various ways and the main one is through computer vision. For example, Campoy *et al*., 2001 presents a solution using stereo vision.

The flying robots have the great advantage of transposition any obstacle. However, although technically feasible, the use of flying robots has problems related to the automation of power line tracking, failures on visual defection as well as the necessity of keeping a safety distance from the power line. All of the above mentioned problems are related to the acquisition of high-quality images, which is hampered by helicopter vibrations and movement (Katrasnik, et al., 2010). In some cases, vegetations can obstruct the vision of flying robot.

The alternative to flying robots is the climbing robot. Most robots presented in articles, moves suspended on the transmission line. In this kind of robots, complex mechanisms for perform the transposition of obstacles is required. An example of structure of climbing robot is presented by Tavares and Sequeira (2004) where the structure is composed by a central body, two lateral arms and a central arm. The central arm is used to help maintaining stability when overtaking obstacles. Additionally, there are claws at the extremities, which can grab the line and when there are no obstacles, the movement is like a worm and when overcoming an obstacle, the movement is a statically stable to variation of the brachiation movement. Other works can be seen on Katrasnik, et al. (2010).

5. ADAPTATIVE STRUCTURE

The biggest challenge when developing the robotic structure is to provide stability and conditions to overcome all obstacles, without forgetting to, always, maintain the weight below a certain value.

Figure 3 shows the schematics of the robot proposed in this work. It is conceived to has three contact points, ensuring a stable movement along the primary line. The use of three supporting points has the advantage of keeping the center of gravity internally of the tripod contact (Fig.3). Moreover, as the distance between the supporting points is large, a small difference in height between the cables can be compensated. The only limitation is that the height difference between cables is not greater than the height of the wheels.

With the load conveniently distributed on the robot structure, each cable support one third of the total weight of the robot. This prevents the cable reaches the limit value for the traction applied to them.

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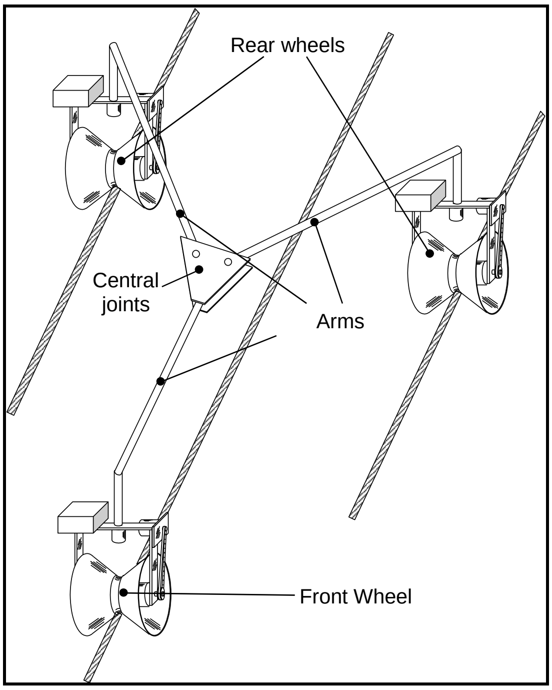

Figure 3. Schematic representation of structure on the distribution line

According to the power company current standards concerning power line network, there is no warranty that the distance between cables of the distribution line are always constant. Therefore, in the proposed robotic structure, two of the three arms that compose the robot, have angular degree of freedom to allow the robot to adapt to different distance between cables (fig.4). This feature is important when the robot performs curves. When approaching curves, the distance between the cables decreases and the distance between wheels has to vary accordingly. Due to this capability of varying automatically the configuration of the arms, the structure is named self-configurable structure.

The material chosen to construct the frame arms was glass-reinforced plastic (fiberglass) because this material has interesting mechanical and electrical properties for the application. This material has a high dielectric constant and combines its light weight with strength.

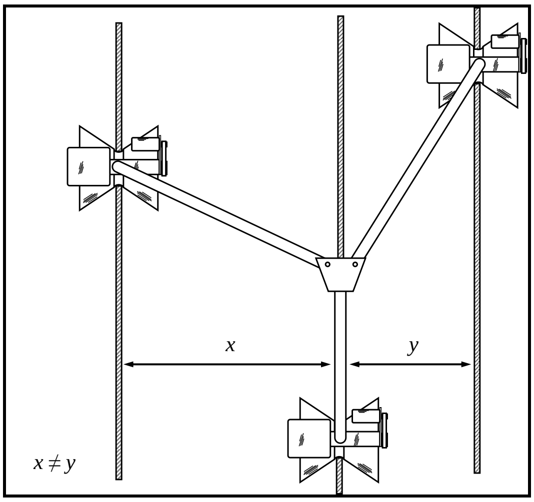

Figure 4. Robot adaptation to different types of distribution lines

5.1 Robot Wheels

The robot wheels are designed having in mind the obstacles to be overpass. The double conical geometry is elected to assure, in all situations, the contact with the surfaces of the wires, insulators and jumpers. In addition, this geometry allows self-guidance (or self-steering) of the robot. The weight of the robot always forces wheel be aligned to the cables and the cable fitted in the channel between the cones.

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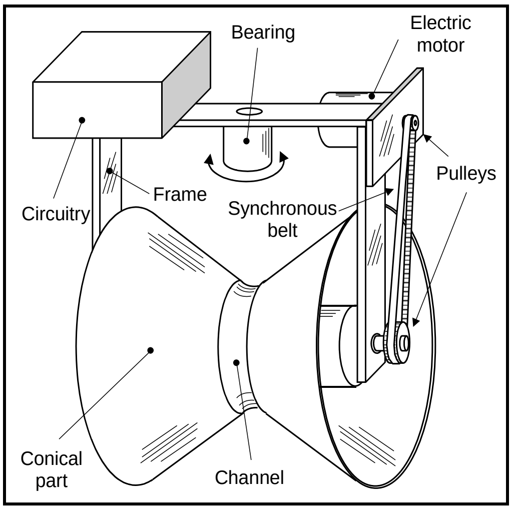

Figure 5. Details of the wheel

The wheel has at its middle part a cylindrical channel with a diameter of about 20mm. This diameter is larger than the diameter of the cable according to the distribution company standard (Fig.5). The wheel rotation forces the wheel to align its axis perpendicular to the axis of the cable, due to the forces generated by the cable/wheel conical surface as shown in Fig.6. Moreover, the double conical geometry prevents robot for falling from the cables.

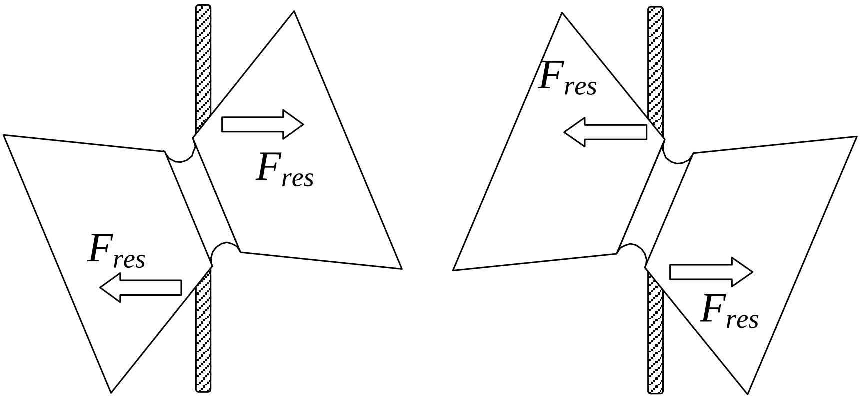

Figure 6. Alignment of the wheel. Normal restoring forces are shown.

When the wheel overpasses an isolator, the robot structure may oscillate and as consequence, may momentaneously lost one contact point. However, other two contact points are maintained. After transposition, the conical angle of the wheel and the weight of the structure, make the cable accommodate into the cylindrical channel.

Latex tubes are also used to increase the friction between the wheel and the cable because they are soft and have a high coefficient of friction. Due to the high flexibility, latex tubes easily conform to cables and obstacles. Thus the effective contact area is increased and, consequently, the friction force between the wheel and the cable increases. In a further test, the wheel trapped in a portion where the cable is curved in a concave way. Even though, the wheel kept the traction force and could transpose the obstacle. In order to overpass larger obstacles, various strips of latex tubes were tied on the wheel channel as shown in Fig.7.

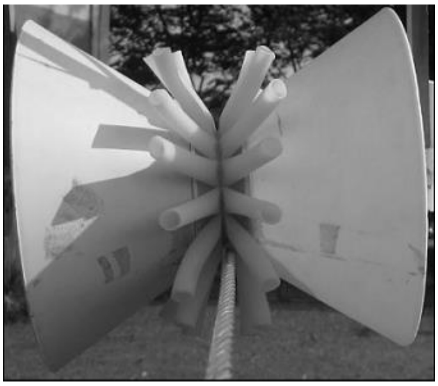

Figure 7. Arrangement of latex tubes on the wheel

5.2 Robot Joints

As can be seen in Fig.3, the proposed structure has three articulated arms that enable adaptation of the structure to different types of distribution lines. The joints of the wheels with the joints of the arms allow the execution of curves. The joints of the wheels have sliding bearings and movement limiters, preventing wheel to rotate 2π radians.

5.3 Transposition of obstacles

The main obstacles considered are curves, insulators, pole top at most 300mm and tensioners. Figure 8 illustrates the transposition of an insulator and the pole top.

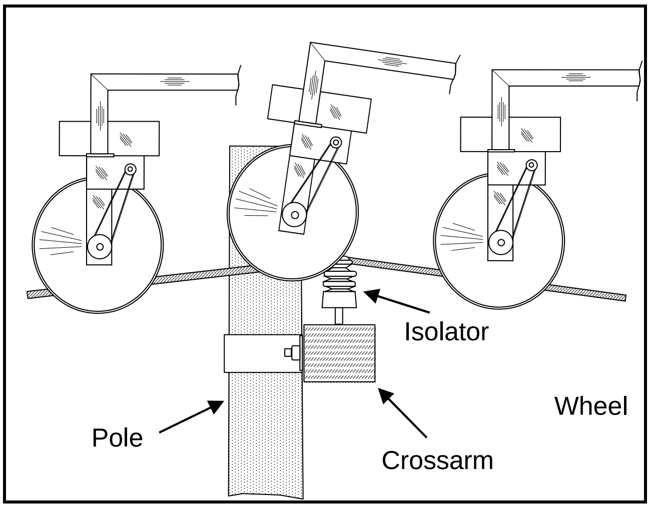

Figure 8. The transposition of an isolator and a pole top.

There are standards for the construction of distribution lines, but it is found that in some cases, these standards are not observed. Thus, despite efforts to cover most of the obstacles, in some cases it is necessary to remove the structure of the distribution line. Even procedure is not troublesome since the entire structure weight 4kg and so it is possible to handling it with the aid of hot sticks and aerial buckets.

5.4 Transmission and motors

The actuators for the motion of the robot structure must be well selected and calculated to allow transposition of the most difficult obstacles. In addition, the strategy used in force transmission represents a significant portion of the weight of the entire mechanical assembly. The power transmission to wheels must not offer risk to the distribution network, such as short circuits. The power transmission must occur at different angles, because the robot joints have to adapt to the network, and to overpass obstacles.

Some solutions are possible such as transmission by fluids such as oil or even air, because the hoses are flexible and can adapt to the structure. However, those solutions are difficult to implement due to the elements required for transmission. Another solution considers using universal joints and long transmission shafts made of non-conducting

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material. In this case, all electric motors to drive the wheels are concentrated in one of the three arms. The torque is transmitted from each motor to each wheel by a long shaft of isolating material and a universal joint. This ensures that there is no risk of causing short circuit between phases of the primary line.

However, the solution adopted here is based on decentralized electronics. Each wheel has a module containing a battery, motor, data transmission and reception circuit and controller. The transmission and reception of data is performed by wireless technology. Details of the control are described in other work.

6. TESTS

Small segment of a distribution line, consisting of four poles and the main types of obstacles was built to check the operation of the structure (Fig.9).

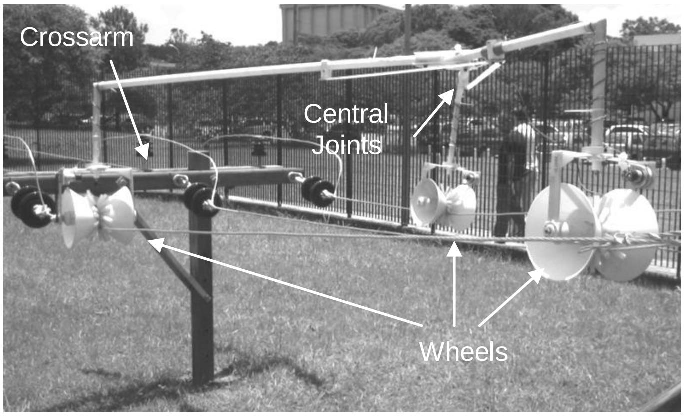

Figure 9. The structure under test

Regarding movement of the structure, we used three DC motors with maximum supply voltage of 24 volts. Those motors were connected in parallel to a power supply. The testing portion was not energized, and therefore, for testing, there was no risk of short circuit.

Tests results shown that the proposed structure is able to transpose the majority of obstacles with the structure keeping the stability. As expected, the self-alignment functionality of the wheel as well as the auto-configurable capability of the structure composed by the three arms demonstrated to be effective. As previously mentioned, when approaching curves, there is a decrease in the distance between the outermost cable of the distribution line and the structure is easily adapted to this change.

Problems were observed when transposing jumpers. While attempting to transpose the jumper, the wheel goes over the curved portion of the cable, but the cable collapses due to the weight of the robot. As consequence, the wheel fallen from the cable. In this testing set up, it was not possible to tension the cables enough as in a real network.

With the exception of the jumpers who had low stiffness, the wheel structure has remained aligned with the cable and thus always moving in the right direction.

7. CONCLUSIONS

This work proposed a new robotic structure capable of running along the three cables of an aerial primary distribution line. It has as important features: i) three motorized wheels, each one running over one phase of the primary line; ii) self-steering wheels i.e., wheels capable of aligning to the cable direction; iii) a self-configurable structure that, is capable of adjusts the wheel position according to the distance among distribution line cables and; iv) electric isolation compatible with the primary line voltage. This structure can be equipped with a variety of sensors to allow automated inspection of distribution line components. The electrician controls and proceeds the inspection from the ground level.

The robot structure is presented, a prototype is constructed and by field tests, the effectiveness of this structure demonstrated. The tests performed on the test bed with a segment of distribution line show the ability of the structure to overpass usual obstacles. The adaptation to different types of distribution lines makes the structure more versatile. As the structure is self-steering, it is expected that embedding sensors to detect network failures will be simplified, because it is not necessary to constantly search for the direction of the network by the sensor. The self-alignment has the advantage of giving greater stability to the movement of the structure, it maintains a desirable balance condition. Although, tests revealed a critical condition in terms of transposition of non-rigid jumpers. The structure was able to overcome the remaining obstacles. For this reason, it is believed that minor modifications may be necessary to include less rigid jumper transposition.

8. FUTURE WORKS

The proposed structure does not represent a definitive solution. Moreover, tests have shown that improvements are required. Among several possible, the most important is the increase in the range of obstacles that can be overcome. The reduction of weight of the structure is desirable, because this implies an easier positioning of the structure in the distribution line. The use of other materials can be a solution as well as a change in the overall geometry of the structure.

9. ACKNOWLEDGEMENTS

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