CIGRE-808

2024 CIGRE Canada Conference & Exhibition
Winnipeg, MB, Oct. 28 – 31, 2024

Drone Aircraft Warning Markers and Robotic project for safe installation on overhead lines

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SUMMARY

This work shows steps of the innovative proposal for the development prototypes of the new Aircraft Robotic Warning Markers - ARWM arose from the experience in using robots to install the Aircraft Warning Markers - AWM that were developed by many R&D institutes around the world. In this conventional robot, the AWM and the robot are placed on the ground cable by the operators and then, using commands on the ground or from the tower itself, the robot pushes the AWM to its desired location and then triggers its closure. Once the operation is complete, the robot returns to the tower and the process is repeated if more than one AWM is to be installed.

The state of de art in robot that installs AWM continue being a very innovative system and much safer in relation to conventional installation methods with a winch or helicopter. Even though it is a great innovation to have the robots install the AWM, the robot system is still large and clumsy considering that the operator needs to take the robot device to the top of the tower, which maintains the operator's exposure to the risk of accidents. Therefore, based on bibliographical surveys, it was considered that it would be possible to place the robot inside the body of the AWM and thus install itself. It was proposed by a Brazilian startup company to Cemig Utiliy in 2021.

The new device ARWM is in phase of development but the entire movement and fixing system on the ground cable inside the AWM has been developed. The conception, design and preliminary tests were carried out in the laboratory and the results of the prototype were promising, proving the possibility of applying the ARWM, with emphasis on the increase in productivity, as the new system allows the

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installation of several ones simultaneously. The target cost of the ARWM must be relatively low and easy to handle in installation with the overhead line energized.

But requirement of need for operator to climb the overhead line tower to fix the ARWM on the ground cables remained. In this case, a solution already in the development is the use of drones to lift the AWM or ARWM without the need for operators to climb the tower of overhead lines. Thus, through a 30-month in R&D Brazilian Agency of Electrical Energy – ANEEL project scope was contracted with the partnership between Brazilians companies: Cemig utility and R&D Instituto Centro de Tecnologia de Software – ICTS and MB-WeldWorks. These stakeholders have been developing the project of new procedure to install AWM or ARWM using an adapted commercial drone for it.

Additionally, the possibility of a solution for cleaning and painting old discoloured AWM in operation using the autonomous drone is considered. The main expected benefits of this R&D project are: i) reduction of risk of exposure during the installation of AWM, ii) maintenance of AWM in operation, without the need to remove them from or install another besides them on the ground cables, and iii) the overall reduction installation when the adapted drone and ARWM reach a high industrial production scale. The project is in 12 months of development and the results shown were until now fantastic.

KEYWORDS

Drone, Robot, Overhead Line, Aircraft Warning Markers - AWM, Aircraft Robotic Warning Markers – ARWM, R&D project, Installation- of AWM.

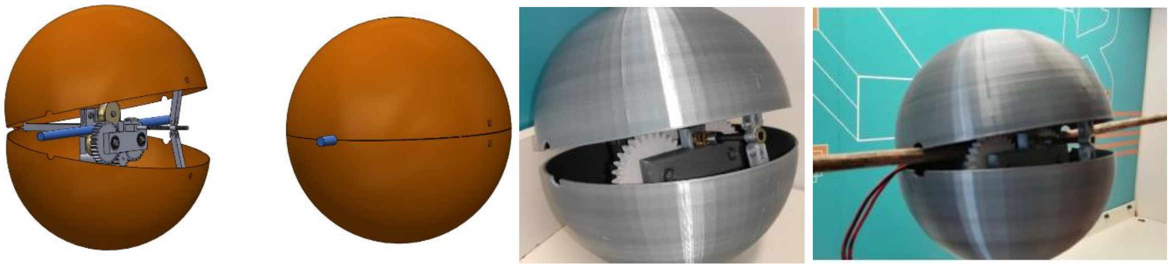
1. INTRODUCTION

The innovative proposal for the development of the new product of Aircraft Robotic Warning Markers – ARWM [1] arose from the experience in using robots to install the conventional Aircraft Warning Markers – AWM (signalling spheres), as shown the current robot in the Figure 1(a) developed by CEMIG and UFMG [2]. In this system, the AWM and the robot are placed on the ground cable by the operators and then, using commands on the ground or from the tower itself. The robot pushes the AWM to the desired location and then triggers its closure. Once the operation is complete, the robot returns to the tower and the process is repeated when more than one AWM must be installed. Despite being a very innovative system in relation to conventional installation AWM methods and very safe in relation to installation with a winch and helicopter the system is still large and clumsy considering that the operator needs to take the device to the top of the tower as shown in the Figure 1(b), which maintains exposure to the risk of accidents.

(a) (b)

Figure 1 a) Robot patented by CEMIG and UFMG for installing and removing AWM from transmission lines in the past [1], b) operator needs to take the device to the top of the tower.

Therefore, based on bibliographical surveys, it was considered that it would be possible to place the robot inside the AWM and thus it could install itself [3]. Thus, the new 3D design of ARWM was developed as shown in Figure 2(a and b). In this new ARWM, the entire movement and fixing system on the ground cable is inside the ARWM and the device is activated by remote or autonomous control. The conception, design and preliminary prototype tested were carried out in the laboratory as shown in the Figure 2(c and d). The preliminary results were promising.



(a) (b) (c) (d)

Figure 2 a and b) design, and c and d) prototype of new Aircraft Robotic Warning Markers – ARWM.

One requirement however remained, the need for the operator to climb the overhead line tower to install the ARWM on the ground cables. In this case, a conceptual solution already done was the use of drones to lift the AWM or ARWM without the need for operators to climb the towers as shown in representation of Figure 3(a and b). The conceptual prototype was developed by a Cemig´s innovative employer in 2018 as shown in Figure 3(c) [4].

Thus, through a 30-month R&D project scope, the partnership between Utility Cemig and the R&D Instituto Centro de Tecnologia de Software – ICTS and the startup MB-WeldWorks are developing in a synergistic way the installation of AWM or RWM using a commercial drone in Brazil. Additionally, the possibility of a solution for cleaning or painting discoloured AWM in operation using the autonomous drone was considered. The main expected benefits of this R&D project are: i) reduction of risk of exposure during the installation of AWM, ii) maintenance of old AWM in operation, without the need to remove them from or install another besides them on the ground cables, and iii) the overall reduction installation when the ARWM reaches a high industrial production scale.

(a) (b) (c)

Figure 3 a) Conventional AWM lifting by drone, b) new ARWM lifting by drone, and c) starting development of conceptual prototype of the mechanism of lifting drone.

2. MOTIVATIONS

The installation of AWM is carried out in different ways [5]-[10]. They can be installed manually during Overhead Line assembly or remotely in several ways with the Overhead Line already assembled. Some of the main installation methods used in Brazil are: a) movement of the technician along the cable/conductor or conventional installation; b) "bicycle"; c) rope; d) cranes equipped with insulated boom extensions; e) robots; f) adapted helicopters; g) drones shown in the Figure 4. What can be seen in all cases is that the AWM is always guided, that is, it depends on some device or equipment to carry it to the handle and install it by human actions on the ground cable. The main motivations of the project were both to develop a new kind of robotic AWM and a commercial adapted drone with new mechanism to install the conventional AWM or ARWM in the Overhead Lines.

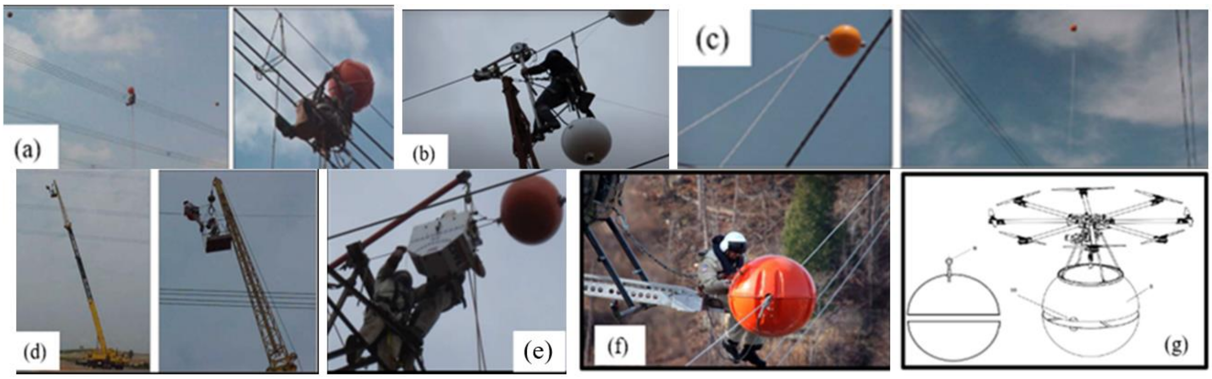
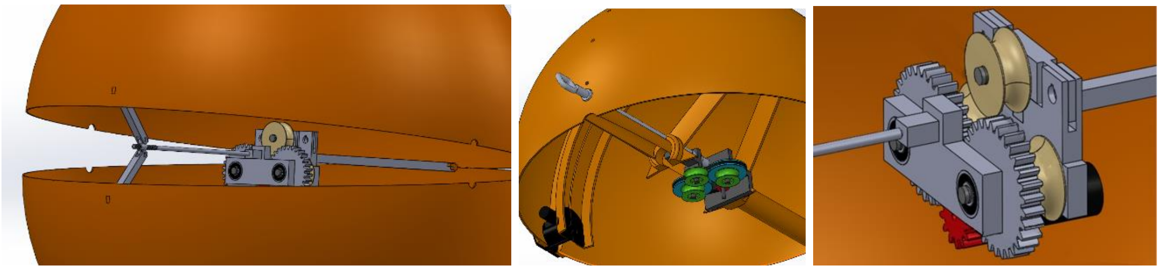


Figure 4 – Summary of installations of AWM methods used in Brazil.

3. PHASES OF DEVELOPMENT

3.1 Scope the design of ARWM

In the R&D project through discussion and analysis of the conceptual models as shown in the Figure 5(a). The mechanisms of movement of the ARWM on the ground cable is shown in Figure 5(b and c). It has been studying and developing yet but this first conceptual assessment looked at essential criteria such as manufacturing cost, total weight of the ARWM, and its effectiveness of delivery and closure mechanisms on the ground cable. Furthermore, R&D efforts are focused on the precise definition of the electronic components necessary for the mechanisms to function, with the aim of guaranteeing reliable and safe performance. This refinement process allowed the project to reach higher levels of efficiency and significantly contribute to improving practices for installing ARWM on overhead transmission lines. The part of the design in the hard energy system still being in developing.

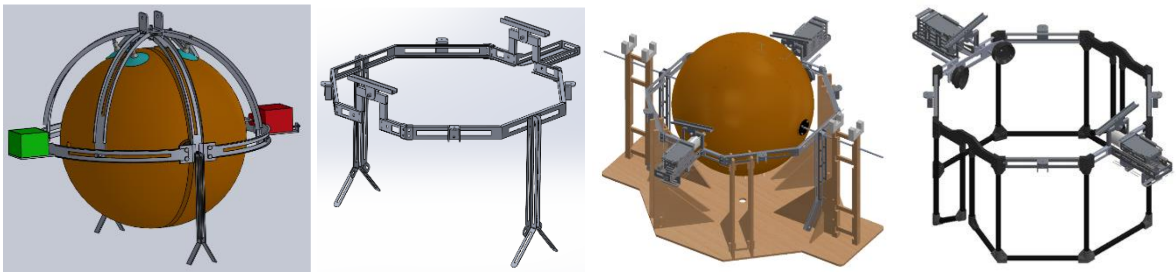


(a) (b) (c)

Figure 5 a) View of the components into the ARWM; b) the axis of drive mechanism; and c) zoom of drive mechanism.

3.2 Scope the design of mechanism lifting and installation AWM

The team of development having discussed and surveyed the positive and negative points associated with possibilities of design of the lifting and installation mechanism of AWM flying with the drone to the ground cable. It was possible to develop a decision using a screwdriver mechanism tool system, in a horizontal position, combined with a suction and pressure lifting system adapted to control the installation of conventional AWM or the new ARWM. This technical architecture presented a greater possibility of interchangeability for installing the AWM as shown in detail in the Figure 6(a) and its design of first prototype in the Figure 6(b). Some initial tests were carried out and small adjustments were necessary. This first prototype not performed satisfactorily during the set of tests carried out. Furthermore, it was manufactured a template for positioning the mechanism of AWM to guarantee standardization of assembly before each takeoff in testing as shown in the Figure 6(c). The knowledge acquired step by step of the designers generated the final of prototype configurations as shown in the Figure 6(d) with added new carbon structured parts.



(a) (b) (c) (d)

Figure 6 a) Lifting and installation mechanism of AWM, b) the first prototype designed, c) Mechanism for installing AWM positioned in the ground template, and d) the final prototype designed.

4. DEVELOPMENT AND PRACTICAL RESULTS OF TEST

4.1 ARWM – Development and Tests in Labs

4.1.1 First stage – ARWM arquiteture and prototype

In the first proposed mechanism, the installation process of the Aircraft Robotic Warning Markers - ARWM begins with the landing on the ARWM on the ground cable through the continue intervention of an electrician. After this teleguided positioning , the mechanism is activated to move itself along the simulation of ground cable. The displacement is done using a gear train in conjunction with pulleys, allowing controlled movement of the device to the desired location for its installation. Subsequently, the closing mechanism is activated by means of an electric motor, which closes the ARWM by activating an articulated arm that joins the two hemispheres. It is important to highlight that the ARWM power system will be designed to operate in the shortest possible time for installation. The Figure 7(a) shows the two ARWM hesmepheres in still conceptual modeling of the described mechanism. For this first proposal, the sphere provided an articulated opening, which allowed the mechanism to operate in an experimental laboratory short span adapted in the parking as shown in Figure 7(b).

(a) (b)

Figure 7 a) Test of ARWM in UniverCemig Site with span of 30 meter of length; and b) ICTS Parking with span of 4 meter.

4.2 Drone and mechanism of installation - Tests in Labs and Overhead Lines

4.2.1 First stage – Drone Manufactorer Facility

In February 2024, still at the Drone manufacturer's facilities was mounted a structure designed to simulate an environment with an extended and tensioned steel cable, with the aim of supporting an AWM without suffering deformations due to its weight. With the environment produced, several technical adjustments were carried out, aiming to faithfully replicate the conditions necessary for the installation of the AWM. The tests conducted in this controlled environment obtained excellent results as shown in the Figure 8(a).

The first field test was conducted without the presence of the AWM as shown in the Figure 8(b). The main objective of this preliminary stage was to examine the operational performance of the drone regarding its take-off and landing capacity and while transporting the mechanism integrated with its accessories. But, during the initial execution of operational tests, an unexpected interruption in the operation of the drone's engine was observed in mid-flight. This situation allowed the identification of both positive and negative aspects of this incident. Continue in the field test as shows in the Figure 8(c) the objective was to reevaluate the AWM release procedures. In this time with AWM attached to the mechanism of installation and properly positioned on the ground. The drone performed a low-altitude flight and tensioning the cable while keeping the AWM in contact with the ground. But the system was not worked property causing damage to the structure of the mechanism.

(a) (b) (c)

Figure 8 a) View of the mechanism of installation AWM in the manufacture drone lab; b) test conducted without the presence of the AWM; and c) test conducted with all set of installation of AWM.

4.2.2 Second stage – no energized overhead lines in UniverCemig Site

In UniverCemig Site (no energized overhead line field lab) the second test in a no-energized network environment as shown Figure 9(a) was performed with success. Figure 9(b) shows the approximation process of the drone with AWM flying. After that, as shown in the Figure 9(c) the time of the AWM was lading on and perfectly installed of first prototype mechanism on the ground cable in the test span.

(a) (b) (c)

Figure 9 a) View of the test site in UniverCemig; b) the approximation process of the drone with AWM flying, and c) the moment of the AWM was lading on and perfectly installed on the ground cable in the test span.

4.2.3 Third stage - energized network in Cemig utility

After the success of installation AWM in UniverCemig Site (no energized overhead line) in February of 2024, the first test in an energized network environment as shown in the Figure 10(a) was accomplished. Figure 10(b) shows the normal approximation process of the drone with AWM flying. After that, as shown in the Figure 10(c) the interference of the electromagnetic field in the environment to ground cable induced the voltage that affected the operation of the solenoid valve. It resulted in involuntary activation function and the consequent loss of vacuum in the suction cup resulting in failure procedure to attach the AWM around the ground cable. Further lab analysis revealed the burnout of critical electronic boards and its components into the drone like an ESP32 module and H-Bridge. Maybe a significant electrostatic discharge occurred.

(a) (b) (c)

Figure 10 a) the first test in an energized network environment near 138 and 345 kV Cemig´s overhead lines, b) flying drone+AWM near ground cable without troubles, and c) the AWM in contact the ground cable was not installed correct. Test shown failure in the operation of the solenoid valve and drone´s boards burned.

4.2.4 *Forth stage – Laboratory of Extra High Voltage of UFMG-LEAT*

After failure in activating the AWM first prototype mechanism of installation in a real overhead line were carried out in a high voltage laboratory to mitigate the electromagnetic interference and protecting it against electrical discharges generated in the installation process. Effective protection of drone systems and better electrical insulation of the mechanism of installation in high voltage environments was essential to ensure the safety and integrity of all system electronic components. Using techniques such as the coverage mesh on the power cables, the use of ferrites, the integration of sensitive devices inside the drone and the floating grounding of the coverage mesh, actions were taken in the prototype to mitigate the adverse effects of electromagnetic interference and discharges. So, it provided reliable operation in exposure of electric voltage by induction from ground cable of the Overhead Lines. The test was carried out in real scale of 40 kV input already using the second prototype of mechanism of installation as shown in Figure 11 (a and b).

(a) (b)

Figure 11 a) Detailed view of test setup in reduced scale lab, b) testing using the second prototype of mechanism.

4.2.5 *Fiveth stage - energized network environment in Cemig utility*

After the success of lab testing in 40 kV high tension the second prototype was tested in the same an energized network environment. Figure 12(a) shows the normal approximation process of the drone with only mechanism of installation AWM flying and touching on the ground cable. After that, in the installation AWM the interference of electromagnetic field continues present but not damage the mechanics of installation was observed. The installation of AWM was complete on ground cable but no complete attachment was register as shown in the Figure 12(b).

(a) (b)

Figure 12 a) View of second test on ground cable of energized 138 kV Overhead Line; b) view the installation of AWM with no complete its attachment in the ground cable.

4.2.6 Sixth stage – Drone AWM Installation Trainning in UniverCemig Site

As part of the scope of the R&D project, practical training in the use of higher-capacity drones sought to train members of the project teams in four dimensions as planning, operation, maintenance, and field practice. The training was carried out with the programmatic content that is summarized in Table 1.

Table 1 - Content of piloting training with a combustion drone and mechanism of installation AWM.

modulo	**topic**	**objective**	**place**
I	operation demonstration skydroid h16 remote control basic; functioning of the generator system; basic ardupilot operation	show how to fly a drone from the controller generator – alternator – rectifier – battery – propulsion show flight modes and failsafes	Field and classroom
II	pre-flight procedure operation in manual mode basic qgc – flight modes takeoff and landing procedure awm installation simulation emergency procedures and fault messages extensive operation training	preparation and checklist made after arriving in the field provide first contact with the drone shows information available on skydroid and different flight modes provide methods to perform these steps safely and efficiently first contact with drone + payload provide correct procedures for closing an operation repeat operation to ensure learning	Classroom and field
III	preventive and corrective maintenance Q&A	provide which components should be checked and how to do it train replacement or repair procedures for main components maintenance – Flight – AWM installation	Classroom and field

On this first day of training the operation of the drone was demonstrated in practice. From this action, the pilots were given comprehensive notions of all the equipment's processes right from the beginning as shown in Figure 13(a). The Skydroid H16 Remote Control and its functionality were also presented in real operation as shown in Figure 13(b). The objective of this operation was to show how to pilot a drone using the remote control. In this practical activity, students were able to practice their first drone movements: rotate on its own axis, rise (gently), descend (gently) and move the drone. These basic activities were essential for students to be able to safely handle the equipment in their basic activities. Figure 13(c) shows the classroom in UniverCemig facility for training.

(a) (b) (c)

Figure 13 a) Pilots getting comprehensive notions of all the equipment's processes right; b) The Skydroid H16 Remote Control and its functionality, and c) classroom in UniverCemig facility for training.

There is direct interaction between the drone and the structure of the mechanism of AWM installation as shown in Figure 14(a) that both are correlated the positioning on the ground cable as shown in Figure 14(b). The positioning of the AWM on the ground cable through direct interaction with the drone is the main delivery of this phase of training of the pilots. This is the biggest challenge for development as the correct and safe assembly of the AWM. So, the practical flight training for the teams involved in the development of this project was quite significant.

(a) (b)

Figure 14 a) Interaction between the drone and the structure of the mechanism of AWM installation; b) The positioning of the AWM on the ground cable through direct interaction with the drone.

5. ANALYSIS OF RESULTS

5.1 ARWM

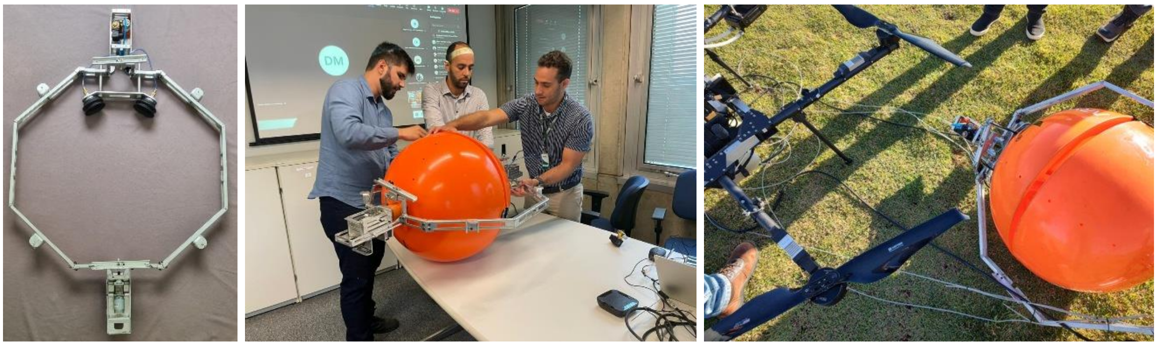
Through a conceptual model designed and tested in the laboratory, the understanding of the proposed ARWM mechanism was expanded. This exercise enriched the perception of the solution to be built as a project delivery and contributed to improving the understanding of the necessary basic components. Other solutions aimed at determining which one has the greatest potential for success will be implemented. This assessment will take into account essential criteria, such as manufacturing cost, total weight of the signaling sphere and effectiveness of the movement and closing mechanisms. But two challenges still to be overcome for ARWM are: i) dependence on electrical energy to drive the displacement motor; ii) the onboard electronics that are crucial to ensuring consistent system performance, but that cannot fail during the installation process.

5.2 Drone and mechanism of installation

5.2.1 First prototype

This prototype performed satisfactorily during the preliminary tests carried out. After the motivating results of installation on a de-energized line, the prototype failed in one test attempts on a 138 kV Overhead Line in Cemig. However, with this first prototype assembled, it was essential to carry out the first real tests. The teams already imagined that the prototype would evolve by the end of the project. Basically, two key points of deficiencies in the structural design were highlighted as: i) thin structure made of aluminum metallic material and not electrical insulator as shown in Figure 15(a); ii) architecture of the physical structure without stability on a work table for housing the AWM as shown in Figure 15(b).

But an important point tested was that the weight of the prototype was supported by the drone and it exhibited excellent behavior throughout the test, lifting the payload of approximately 12kg without difficulty. It also carried out all the control activations as planned, occurring when the AWM was released. However, a setback was observed: both sides of the AWM were not released simultaneously. The side containing the eyelet remained stuck due to the weight that the AWM exerted on it, resulting in significant deformation of the mechanism as shown in Figure 15(c).



(a) (b) (c)

Figure 15 a) Detailed view of manufacture the 1st prototype structure; b) nonstable architecture of the first prototype with AWM; and c) significant deformation of the mechanism after its failure in testing process.

From a positive point of view, the situation of failure highlighted the effectiveness of the security protocols implemented in the drone control system worked well. Specifically, upon internal combustion engine failure the battery power system promptly took control of operations, ensuring the stability of the equipment was maintained. This contingency mechanism allowed the operator to interrupt the ongoing operation and carry out an emergency landing procedure without major complications.

On the other hand, as a negative aspect, there is a limitation in the flight autonomy provided by the backup battery under conditions of combustion engine failure. The two minutes of period the time autonomy implies significant risks in scenarios where the drone is operating at long distances from its base, as the time to implement security measures may be insufficient to guarantee the integrity of the equipment and the safety of the operation in emergency in landing on.

After the set of failure with the first prototype it was discontinued, and the folks of R&D project started the development of the second prototype. Figure 16(a) shows the last failure tentative of installation of the first prototype in the 138 kV OHL. Figure 16(b) shows the zoom of AWM attached with closure failure around the ground cable.

(a) (b)

Figure 16 a) Detailed view of the last failure tentative of installation the first prototype; b) the zoom of AWM attached with closure failure around the ground cable on the 138 kV OHL.

5.2.2 Second prototype

Basically, the second version of the mechanism prototype of installing AWM has evolved robustly. The prototype-carbon was lighter in relation to the first prototype-aluminum and considerably improved the electrical insulation of the system by using polymer structural material instead of aluminum metal bars. Figure 17(a) shows the second prototype built using 3D printing and carbon tube bars. Therefore, the field test on the 138 kV Overhead Line was redone as shown in Figure 17(b), but even with all structural and electrical insulation improvements, the AWM installation mechanism was completed but it was not completely enclosure as shown in Figure 17(c). The AWM coupling on the ground cable was not correctly installed as expected.

(a) (b) (c)

Figure 17 a) View of the second prototype built using 3D printing and carbon tube bars, b) the field test on the 138 kV Overhead Line, and c) the AWM installation mechanism was completed but not completely its enclosure.

6. NEXT STEPS OF DEVELOPMENT

After the development step by step with 50% of the physical execution of the R&D project through simulations, prototyping, assembly, laboratory and field tests and various adjustments were promoted. Thus, it was feasible to experimentally enable new technologies for installing AWM´s overhead lines to reduce human interaction in this complex process and minimizing the risk of accidents. The next step of project development are:

a) Mechanism of Installation AWM by Drone: carry out more real tests on energized lines with the prototype in its final formation;
b) ARWM: continue the prototype design process considering the challenge of device's propulsion system in all cycle of live;
c) ARWM: carry out real tests on energized lines with the prototype in its final formation;
d) Installation Simulation Environment: develop the computational module;
e) Patents: Submit requests for patent and software registrations, if applicable;
f) Business Plan: Finalize the project with the prototypes in operational condition to calibrate and validate the business plan and thus begin the technology licensing process.

7. CONCLUSION

This work shows parts of the innovative project R&D for the new Aircraft Robotic Warning Markers - ARWM arose from the experience in using robots to install the Aircraft Warning Markers – AWM. In these conventional robots, the AWM and the robot are placed on the ground cable of Overhead Line by the operators and using remote commands on the ground or from the tower itself. Then, the ARWM has been developing entire movement and fixing system inside itself. The conception, design and preliminary tests were carried out in the laboratory and the results of the prototype were promising, proving the possibility of applying it in OHL The target cost of the ARWM must be relatively low and easy to handle or apply, remain the main advantage installation with the overhead line energized.

But caveat of need for operator to climb the overhead line tower to fix the ARWM on the ground cables remained. In this case, a solution already in the development is the use of drones to lift the AWM or ARWM without the need for operators to climb the tower of overhead lines. Thus, through a 30-month in R&D Brazilian Agency of Electrical Energy – ANEEL project scope was contracted [1], with the partnership between Brazilians companies: Cemig utility and R&D Instituto Centro de Tecnologia de Software – ICTS and MB WeldWorks. These stakeholders have been developing the project of new procedure to install AWM or ARWM using an adapted commercial drone for it.

Additionally, the possibility of a solution for cleaning and painting old discoloured AWM in operation using the autonomous drone was considered. The main expected benefits of this R&D project are: i) reduction of risk exposure during the installation of AWM, ii) maintenance of AWM in operation, without the need to remove them from the ground cables, and iii) the overall reduction installation when the adapted drone and ARWM reach a high industrial production scale. The project in 12 months of development and the results shown were until now fantastic.

Finally, the great economic advantage that was estimated by business plan by use of the new technology (75% reduction in installation cost of new unit) and (93% reduction in maintenance cost of unit in operation) must be validated in future commercial applications, that is, when this technology to license for the market [11]. According to the "PayBack" of 3.5 years from the business plan estimated in the R&D Project, there is a great opportunity to apply the products to the various AWM must be done in Brazil and abroad.

ACKNOWLEDGEMENTS

This R&D project (Cemig GT0670) was funded by ANEEL (Brazilian Electricity Regulatory Agency). Special thanks to Cemig utility and R&D Instituto Centro de Tecnologia de Software – ICTS and MB WeldWorks by the friendly cooperation dedicated to this joint development project.

BIBLIOGRAPHY

[1] PD-04951-0670 - P&D-GT0670 - Solução Autônoma integrada para instalação e manutenção de esferas de sinalização em linhas de transmissão e distribuição - 2023.

[2] CEMIG – Patente Nº INPI – PI0205916-9 – Cemig GT and UFMG.

[3] MB WeldWorks Patente Nº INPI – BR 20 2021 009048 6 - Esfera De Sinalização Autônoma Para Cabos De Linhas De Transmissão Aérea Ou Similar – Banco de Patentes INPI, 2021

[4] INPI, 2020 - BR 10 2020 003428 6 A2 - Dispositivo Para Instalação E Manutenção De Esferas De Sinalização Em Redes De Transmissão E Distribuição De Energia Elétrica – Banco de Patentes INPI, 2020.

[5] Folder Delta Box – Aircraft Warning Spheres - https://www.delta-box.com/en/wp-content/uploads/sites/2/2021/03/22-Aircraft-Warning-Spheres-compresse.pdf – acesso em 27/05/2023, 15:30.

[6] Folder P&R Technologies – Power Line Markers & Low Line Markers - https://pr-tech.com/product-category/power-line-markers/ - acesso em 27/05/2023, 17:00.

[7] Güçyetmez, M., Hayber, S.E, - "A New Warning Sphere Design with Side Emitting Optical Fiber Technology on Transmission Lines" – International Journal of Engineering Research and Development – doi: 10.29137/umagd.1116554 – versão final 31/07/2022.

[8] HAVAD Industrial Limited – Warning Sphere - https://www.warningspheres.com/warningspheres/index.html - acesso em 28/05/2023, 10:30.

[9] PFISTERER Switzerland AG – Warning Spheres - https://www.pfisterer.com/fileadmin/pfisterer/downloads_en/Warning-Spheres-PI-EN.pdf - acesso em: 27/05/2023, 21:00.

[10] US9932110B2 - Method for installing an object using an unmanned aerial vehicle - Google Patents. [s.l: s.n.].

[11] Carlos Nascimento and at. eli, 807 - Research project business plan for installation and maintenance of Aircraft Warning Markers in overhead lines – Cigre CAN 2024