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Experiences and risks when dealing with remote inspections of Factory Acceptance Tests on EHV Inductive Equipment

Pablo Andrés NARVÁEZ BURGOS*
Interconexión Eléctrica S.A.
Colombia
panarvaez@isa.com.co

SUMMARY

The need for a factory acceptance test (FAT) inspection of inductive equipment has become a standard practice for electric utilities when dealing with extra high voltage equipment (EHV). This is mainly because of the necessity to validate the manufacturing process and the standards and requirements imposed on the supplier for the correct performance of the equipment in a transmission system. All of this becomes even more relevant when considering that these assets' life cycle costs are higher than any other asset within a typical substation.

In this context, companies in the transmission sector have been making a great effort to participate in person during the FAT, seeking to serve as a means of evaluating the technical characteristics in the supplier's plant and a training platform for new inspectors. Additionally, consulting companies have included this service in their portfolio to aid the industry when this type of inspection is needed and cannot be covered by internal resources, either by lack of availability or expertise in specific tests.

As the COVID-19 pandemic continues, new measures are being implemented to reduce the transmission of the virus, which includes additional controls and restrictions for traveling internationally. With these elements in mind, the role of an inspector is currently being evaluated in each organization. The activities carried out as part of a remote FAT inspection have had to undergo profound changes in how these processes were articulated. This is required to redefine the framework of responsibilities, requirements, and acceptance policies both internally and towards suppliers, seeking to guarantee that assets could be dispatched and projects would not be impacted on account of the new inspection framework.

In the first section, this article seeks to present the available means in the industry for remote inspections with global manufacturers, including a qualitative comparison of their benefits and potential drawbacks. Also, an explanation and results of the options adopted, implemented, and used in our company with more than 60 FAT inspections of EHV inductive equipment in factories from Asia and America between 2020 and 2021 are made. Although there is no single correct approach, each client is responsible for identifying and selecting the option that better suits their procurement and inspection needs, considering their main manufacturers, quality, and contractual agreement between the companies.

The following section summarizes the main risks evaluated when dealing with a remote FAT inspection. A brief description of the risk assessment is also included, explaining the causes, preventive measures, consequences, and protection measures that need to be considered to make a conscious decision to

choose this type of inspection. For this, a specification-based analysis is created, using the main chapters of a procurement standard for a power transformer.

Finally, recommendations are provided to create a framework between customer and supplier when a remote inspection is needed. A contractual agreement is also proposed to define the scope and evaluate the potential risks involved. New alternatives of inspections are proposed as future work, looking to increase the reliability of the activities supervised by the inspectors.

KEYWORDS

Transformer, Reactor, FAT, Inspection, Remote, Risk

1. REMOTE INSPECTION

The need for new alternatives for FAT inspections has increased while the COVID-19 pandemic spread across the globe. The manufacturers prepared new options for factory inspections, trying to support customers looking to continue their original manufacture and testing schedule without additional delays due to the logistical nightmare that the pandemic caused. Although their original purpose was to fulfill the milestone of a successful FAT while allowing an inspection, it also brought unexpected elements into this vital stage in the delivery process. In the following figure, a brief illustration of the initial conception from the manufacturers.

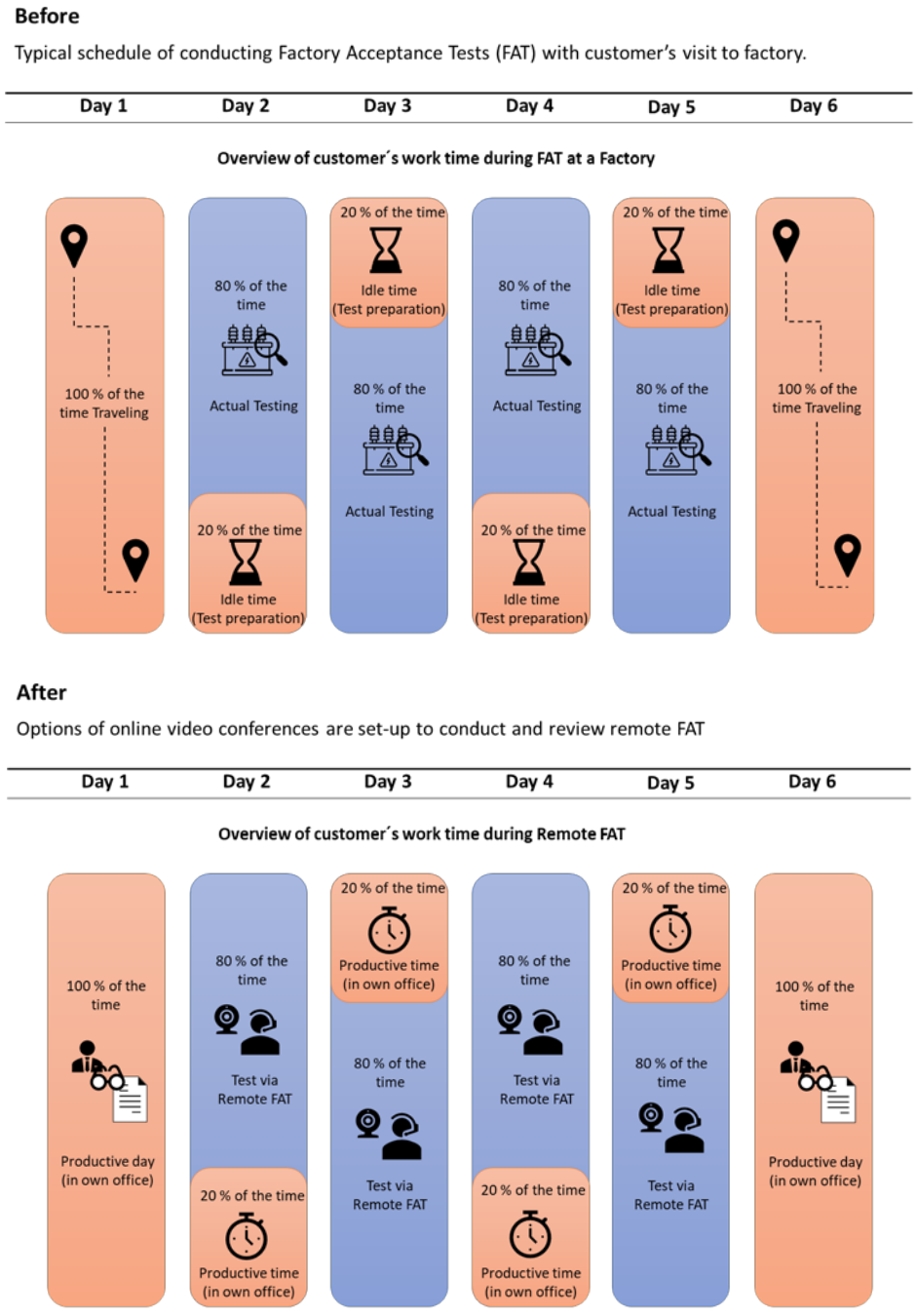

Figure 1 Before and after remote FAT work time of the customer. Adapted from *[1]*

The figures represent the main priority for some utilities, trying to improve the available time of the inspector during testing while keeping the project's schedule as initially planned. In the following section, we will evaluate the impacts of this decision and explain why it must be carefully assessed.

In order to allow a remote inspection, manufacturers have prepared options for the customers to choose from, depending on the available resources, risks, and time to perform the FAT. The following are options presented to us, and we summarize a qualitative sensibility to identify benefits and potential drawbacks in each.

1.1 Synchronous Remote Inspection

This type of inspection uses a simultaneous (synchronous) interaction between the customer and the testing engineer. It requires a common chat-based collaboration platform that allows sharing video from among other sources, from a closed network video recorder (NVR) inside the factory. The integration of cameras from multiple locations allows controlling information from the test area and the control room, where customers and factories can be located in different cities or countries. The following figure shows the main characteristics of this alternative.

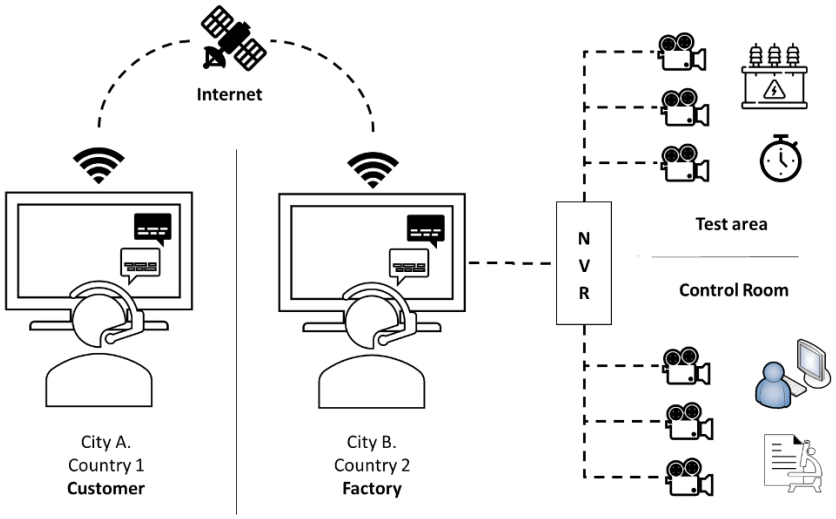

Figure 2 Synchronous Remote Inspection. Adapted from *[1]*

A summary of the main benefits and drawbacks is presented.

Benefits	Drawbacks
Immediate attention to comments from the inspector.	As multiple cameras are set, for a single inspector can be challenging to cover all simultaneous streaming while the test is happening.
Additional cameras in a visor or handheld devices can be included in the meeting easily.	Without the inclusion of a handheld camera, the views of the equipment and testing gear are restrictive.
It allows simultaneous translation if the customer and factory do not share the same language.	For the static cameras, the streaming can be manipulated.
Allows a simultaneous preparation and agreement of the pending points.	Depending on the time difference between factory and customer, it can be challenging to participate actively.
Additional experts from the client can be involved in the inspection, allowing multiple perspectives for its analysis.	

Table 1 Benefits and Drawbacks of a synchronous inspection

Although this option is one of the most advanced and allows reaching a close approximation of a traditional FAT inspection, the effectiveness of this alternative, or any other to be honest, is based upon the trust between the customer and the manufacturer. Trust becomes a fundamental element in the inspection, as the client has limited options to control and confirm the validity of the information provided during the inspection. Usually, on a face-to-face inspection, the customer can verify each of the testing equipment used, confirm the serial number and calibration dates, and perform basic simulations to confirm the reliability of the results. Now, the inspector depends upon the information shown on the screen and results provided by a third party as the only means to assure the test's validity. In the next chapter, we will describe the risks that a company has to evaluate and give some alternatives to help mitigate the uncertainty posed by each risk.

1.2 Asynchronous Remote Inspection

For this option, a daily recorded procedure is adopted. The manufacturer stores simultaneous streaming from each of the available cameras in the laboratory and control room and then creates a pre-recorded layout for sharing with the customer. Day by day, the customer is responsible for verifying the results and raising any comments if something must be repeated or verified as per the client's requirement.

Although not as simple as the previous option, it allows monitoring the results and storing the process in case any future difficulty arises.

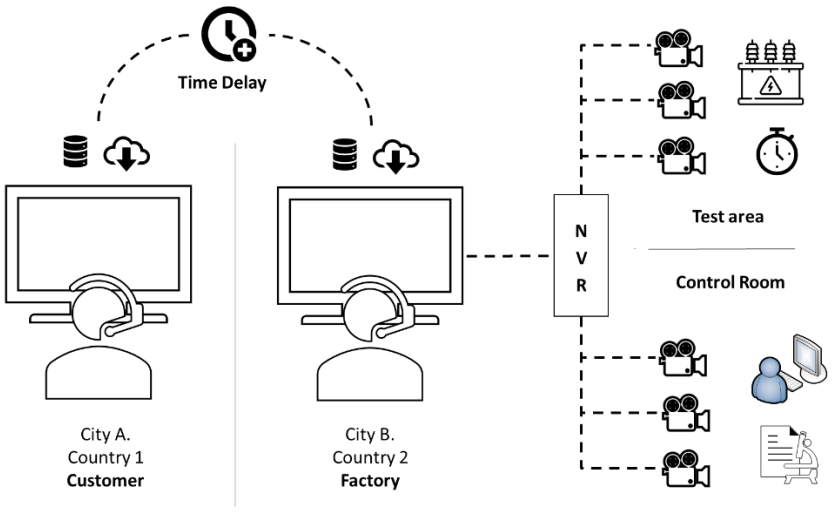

Figure 3 Asynchronous Remote Inspection. Adapted from *[1]*

A summary of the main benefits and drawbacks is presented in the following table; most of the drawbacks of the previous option remain in addition to the ones included below.

Benefits	Drawbacks
It tackles the issue of time difference while maintaining daily progress being verified between customer and manufacturer.	It carries a high responsibility for the customer as no immediate action can be taken due to the prerecorded feed.
A daily meeting is encouraged, as it becomes the point where both parties share the progress and comments of the previous day and outline the future activities.	The delay can allow the content of the streaming to be manipulated or altered to avoid identifying issues
	Allows attention to the inspector's comments to a certain degree, as any deviations detected in the prerecorded content can lead to additional delays if a correction is needed.

	It does not allow direct interaction with the test crew from the laboratory, as it is usual that the quality manager from the manufacturer serves as the pivot point for all interactions. This can delay any attention in comments or technical difficulties during the test.

Table 2 Benefits and Drawbacks of an asynchronous inspection

This alternative is mainly suggested by manufacturers from Asia, as they are aware of the impact that the time difference with America may bring over the engagement of the inspector during asynchronous remote FAT. As a middle point, a hybrid alternative of this option was explored by including a third-party inspector in the FAT while the information was recorded and submitted to the final client.

This hybrid asynchronous option can be used when dealing with new manufacturers or plants with no previous inspection from the client or a third party.

1.3 Our Approach

To some clients, adopting the path of a remote inspection is only possible when a clear structure of responsibility with the manufacturer has already been established. This means to create a contractual obligation among parties in case a deviation is later detected at the site, during Site Acceptance Test (SAT), or even in operation. Others have made an additional effort in negotiating higher warranties in the lot where a remote inspection was performed, using it as an alternative to deal with nonconformities once the unit is at the site.

As previously indicated, there is no single correct approach; each client is responsible for identifying and selecting the option that better suits their procurement and inspection needs, considering their main manufacturers, quality, and type of contractual agreement between the companies.

In our case, after using different combinations of the options mentioned above to deal with a remote inspection of inductive equipment, we selected the synchronous approach, as this brought the alternative to use additional handheld cameras for specific visual requests, allowing a more detailed view of surfaces/markings while testing. In addition, we received options from manufacturers in some of their facilities where their NVR allowed the customer to remotely operate the cameras, relocating or zooming as needed. This was highly appreciated as it improved the quality of the remote inspection.

The following figure shows the units that had to undergo a remote inspection for the ISA Group in 2020-2021.

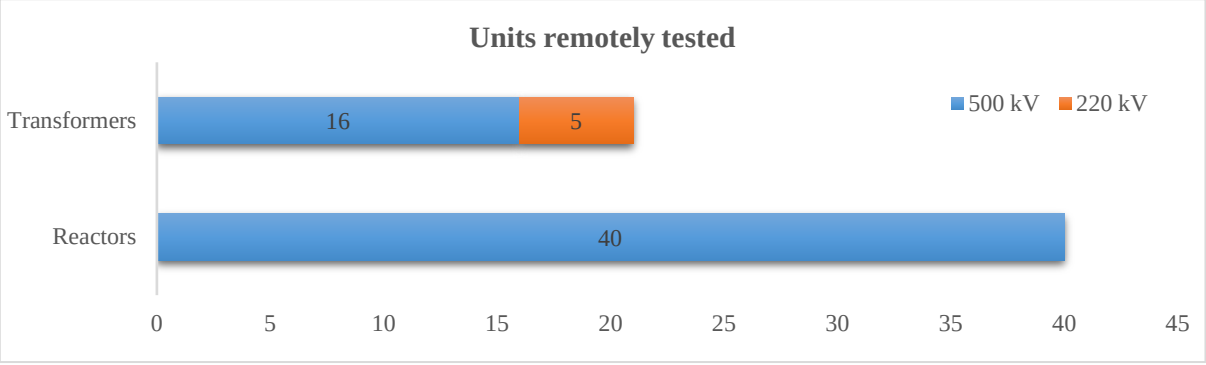

Figure 4 Units remotely tested for ISA Group

As it can be seen, an important number of units were remotely inspected, and the number continues to increase, as new travel restrictions still bring difficulties for a face-to-face FAT. This is one of the reasons why internally in ISA Group, we evaluated the impacts to each project, the risks associated with the remote inspection, and the contractual conditions that had been set with the manufacturers to proceed with a remote inspection.

Due to the magnitude of the activities, there was also de alternative to involve a third-party inspector in the FATs, but for some projects, the time slot of the testing laboratories was not flexible enough to find a qualified company that was available. We believe that this service will continue to have high demand globally, and some inspectors have already manifested that they are over-booked for the upcoming years. This is an opportunity for consultants and engineering companies looking for a new presence in regions where this service is currently needed, closer to EHV equipment factories.

In Table 3, a detailed scope of the main characteristics of the studied cases is shown, trying to illustrate the complexity of the inspections and the time it took to undergo multiple remote inspections of this type of EHV inductive equipment.

Case No	Destiny	Type	Origin	Rated Voltage	Rated Power	Quantity	Status
1	Perú	Reactors	America	500 kV	33,3 Mvar	12	Commissioning
2	Perú	Reactors	America	500 kV	25 Mvar	8	Commissioning
3	Perú	Reactors	America	500 kV	33 Mvar	4	Commissioning
4	Perú	Reactors	America	500 kV	30 Mvar	8	Commissioning
5	Perú	Transformers	Asia	500 /220 kV	250 MVA	4	Commissioning
6	Perú	Transformers	Asia	500 / 220 kV	250 MVA	4	Commissioning
7	Perú	Transformers	Asia	220 / 110 kV	33,3 Mvar	4	Commissioning
8	Colombia	Reactors	America	500 kV	28 Mvar	8	Commissioning
9	Colombia	Transformers	Asia	500 / 230 kV	150 MVA	4	Commissioning
10	Colombia	Transformers	Asia	500 / 230 kV	150 MVA	4	In Transit
11	Perú	Transformers	Asia	220 kV	50	1	In Transit
12	Perú	Reactors	America	500 kV	40 Mvar	1	Not yet tested
13	Colombia	Reactors	America	500 kV	28 Mvar	6	Not yet tested
14	Colombia	Reactors	America	500 kV	47 Mvar	8	Not yet tested

Table 3 Main characteristics of the inspected units' origin and the project status

Even up to now, a high number of units remain to be tested in the coming months (cases 12 to 14), where we are considering the option to have a remote inspection as well.

A decision will have to be made once the travel restrictions are lifted, that is, to continue with the remote inspection or to continue with a standard FAT. We trust that this change due to COVID restrictions brought us additional options to the inspection process, but there is still significant work to be done, especially in the technology department for both client and manufacturer.

Some of our subsidiaries in ISA Group, for applications different from EHV equipment, have already used a mixture of traditional and remote inspections [2], allowing an improvement or complementing the skills of the traveling inspector with knowledge from other specialists. Using visors or helmets with simultaneous communication, they can meet, share information, and understand a failure as the test progresses. Usually, this took weeks with a traditional inspection. This is especially important when multiple subjects and topics come as part of the inspection, as this activity encompasses several fields of knowledge, from design and operation to electrical, mechanical, or even control and protection. This mixture of specialties in an inspection will be a step towards thoroughly evaluating the whole life cycle.

2. RISK ASSESSMENT FOR A REMOTE FAT INSPECTION

In this section, a summary of the main risk identified in a remote FAT inspection will be presented. This assessment was motivated by the need of each case to confirm the understanding of the possible effects this may cause on their process. It also served to keep track of the preventive measures adopted and the proper implementation in future inspections.

The structure of the analysis considered the main sections of a purchase specification of inductive equipment as well as the failure location identified in existing literature [3]. A brief description of the risk will be made in each section, explaining causes, preventive measurements, consequences, and optional protection measurements for each case. The internal matrix for the assessment of remote inspection had close to 30 risks per case, but in the following lines, only the most relevant will be developed.

- **Main tank**

The activities related to the metal preparation and welding of the tank become one of the most difficult to inspect remotely, even with additional cameras or photographic evidence. Deviations are hard to identify as there are many factors involved, as the required specific skill set of the inspector to distinguish an issue or the large surface of the tank that needs to be inspected, which for this type of equipment can range from 70 m2 to 150 m2.

The risks involved in this activity are early failures or deviation of the requirements of the specification, caused by deviations in the application of the paint, as it does not follow the minimum thickness of the standard or pores in welding are left in critical zones of the tank.

As preventive actions, a couple of additional mechanical tests were set, in addition, to bringing a third-party inspector to validate compliance while the tank was manufactured. Other tests aimed to simulate close-to-operation conditions, allowing the identification of early leakages in the units.

For a protective measure, the responsibility transfer for site warranties was contractually set in case additional deviations of this type were detected during transit or commissioning.

- **Bushing and OLTC deviation**

The risk of these components was early failure or deviation from our specifications, these accessories came from recognized global suppliers; for them, we validated the compliance with the type test of this product as well as the routine test of all the units. One issue we experienced with the bushings was a logistics difficulty that did not allow all bushings to arrive at the test laboratory at the right time for the FAT in some units. The risk was an early failure or manufacture deviations as it was not type tested as per our specification.

For preventive actions, the manufacture sets individual tests to the bushing to cover and fulfill our specifications. As a protective measure, a spare bushing was arranged from previous projects to be ready in case a bushing failed during the individual test or if additional transport delays happened.

- **Current transformers**

The main risk was a deviation from the specification, as local suppliers usually manufacture them within the same country as the main manufacturer of the EHV inductive equipment. One of the preventive measures was to simultaneously inspect the specific vendor tests and additional requirements set in our specification. Another preventive action was early delivery of the designs of the CT to validate the compliance of the product before purchase.

The consequences were deviations from our direct client of the project or deviations from internal product fulfillment. Both cause delays in the resupply. As protective actions, early delivery of the designs was requested to validate the compliance of the product.

Although the preventive action has worked in the past, a high number of CTS deviated from specification during our inspection. We identify that the CT vendor did not receive the request for early designs, as it was handled directly by the main manufacturer. These deviations led to delays in the supply in plants of Asia and America as well.

This serves as feedback to our design department as well as our subsidiaries' procurement teams to control them directly while the design of the units is not yet approved.

- **Protection and control accessories**

The main risk for these components was that they would not follow the specification or agree with the approved designs for the accessory; the main cause was due to changes that were not submitted to the client or intentional replacements made by the manufacturer. As a preventive action, a specific checklist is set as part of the specification to confirm the supply of the agreed product, and routine tests under inspection to validate the compliance of the functions. The consequences are un-approved dispatch, delays, or over-cost for the project due to local replacement needed at the site.

For a protective measure, the responsibility transfer for site warranties was contractually set in case deviations of this type were detected during assembly or commissioning.

- **Routine, type, and special tests**

In this section, individual analysis was made for each of the routine tests performed on the unit. The main topics explored were low voltage tests, dielectric tests, oil and paper tests, temperature rise tests, noise, and harmonic content. In the case of low voltage tests, the main preventive condition is the responsibility of the manufacturer to avoid high voltage failures that can be easily avoided by detecting issues in the low voltage test, covering elements from cross-connections to loose fittings.

But as the test increased in complexity, the virtual inspection lagged with alternatives to control possible deviations, and then the option was created a protective measurement that transferred high responsibilities to the manufacturer. The possibility of alteration either in the results or in the connections for the test equipment may lead to identifying as inviable a remote inspection where there is no trust between manufacturer and client, with proper contractual agreements set.

As a result, it has become a common practice among utilities that require a certain volume or quantity of a good over a specific period to select a manufacturer with which a special framework agreement can be negotiated among the involved parties. This type of contractual relation sets a trust commitment creating a long-term responsibility where common goals and needs can be met

3. CONCLUSIONS

As previously shown, the risks, causes, and consequences follow a specific client by client and case by case analysis, and the main recommendation is to evaluate your risk assessment with the project team and explore possible financial, reputational, and time impacts over each case. This article intended to acknowledge the difficulties and uncertainty that a remote inspection carries and to bring awareness over the possible effects that may cause an undetected deviation during a remote FAT.

Although no financial and reputational measurements were included in this paper, due to the sensibility of the information, each company should evaluate and plan accordingly for future inspections as the impacts are relatively high when compared with other assets in a substation.

Considering that trust becomes a fundamental element in the inspections, the relationship between the customer and manufacturer should also be explored and improved. An alternative relationship with the manufacturer is also discussed, but the decision to shift towards a framework agreement needs to be evaluated at a high level in an organization, as it may affect the competitiveness if not carefully designed.

It must be clear that the inspections for EHV inductive equipment will change, and the responsibility of creating the best way to embrace falls upon the customer.

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