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OUTSOURCING PREVENTIVE MAINTENANCE ON UNDERGROUND POWER TRANSMISSION CABLES

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ABSTRACT

This paper will present Kuwait's ministry of Energy's experience with outsourcing preventive maintenance on power cables. The structure of the current contract and the tests carried out are discussed. While testing, inspecting, and reporting is left for the contractor, the decision of where these tests shall be performed in the network is left for ministry staff to decide. The criteria by which cables are selected for testing are outlined. The importance and quality of outsourced preventive work could be highlighted by result analysis. Such analysis is discussed and presented briefly. Finally, enhancements planned for future contracts are presented.

KEYWORDS

Power Transmission Network, Outsourcing, Underground Oil-filled Cables, Preventive Maintenance

INTRODUCTION

Transmission network cables are manufactured and installed through a firm system of standards that account for safety and reliability [1]. However, with networks around the world getting older, the necessity to maintain and pay closer attention to cables is becoming more and more important as the cost and effect of a cable failure may impact a large area of consumers [2]. Because of this, a policy of doing no more than maintaining an efficient team of fault repairers is not enough to keep up with the demand of such a network. This policy must be augmented with a scheme of preventative maintenance that relies on techniques of condition diagnosis, failure prevention, failure prediction, and fault analysis. Therefore, a good maintenance team must try seriously to know why faults occur and try to prevent them from happening again. It must carry out diagnosis tests to know the condition of the network at hand and where it might be in need of intervention. It must also know where to look for weak components and replace them and how to find such information. Further, it must do this wisely and reasonably with an acceptable degree of precision using all the data and resources available while weighing the cost of failure against the cost of preventative measures [3][4][5].

With all of this in mind, Kuwait's ministry of Energy's Electrical Transmission Networks Sector has undertaken preventive maintenance practices since long and the extent of such practices would vary in time according to staff and resource availability. Since year 2000 however, outsourcing preventive maintenance were considered as an option for preventive work on underground transmission feeders. The ministry has already successfully outsourced preventive works on transmission overhead lines, transformers, and substations. In 2000 a pilot contract was introduced for power cable. This pilot contract later evolved into a three year contract of preventive maintenance on power cables.

This paper discusses in three sections the ministries experience with outsourcing preventive work. The first section focuses on the evolution of the current contract from the pilot stage, as well as an introduction of the structure, specifications and tests performed by the current contract. The second section outlines the advantages and disadvantages of outsourcing preventive maintenance, in addition to issues regarding the selection of cable feeders for preventive work. The final section briefly deals with data analysis to verify the effectiveness and significance of the works carried out by the contract to justify going further with such preventive measures.

A CONTRACT FOR PREVERNTIVE MAINTEANCE ON POWER CABLES

Kuwait electrical transmission network holds around 5000 km (route length) of underground links. Underground cables currently constitute 54% of the total circuit of transmission feeders; the rest (46%) is overhead lines. Nearly 96% of these feeders are oil-filled cables. The highest transmission voltage level is 300KV, but it only constitutes 4.5% of the network. The other two voltage levels 132KV and 33KV make the bulk of the network with 69% and 26.5% respectively.

As the network is now ageing the need for a better policy in preventive maintenance is more important than it has ever been. While the maintenance team is quite experienced and structured when it comes to corrective maintenance, preventive maintenance has always had its ups and downs. Issues like staff and resource availability, difficulty in hiring new skilled staff, weather conditions, links availability for shutdown, have always interfered with the quality and quantity of preventive maintenance performed. Therefore, the focus of the maintenance team was always shifting from preventive maintenance and more towards other responsibilities, like stock management, availability of spare parts, strengthening the corrective or repair maintenance capabilities, and the 24-hours emergency repair teams. While stock management and 24-hour emergency corrective maintenance is important, a good policy of preventive maintenance would help ease the tension of these tasks. Preventive maintenance could predict faults before they occur and it could point at the weak parts of the network. Due to these reasons, it was thought that by outsourcing preventive maintenance on a regular basis using clearly defined and structured contracts would definitely regulate the progress of and strengthen preventive work in the network. With outsourcing, preventive maintenance could be

better organized and regularly performed; this in return would make it more useful and effective.

What to Outsource and What not to Outsource?

Preventive maintenance can be broken into two parts External and internal [6]. External preventive maintenance is that which prevents damages to the cable due to external forces, like third party civil work. This type of prevention is not the concern of this preventive maintenance contract. Such external preventive maintenance is performed in-house. The contract will only deal with prevention of damages due to internal causes. To do so, various tests will be performed on certain specially selected cable feeders to assess their overall condition and their vulnerability to failure. These tests are defined in the contract for the contractor to carry out, but when it comes to where (or on what feeders) these tests are to be performed, this decision is kept for the in-house staff to decide.

Also, since the 300KV network feeders are relatively new compared to other voltage levels, and due to the fact that they were few and already closely monitored by the maintenance department, they were excluded from being maintained through an external contract. 33KV feeders were also excluded, but for the following three main reasons: First, they were mostly highly loaded and harder to shutdown for maintenance; second, the 33KV network is undergoing a replacement and redesign phase; third, cost of failure in 33KV network is relatively less than 132KV which may not justify the cost of preventive maintenance.

From these premises the first pilot contract was born in year 2000. But before discussing this contract a brief explanation of how such contracts are granted in the state of Kuwait may be necessary.

How Contracting Works

The power network in Kuwait is run by the government through the ministry of Energy. Therefore, it is subject to state of Kuwait regulations of only contracting through the Central Tenders Committee (CTC). A Contract will be publicly issued on behalf of the ministry by the CTC and the lowest bidder will be considered for approval. If the lowest bidder showed any flows in his offer or did not meet the requirements of the contract, the second lowest bidder will be considered and so on. Also, all bids may be rejected if the pricing was thought to be too high. Such decisions are left for a committee of technical and legal staff that gets created to study a tender. However, the contract is not open for all bidders. Only pre-approved companies are allowed to participate. These are companies that are reregistered with the CTC and have proven experience in Kuwait or outside of work similar to the one in the contract. Currently, companies that are allowed to participate in the cable preventive maintenance contract are mostly international cable manufacturers. The ministry however, is allowed to contract directly with a company if the scope of work does not cost more than 5000 KD (approx. 13,000 Euros).

Preparation of technical specifications for the contract is left for the maintenance department to write and pass on to the legal department to issue the full tender request. This process requires that tenders and specifications be prepared and ready at least one year from the time work is expected to start. This, as will be discussed below, pose a challenge to the maintenance team which must decide where to perform preventive maintenance two years in advance.

The Pilot Contract Stage

The first Preventive maintenance work on a power cable feeder ever to be performed through outsourcing started in year 2000 and it was through direct contracting with the same cable manufacturer. The contractor was assigned to work on two feeders of its make. Another small contract also followed with a different contractor also dealing with two feeders of the contractor's make. In year 2001 three contracts were issued they contain between 12 to15 feeders per contract. They were offered to different companies regardless of make of the cable. These last three pilot contracts held the basics from which the current three-year major contract was created. Various tests where performed on each feeder ranging from simple visual inspections to oil diagnostic tests.

Lessons Learned from the Pilot Contracts

The following points explain the changes incorporated in the final format of the contract as influenced by the experience gained from the pilot contracts:

- **Exclusion of Serving Test:** This test has proven to be too expensive, too time consuming, and not very effective when it comes to long in service oil-filled cables. Most faults discovered with this test were minor and did not affect the quality of service, insulation, or insulating oil. However, this test is known to be very useful for new circuits at the time of laying to discover laying faults or carelessness.

- **Inclusion of Flushing Procedure:** Various feeders did not pass the oil tests. This means the oil in the cable needs to be flushed out, treated, and sent back in. If the oil is untreatable, or was treated but still didn't pass the above oil tests, new oil will be injected in the cable. Due to these preventive maintenance tests, the list of feeders needing of flushing was accumulating. This list would increase once a major preventive maintenance contract is issued with more than 60 feeders. The maintenance department would be unable to keep up with the load. Therefore, it was thought that the flushing task would be added in the preventive maintenance contract. This way a contractor will be testing an oil-section and at the same time be responsible for its flushing and oil treatment if oil tests were found below standards.

- **Computerized Data:** The contractor is required to make the data collected available in software format for easy analysis by ministry engineers. This would help in assessing the quality and effectiveness of preventive measures.

- **Digital Photos:** It was decided that when reporting any wear out defects, like cracked manhole walls, rust, broken gauges...etc; the report should include clearly labeled and dated digital photos. Before-and-after photos must also be included in reporting any clearing out of dust and debris. Digital photos help in assessing the effectiveness of visual

inspections, and it may act as a lucid representation to help justify visual inspection costs.

The next section describes the format of the current major contract for preventive maintenance on power cables. It shall illustrate the various tests performed and methods of payments to the contractor.

Current Contract Format

The current preventive maintenance contract can be broken into two parts: Preventive Maintenance and Conditional Maintenance

Part 1: Preventive Maintenance (Diagnostics)
This part is the one this paper is mostly concerned with. It is the main part of the contract and the reason why it was created in the first place. The preventive tasks performed are as follows:

1. Visual Inspection:
o Visual inspection is performed on the entire exposed hydraulic and electrical system for signs of damage, wear, and oil leaks and to report with recommended action any such signs. This visual inspection is done separately for every oil section of the feeder. The system may consists of the following components: pressure tanks, valves, gauges, joints in pits, all exposed pipe works, all exposed cables, Cable sealing ends, and earthing system.

o Checking of unburied Joint pits and oil tank pits for any accumulated dust or rubbish and remove from site. Report any needed civil repairs, and generally tighten loose fittings such as earth bolts and oil feeding connections.

o Checking of name plates and pressures setting labels at all locations, and provide missing labels.

2. Oil Pressure Gauge Checking:
o Calibrate oil pressure gauge for correct reading.

o Test that the low oil pressure alarm and low oil pressure trip signals function correctly.

3. Oil Tests:
The following tests are performed on the oil system. Based on these tests the system may undergo oil treatment.

o **Residual Gas Pressure Test:**
This test checks the gas content in pressure tanks and cable sealing ends. The gas content should be less than 20 torr.

o **Impregnation Test:**
This test checks the impregnation coefficient (K) for every oil section. K is defined as follows:

$$K = \frac{dV}{V} \times \frac{1}{dP} \qquad [1]$$

where dP = (P2-P1) which is the drop in pressure after withdrawing of oil in bars. P1 is the stabilized pressure after isolation of oil section from all tanks and feeding points. P2 is the stabilized pressure after withdrawal of a specified amount of oil related to cable length. dV is the volume of oil withdrawn in litres, and V is the total volume of oil in the oil section in litres

K relates pressure to volume when oil is withdrawn. K ideally should be zero, but K is acceptable if it does not exceed 4.5×10^{-6}.

Part 2: Conditional Maintenance (Oil flushing and Treatment)
Based on the result of the above specified oil tests, this task is performed on the hydraulic section. If one or both of the above tests were below standard then the oil section is shifted for flushing. Flushing is performed for 20% of the quantity of oil in the oil section. The tests are then performed again. If the oil tests results are back to normal flushing is discontinued, if not, another 20% will be flushed and so on. In some cases full volume of oil is flushed out. The oil flushed out will be treated in a treatment unit to degasify it and improve its breakdown voltage. The treated oil is then injected back into the cable. Nearly 85% of the time the oil is treatable. When it is untreatable it will be sent to the maintenance department to be replaced by new oil.

Contractor and Owner Relations
In order to make sure that work goes smoothly in the site and according to schedule the following set of rules are enforced during the execution of the contract:

o The contractor company should familiarize itself with the safety rules and regulations of the ministry and abide to it at all times.

o Contractor shall not perform any work without a signed permit-to-work form from the concerning ministry cable engineer.

o Contractor shall submit daily reports of work performed to the concerned engineer that contains clear information of the work done and tests performed and results achieved. These reports are to be written in specific forms using a format agreed upon between the contractor and the ministry's cable engineers. This report should also include before-and-after pictures of cleaning work performed or of any wear-outs or defects reported.

o Every month the contractor is requested to submit an official progress report describing briefly the work performed in a month and the progress of the contract work value compared to the time elapsed.

o All forms submitted must be signed and agreed upon by the supervisor engineer and the contractor.

o The contractor shall not work on ministry equipment or in ministry's property without the presence of a technical supervisor from the maintenance department.

Payments to Contractor
How to pay the contractor must be clearly defined to avoid confusions, disagreements or variation orders. Therefore, all pricing must be agreed upon at the time of signing and items must be individually priced.

When submitting its offer, the contractor must specify exactly how its offer is distributed over the contract scope of work. For preventive maintenance the contractor must specify how much it shall charge for visual inspection and pressure gauge testing for each oil section specified in the contract. Information of oil sections of cable feeders shall be provided in the tender. An offer must also be made on how much the contractor is charging for each of the oil tests. A fixed number of oil tests are performed throughout the contract time. As for oil flushing and treatment work, the contractor must specify a price per litre of oil flushed and treated; a fixed amount of oil is also specified in the tender. Payments are issued only in accordance to these prices. No payments are allowed outside these boundaries. Also, the supervisor engineer and his section head must approve the payment and provide consent that such work is performed according to contract specifications.

At the time of contract signing the contractor is permitted to request an advanced payment equivalent to 10% of contact value. After the commencing of contract work, the contractor is able to ask for payments every three months and according to work performed and pricing specified at the signing of the contract. A 5% of contract value is retained until contract time and a guarantee period of 2 months have passed.

TECHNICAL ISSUES WITH OUTSOURCING PREVENTIVE MAINTENANCE

Advantages and Disadvantages Encountered

Outsourcing maintenance work in general has its advantages and disadvantages. The main advantages experienced are listed below:

o More organized and regular preventive maintenance due to clear time charts, contract structure, and progress requirements.

o With outsourcing, preventive maintenance data recording and data presentation has improved.

o Outsourcing requires less in-house engineers and technicians.

o Preventive maintenance work has become smoother as it is now being done all the time and through fixed schedules unaffected and separated from other maintenance tasks.

o Outsourcing has helped in creating a competitive market which is always good for the national economy. This has helped in making the contract price drop down over the years as seen in **figure 1** below. The plot shows the drop of item price per oil section in contracts of the past five years.

All of the above points can surely help in making preventive maintenance more effective. However, some disadvantages and shortcomings have also been experienced with outsourcing preventive maintenance. They are listed below:

o With contracts and contractors present more paper work is needed. Such paper work may be technical in nature and requires an in-house skilled engineer to be appointed to study and review.

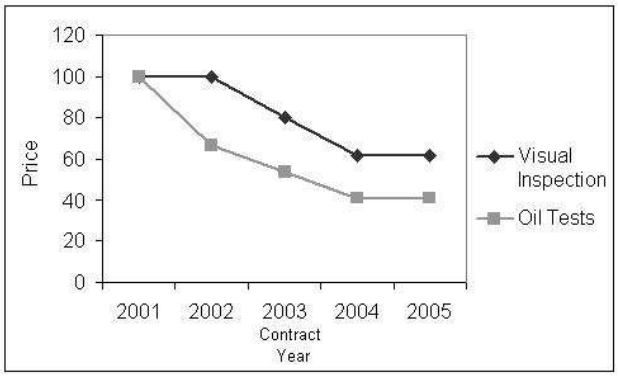

Figure 1: Drop in item price per contract year.

o There is always the fear of losing skill as work is done by contractors and not by in-house personnel. However, this problem is less of concern as flushing work, oil treatment, and oil tests are still being carried out by the in-house repair teams on feeders being repaired after faults.

o It is not always easy to make sure supervision on contractor is properly done. In order to tackle this disadvantage the following steps were taken: Before and after photos, on-site dual signatures by contractor and supervisor on test sheets, not accepting contractor work if an in-house personnel was not present at all times, changing supervisors between time to time to refresh the work environment and break the routine, and finally, evaluation teams to visit work sites and assess the quality.

o Is the work load proper to the time of the contract? In other words, is the contractor over or under worked? The current contract work load is based on experience from pilot and previous contracts. This work load must always be evaluated at the end of the contract before making the specifications for the new contract. From experience this does vary from contractor to contractor and pose a challenge whenever a new item is added to the contract.

Another challenge facing outsourcing preventive maintenance is where such maintenance needs to be performed. This, of course, must be decided early before issuing of the tender which maybe two years before actual commencing of work. The contract must have specific oil sections of feeders that need preventive maintenance; the next section focuses on this challenge.

Selection of Feeders for Preventive Maintenance

While testing, inspecting, and reporting is left for the contractor, the decision of where these tests and preventive measures should be performed in the network is the job of the ministry's experienced staff to decide. The criteria by which cables are selected for tests under such contracts are outlined here. Challenges facing staff in the selection process are emphasized because preventive maintenance tests in the wrong place can be a waist of time and resources. The selection process is to depend on the following technical aspects: **Failure history**, **average load**,

and **age of cable**. However, non technical aspects must be considered as well. Examples are as follows:

o **Accessibility to Area:** some areas require special permits to enter. The contractor must be allowed some extra time to arrange for permits.

o **Season**: Some cable feeders are impossible to get in high load season (summer in the case of Kuwait.) Therefore, these feeders must be a priority in winter and other less loaded feeders must be left for summer.

o **Arrangement with Control Centers**: before switching off a cable control centers must be notified and their consent acquired. This arrangement is done twice. First, it is done at the start of the contract with the full program that includes a rough timeline of all feeders undergoing preventive maintenance. Later, control center permission is acquired around one week before maintenance time for each feeder.

All of this makes it very challenging to decide a list of feeders for a 3 year contract before its starts. Nonetheless, proper arrangement with consumers and control centers before hand has made this possible for current and past contracts. Also for certain feeders the contractor is made aware that the feeder under work may be demanded back in operation immediately and the contractor should be ready to normalize it within a maximum of four hours.

To Mimic Expert Decision Making

As mentioned earlier the implementation of such contracts on a regular basis poses a challenge in providing circuits that truly need preventive maintenance. Currently, feeders that undergo preventive maintenance are chosen by expert staff; this is planned to be replaced by a more systematic approach that would be open to all staff. By a better policy of data collection, computerizing old collected data, and regular data analysis, expert knowledge can be saved and retrieved easily for preventive measures. With this in mind a system is currently being developed that would output a rating for all underground feeders based on their likelihood of failure. Currently, this prediction system's inputs are failure history, area (or load), age of circuit, and manufacturer. While the system is still underdevelopment, preliminary results were very promising in mimicking expert knowledge. One example of system output is the division of all feeders in the network to four groups according to their likelihood of failure as shown in **figure 2** below.

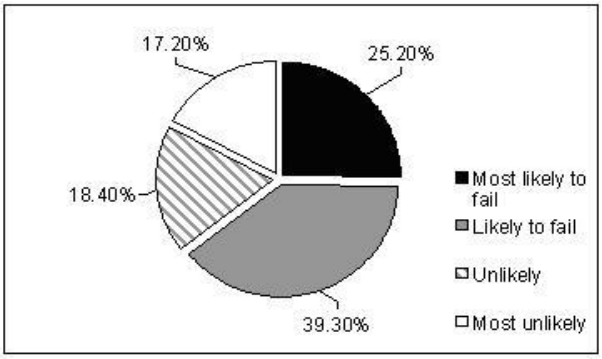

Figure 2: Division of all Underground feeders in the network based on their likelihood to failure.

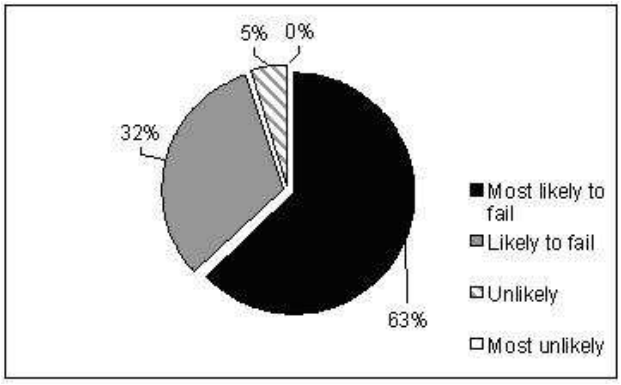

Figure 3: Prediction system ratings of all feeders chosen by experts for preventive maintenance; notice how most feeders have a high rating

When this division is compared to expert staff selection of feeders for preventive maintenance, there was an agreement. Most feeders that were chosen by expert staff for preventive maintenance have had a *most likely to fail* rating as shown **figure 3** above. It is clear from the figure that 92% of feeders chosen for preventive maintenance were rated by the system as either *most likely to fail* (63%) or *likely to fail*. The development of such systems based on collected data can serve as a reliable aid to staff in deciding were to perform preventive maintenance.

DATA ANALYSIS TO VERIFY THE EFFECTIVENESS OF WORK CARRIED OUT

Verification of the significance of tests carried out is the most important reason to keep preventive maintenance work going on. With several such contracts already finished, the importance and quality of such outsourced preventive work could be highlighted by previous contracts' results analysis. One example is given in this section related to oil tests.

To assess the significance of oil tests the data of previous contracts were analyzed. **Figure 4** below shows the number of cable feeders tested per contract and the percentage of these feeders that did not pass the oil tests. Here, a feeder is considered faulty if it has at least one section or one tank in need of oil treatment. In most cases an oil-filled feeder may have 3 oil sections (one for each phase) and six pressure tanks (three on each side). In oil treatment, priority is based on how severe the condition of oil is and the number of oil sections faulty. **Figure 5** below divides the feeders tested and found faulty in the past four contracts

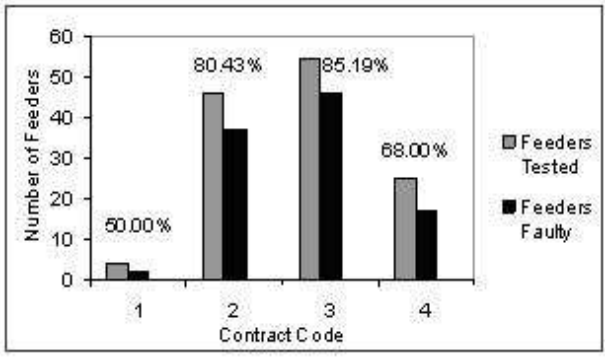

Figure 4: Number of feeders tested per contract and percentage of feeders found faulty

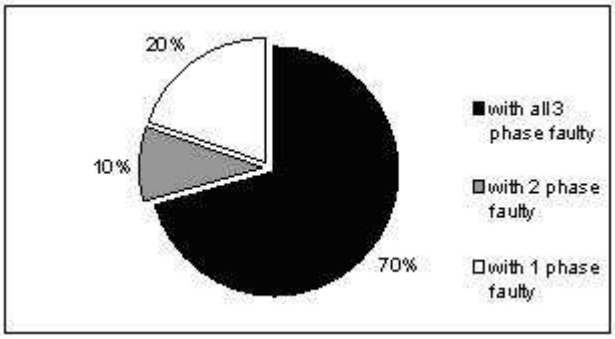

Figure 5: Division of feeders found faulty according to the number of oil sections (phases) found faulty.

according to the number of oil sections (or phases) found in need of oil treatment. Notice, how most feeders have all three phases in critical condition.

It is clear from the data analysis that such preventive measures help in identify the condition of feeders in the network. The fact that 79% of all feeders tested (an average of 71% of feeders tested per contract) found in critical condition is very significant in highlighting the importance of preventive work done on these contracts. With this high percentage, tests are clearly not being performed unnecessarily. Similar analysis can be made on each item of the contract like gauge calibration, visual inspections, and so on. Such analysis helps to justify the continuing, discontinuing, or periodicity of these tests.

ADJUSTMENTS AND ADDITIONS FOR FUTURE CONTRACTS

In order to improve the output of outsourcing preventive maintenance on power cables there should always be a constant evaluation of finished contracts and finished work. Any issues raised or problems faced during the execution of a contract, is noted and filed by the maintenance section head. These notes are reviewed at the time of writing of new contract specifications. Contractor staff as well as ministry staff can all contribute to this open discussion of possible improvement on the contract scope of work. Plans for future contract include the following:

o Adjustments of work load: Currently the work load is in accordance with the time specified. Therefore, there should not be an increase of work load for future contracts without either the increase of contract time or the increase of contract equipped staff. For the next contract, the number of cable oil sections to be tested is planned to be doubled, but the time period of the contract will remain the same. Therefore, the participating contractors are expected to submit offers with double the staff and equipment of previous contract.

o Currently under study is a proposal for retesting of cables with flushed or treated oil sections within one year or six months after treatment to verify that the problem did not return. If the gas content appeared to have risen above critical level again, then this oil section will be shifted to the repair team to investigate possible gas leakage from switchgear or to locate faulty joints.

CONCLUSION

Outsourcing preventive maintenance may serve as a good option to help regulate preventive maintenance and make it more effective. While outsourcing has its disadvantages, the real issue for any reliable network operator should be the efficiency and effectiveness of preventive maintenance whether in-house or outsourced. In the case of the network of this paper, outsourcing was a better choice. However, the measure of how well preventive maintenance is doing requires continuous review of contracted work, data collection, and data analysis.

While the testing process was outsourced, in-house staff retains a more challenging job of deciding where these tests are to be performed taking into account technical and environmental issues; such decision must be based more on available data and data analysis than on subjective expertise. Also, in-house staff must organize work time charts in advance with an appropriate work load that would not leave the contractor over or under-worked at any point during the contract period. Such in advance preparation, however, should make the contract stand on solid ground and be executed without delays or obstacles. And all of this, in return, should help make the network more reliable and its weak spots identified.

REFERENCES

[1] E. Peschke and R. von Olshausen, 1999, *Cable Systems for High and Extra-High Voltage; Development, Manufacture, Testing, Installation and Operation of Cables and their Accessories,* Publicis MSD, Germany.

[2] J. A. Casazza, 1993, *IEEE Case Histories of Achievement in Science and Technology Volume 2: The Development of Electric Power Transmission; The Role Played by Technology, Institutions, and People*, IEEE, USA.

[3] J. Moubray, 2001, *Reliability Centred Maintenance,* Butterworth-Heinemann, UK.

[4] R. N. Allan and R. Billinton, 1995, *"Concepts of Data for Assessing the Reliability of Transmission and Distribution Equipment"*, IEE's 2nd International Conference on The Reliability of Transmission and Distribution Equipment, IEE.

[5] J. Hamman, 1995, *"Experience with the Use of RCM in a Transmission Maintenance Environment"*, IEE's 2nd International Conference on the Reliability of Transmission and Distribution Equipment, 192-7.

[6] Cigre, 2005, *Maintenance for HV Cables and Accessories, 8-9.*