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Planning for the future in uncertain times

Shortcomings and proposed improvements to the current practice used by Eskom Transmission to determine asset health index of overhead transmission lines

S A MUSHABE, R A VAJETH

Eskom Holdings SOC Ltd

South Africa

SUMMARY

Over the years, the maintenance strategies for overhead lines in Eskom Transmission Division have centred on a scheduled or time-based inspection and assessment approach. Using this time-based approach, a transmission line is assessed at least once a year with a "*fast*" aerial inspection. Every 4 years, an overhead transmission line gets a "*detailed*" aerial inspection. No measurements, tests or samples are performed to determine remaining life of the assets. The inspection methods used rely predominantly on visual imagery obtained using a multi-spectral camera to determine the condition of the transmission lines. A condition-based maintenance approach for the inspection and assessment of transmission lines has been investigated and is currently being adopted by Eskom Transmission as an alternative. Part of this approach includes determining the asset health of the overhead line, and for this, a health index was defined.

Given the magnitude of the task at hand: the numbers of towers and the vast area covered by the existing overhead lines, using the condition-based approach was a mammoth task. As a starting point, an abbreviated health index was defined and used to get an overall picture of the asset health of the overhead lines within Eskom Transmission. The required outcome of the exercise was to determine the shortcomings, pitfalls and efficiency of the strategy. This paper describes how the abbreviated health index for overhead lines was carried out; it briefly shares the results of the exercises undertaken by Eskom Transmission and details the challenges and shortcomings that were experienced by the teams involved during the implementation of the exercise.

KEYWORDS

Overhead line, inspection, maintenance, asset management, health index, condition monitoring

arigyes@eskom.co.za

1 INTRODUCTION

There are 358[1] overhead transmission lines that are owned, maintained and/or operated by the Eskom Transmission Division. These overhead transmission lines are divided across the 10 Transmission Grids. The transmission lines cover approximately 32 500 km (route length), over 275 000 km in conductor length (excluding earth wires and/or OPGW) and over 85 900 towers.

The Eskom Transmission network comprises mostly of 400kV and 275kV HVAC transmission lines. They make up 45% and 40% of network, respectively. Other transmission lines in the network operate at 765kV, 220kV or 132kV. There are 2 lines that are rated 88kV and 2 x HVDC 533kV lines that run from Apollo MTS to Cahora Bassa in Mozambique.

The age profile of the transmission lines is shown in Figure 1[2]. For this study, the age assigned to a transmission line was the earliest recorded date on the Transmission Spatial Information System (TxSIS) database. For example, for a line between Substation A and Substation B with 100 towers, if the first 10 towers from Substation A were built in the year 2000 (17 years) and the rest of the towers were built in 1990 (27 years), then the line from A to B is assigned 27 years. From the age profile, it is then clear that there are sections of at least 206 lines that are between 40 and 60 years old. The two 88kV lines do not have any recorded construction year on the TxSIS database.

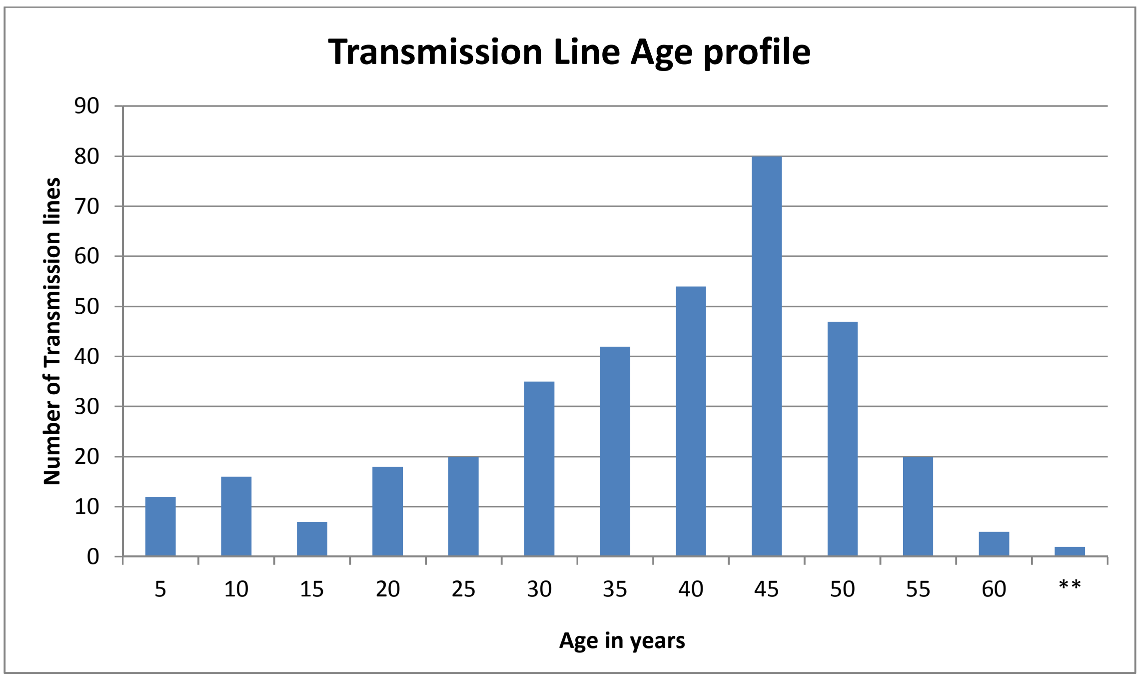

Figure 1 Transmission Line Age profile [**-unknown year of construction]

The maintenance strategy predominantly used by Eskom Transmission for overhead lines has been a time-based approach. Using this approach, a transmission line is assessed at least once a year with a "fast" aerial inspection. Furthermore, every 4 years, an overhead transmission line gets a "detailed" aerial inspection. The purpose of a detailed aerial

[1] 358 transmission lines as of the beginning of the 2016/2017 financial year.
[2] Age of the line at the end of the 2016/2017 financial year.

inspection is to evaluate the condition of the line hardware, conductors, conductor spacers, insulators, earth wire and tower structure from as close a distance as possible utilising a helicopter without putting the safety of the crew at risk. However, the "detailed" aerial inspection neglects the foundations as well as sections of tower that are not visible from the air. No measurements, tests or samples are performed to determine remaining life of the assets. This inspection method relies predominantly on visual imagery obtained using a multi-spectral camera to determine the condition of the transmission lines. Moreover, the efficacy and cost of this approach of inspection and assessment is questionable and in many cases unfavourable.

In an effort to steer Eskom Transmission from a scheduled maintenance program to a condition-based maintenance program, a maintenance strategy for metal structured power lines was developed early in 2015. The purpose of the strategy document, among others, was to define and detail how an overhead transmission line was inspected and assessed and from the resulting data, how the health of the overhead transmission line was determined. In the strategy document, the asset and its components were defined and health index criteria were developed to establish their condition relative to their established end-of-life. From this an abbreviated health index was defined and used to get an overall picture of the asset health of the overhead lines within Eskom Transmission.

2 ABBREVIATED HEALTH INDEX

During the exercise, the measures applied to determine an abbreviated health index were as follows:

- A line was rated as whole and not per individual span or individual tower.
- All lines including wood-poles lines were assessed.
- For this exercise, the age of the whole line was taken as the age of the oldest tower found on the line as recorded on the TxSIS database.
- Bypasses were excluded from this list.
- Fibre optic systems (OPGW, AdLash™) were excluded from the line ratings unless they had a significant impact to the line performance and/or health, for instance in cases where the AdLash™ failed.

The overall ratings of components were based on visual reports taken from the latest detailed and ground inspections. Further to this, the field operators were interviewed to provide insight on other issues on their lines that may not be captured in the regular inspection, for example: previous failures, line performance and vandalism issues. No samples were taken on lines for this exercise. However, if sample test results were available, information from the test reports was used.

Each parameter for each line was then evaluated using a letter condition rating, from A (very good) to E (very poor), as shown in Table 1. The ratings were assigned factors: A – 4, B – 3, C – 2, D – 1 and E – 0. Each component and each test/criteria is assigned a weighting based on the importance in determining the end-of-life. The condition rating is multiplied by the assigned weight, and a weighted score is calculated for each asset class. The criteria shown in Table 2 were considered when assessing the structures asset class. The criteria shown in Table 3 were considered when assessing the conductor asset class.

Table 1 Health index rating for Overhead Transmission Line

Health index	Condition	Description	Requirements
85 - 100	Very Good (A)	Some ageing or minor deterioration of a limited number of components	Normal maintenance
70 - 85	Good (B)	Significant deterioration of some components	Normal maintenance
50 - 70	Fair (C)	Widespread significant deterioration or serious deterioration of specific components	Increase diagnostic testing, possible remedial work or replacement needed depending on criticality
30 - 50	Poor (D)	Widespread serious deterioration	Start planning process to replace or rebuild considering risk and consequences of failure
0 - 30	Very Poor (E)	Extensive serious deterioration	At end-of-life, immediately assess risk; replace or rebuild based on assessment

Table 2 Structures Asset Class parameters – abbreviated health index

Criteria	Weight	Considerations
Foundation and stubs	4	Corrosion/Rust, Fatigue or damaged concrete or stubs, Soil erosion and movement or water drenched
Earthing	1	Damaged, rusted and missing earth straps and towers with footing resistance values higher than specified
Structure	4	Corrosion/Rust, fatigue or damaged legs and members loose and missing bolts
Insulators	4	Glass insulators: Corrosion/rust of pins and caps, broken discs, pollution on insulators surfaces Composite insulators: Corrosion/rust of pins and caps, broken sheds, shed pollution, tracking or burn marks, condition of end seals, corona rings installed and condition thereof
Hardware	3	Corroded/rusted hardware, fatigued or damaged hardware, loose or missing bolts and nuts

Table 3 Conductors Asset Class parameters – abbreviated health index

Criteria	Weight	Considerations
Phase conductors	4	Discolouration, burn or flask marks, rust, damage, loose/broken strands and bird caging.
Splices and dead ends	2	Discolouration– signs of overheating, damage
Earth wires	2	Discolouration flask marks, rust, damage, loose/broken strands and bird caging.
Spacers and Dampers	1	Damaged, loose, displaced and missing spacers and dampers

These factors were then multiplied with the criteria weighting. The result was normalised and given as percentage. Table 4, Table 5 and Table 6 show how the health index was calculated for a line, referred to in this document as Line 1.

Table 4 shows the abbreviated health index for the structures on Line 1. The maximum score, if all the criteria under the structures asset class were scored with an A, is 64. The actual score based on the inspection reports is 18. 18 out of 64 is 28.1%. This score is below the 30% mark. As a result, the structures asset class is rated E (see Table 1) despite having none of the individual criterion scoring an E rating.

Table 4 Abbreviated rating for Structures on Line 1

Criteria	Foundation and Stubs	Earthing	Structure (Tower)	Insulators	Hardware	Score
Criteria rating	D	B	D	D	D	E
Criteria Weighting	4	1	4	4	3	64
Weighted Score	4	3	4	4	3	18

Similarly, Table 5 shows the abbreviated health index for the conductor system on Line 1. The maximum score is 36, the actual score is 17 which results in 47.2% rating. This is below the 50% mark and the conductor asset class is rated D.

Table 5 Abbreviated rating for Conductors on Line 1

Criteria	Phase Conductors	Earth Wires	Splices & Dead-ends	Spacers & Dampers	Score
Criteria Rating	C	C	C	D	D
Criteria Weighting	4	2	2	1	36
Weighted Score	8	4	4	1	17

The overall rating of Line 1 is 37.7%. It is rated with a D. This is calculated by taking the average score between the score for the structure asset class and score of the conductors asset class. The asset classes have equal weighting as indicated in Table 6.

Table 6 Overall Rating for Line 1

	Structures (X)	Conductors (Y)	Overall Score (X+Y)/2
Score	$^{18}/_{64}$	$^{17}/_{36}$	$^{217}/_{576}$
Percentage	28.1	47.2	37.7
Rating	E	D	D

3 OVERHEAD TRANSMISSION LINE HEALTH INDEX FINDINGS

Using the abbreviated Asset Health index described in the previous section, the transmission line health index was compiled for the 358 transmission lines. The results are shown in Figure 2 and the ratings are summarised as follows:

- A – 32 (8.9%) lines in a very good condition, only minor signs of deterioration (almost new)
- B – 132 (36.9%) lines in a good condition, some of the components showing signs of deterioration
- C – 163 (45.5%) lines in a fair condition, a high number of components showing signs of deterioration
- D – 25 (7.0%) lines in a poor condition, wide spread signs of deterioration
- E – 6 (1.7%) lines in a very poor condition, extensive and serious deterioration

Many of the problematic lines are in harsh environments – coastal regions or in areas with industrial/mining pollution. There seemed to be a stronger correlation between abbreviated health index and the environments in which the lines traverse than with the actual age of the lines.

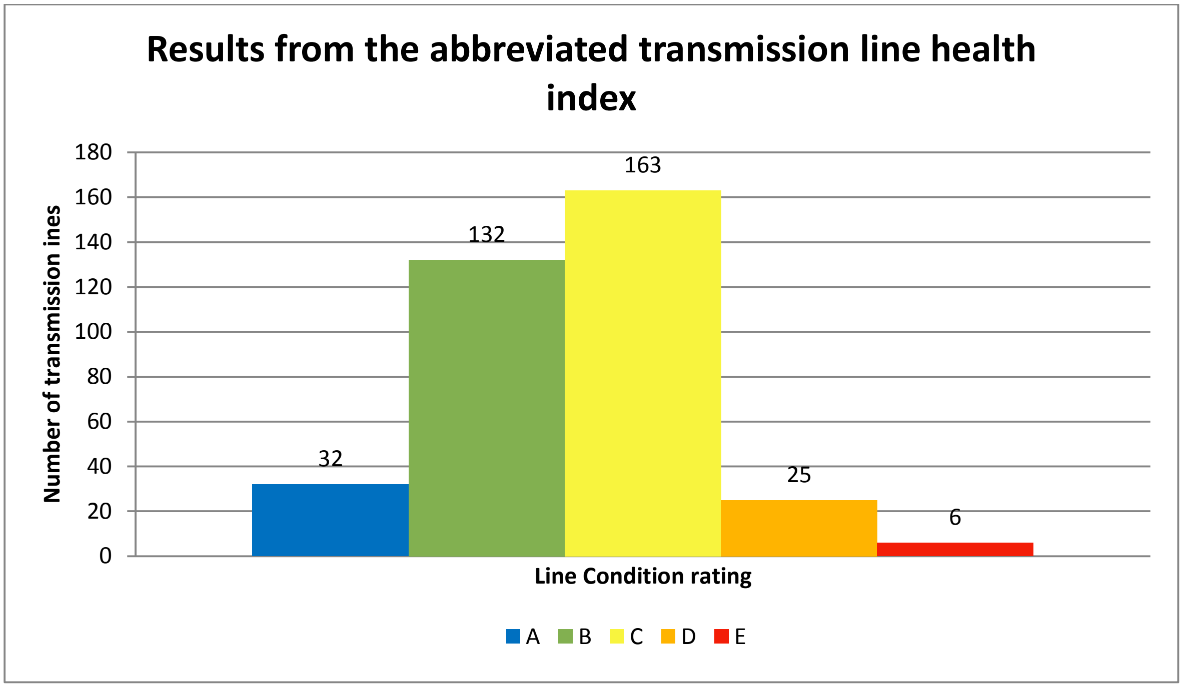

Figure 2 Results from the abbreviated transmission line health index

4 CHALLENGES OF OBTAINING A HEALTH INDEX

There are 358 transmission lines in the grids, over 85 900 towers covering 32 500 km. In order to complete a valid health index of all 358 lines, one would need to assess all the towers and all the spans on the line to compile a condition rating, including taking samples for each line.

During the exercise to obtain an abbreviated health index, it was apparent that a few challenges would have to be overcome within the business before Eskom Transmission could fully adopt the condition based maintenance approach for overhead lines. Some of the challenges are discussed below.

4.1 Data capturing

During a detailed inspection, data is captured on a line and servitude Inspection report, in which defects that are identified on the line are marked for each tower. The components covered are the insulators, hardware, conductor, foundation and optical fibre. Other issues that are captured in the report are the presence of bird activity, the type of pollution the line is exposed to as well as a brief description of the environment where the tower is located (e.g. land use or servitude condition). The defects are supported with photos and videos.

The inspection report works well for the identification of defects. Towers where a defect is found are marked and comments are given. No information is given for towers that have no defects. Consequently, the report becomes inadequate to use for the completion of a health index for the line. One can only make assumptions for the towers with no comments. The towers with defects merely indicate the presence of a defect. There is no assignment of a condition rating for each component. Furthermore, the manner in which an inspection report is completed varies from operator to operator. In some cases there is more focus on the condition of the servitude and less on the actual conditions of the lines. This is largely due to the manner in which questions are posed in the inspection report. Several questions are ambiguous and lead to various interpretations of what is being asked. In other cases, the field operators were not clear on what to look for during a visual inspection nor how to identify all signs of deterioration on transmission lines.

The inspection reports will need to be revised and a uniform methodology of completing the form will be required. If detailed aerial inspections are used in future for the capturing of data to complete a health index, the inspection sheet will have to be adapted accordingly.

4.2 Data storage

Another challenge that requires attention is data storage. For one to have an effective system, one requires accurate records of as-built infrastructures. Having an asset inventory should include information on all the major components/assembles including material, type, size, manufacturer and installation year. Further to that, the inventory data would be updated each inspection cycle and following changes due to maintenance and construction activities. [1]

Presently, there is no central storage facility of inspection photos, reports and/or investigations. Information is kept at the respective transmission grid field offices on individual computers or hard drives. Some information is captured on the TxSIS database, and this requires a considerable amount of time to quality check and control. Work is currently being done to develop a system that allows operators to capture information for condition monitoring of transmission lines in field, integrate seamlessly with the current plant management systems and be available online for all the relevant stakeholders.

4.3 Type and Frequency of Inspections

The existing maintenance strategy contains a task selection table. This table defines the overhead lines based on their functional importance, usage/duty cycle, environment and health. Thereafter, maintenance tasks and the frequency of the tasks are defined. The completion of this task selection is beneficial as it provides guidance as to the frequency of the various maintenance tasks, including condition monitoring.

As mentioned before, many of the assessments required to complete the health index of transmission lines are done visually using a multi-spectral camera. However, some of the condition criteria or assessments require samples to be taken. Line condition assessments or audits would be required on all the transmission lines as detailed aerial inspections will not be sufficient.

Over the two financial years, 2014/15 and 2015/16, 178 lines had a detailed aerial inspection or ground inspection performed. Every year, the same 23 lines get detailed inspections either because these lines are in an urban setting where helicopter use is limited or the lines are in remote areas.

Over the period from 2014 to 2017, only 227 different lines will have a detailed aerial inspection. However, budget constraints on the number of hours flown by helicopters are making it tougher to get to all the lines. Even then, in the current format, the information received is not sufficient for a health index as samples and prescribed tests do not form part of the existing scope for detailed aerial inspections.

4.4 Sampling and testing

For a complete health index, samples are required to be taken for various tests. These are:

- Conductor samples are required for tensile tests, tensile ductility tests, wrapping tests, zinc coating measurements and torsional ductility tests.
- Earthwire samples are required for tensile tests, tensile ductility tests, wrapping tests, zinc coating measurements and torsional ductility tests.
- Hardware samples are required for corrosion examinations.
- Insulator strings are required for pollution conductivity testing.

Other tests or inspections include corrosion measurements on tower members, conductor sag measurements, tower footing resistance measurements as well as the use of a multi-spectrum camera scan to detect hot spots and excessive corona. Moreover, excavations are needed in order to expose stubs for inspection. In some cases, this action requires outages to be taken on the Eskom network.

Of all the samples needed, conductor samples are the hardest to acquire. They require outages to be taken on the line and a full recovery team on hand to replace the section of conductor that is removed from the line. These are not always readily available at the same time and in some cases network constraints prevent outages for significant periods to allow teams to acquire the samples. Experience within Eskom has also shown that for some lines (especially lines that are partly inland and partly coastal) more than one conductor sample is required to give a suitable representation of the line. Lines that run perpendicular to the prevailing wind direction are often more likely to show greater signs of corrosion damage than line that run parallel.

4.5 Resources

At the moment, the transmission field operators are responsible for collecting the data and providing a health index, while analysis of the results is performed by the relevant engineering department.

The current field operators are involved in the capturing of data for detailed line inspections. Naturally, there is a lot of movement of staff from grid to grid, and local knowledge of lines diminishes as new staff move in and out. The staff is trained to recognise defects on lines, but not necessarily trained to monitor and carry out condition assessments of lines.

Additionally, testing facilities, labs, equipment and tools are required to run tests on samples. All these items require more time and money allocated for these tasks to enable the completion of a health index.

Over the years, Eskom has investigated ways in which advancements in technology can be used to improve on the efficiency of the maintenance program without increasing the manpower numbers. Some examples that have been integrated in to the maintenance strategy include the use of multi-spectral cameras, and the use hand-held tough books that are linked to the plant management system. The use of unmanned aerial vehicles and line robots for overhead line inspections is still under investigation. However, these interventions all require trained and skilled personnel to operate and produce quality reports.

5 CONCLUSION

After the exercise using the abbreviated health index for overhead transmission lines was completed, a few learnings were made and can be summarised as follows:

In order for Eskom Transmission to fully adapt the condition-based approach, the shortcomings with data storage and data capturing will have to be addressed. A complete asset registry that includes information on all the major components/assembles including material, type, size, manufacturer and installation year will have to be commissioned and maintained.

A training program for the operators will be required to ensure that the operators are fully knowledgeable of the components on the transmission lines as well as are to identify defects and accurately comment on the condition of the transmission line. Furthermore, the operators are equipped and trained to use and interpret the results of the various tools and equipment used to carry out the inspection activities.

A review of the inspection report that is used by the operators has to be revised in such a manner that the information required can be captured accurately without ambiguity. Finally, the completion of the task selection table for each line will be necessary in assisting the asset managers and operators in determining the frequency of future inspections and the locations along the line where samples should be taken.

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