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Health Index Evaluation of Overhead Transmission Line Assets in Nigeria Using AI Models

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***Abstract*— *This study is aimed at evaluating the health index of overhead transmission line assets in Nigeria using artificial intelligence models (ANN and ANFIS). The data used in this study was obtained from linesmen inspection report of Uyo/Itu 132 kV transmission line, which consists of 59 towers labelled from T1-T59. ANN and ANFIS were used in evaluating asset health index. It was observed that environmental factors are the major degradation factors in overhead transmission lines failures, contributing 40% of the entire failure events encountered in the transmission network. The findings made in this study can help to reduce capital, operational and maintenance expenditures.*

***Keywords*— *Artificial Intelligence, Asset Management, Health Index, Transmission Line.*

I. Introduction

Nigeria is a developing country, and developing countries have many developmental challenges to grapple with, not least, access to affordable, clean and stable power supply to all its populace. This is true because access to affordable, clean and stable electricity supply is paramount to attaining and sustaining socioeconomic and technological development by any country [1]. Nigeria has been found wanting in this regard; most Nigerians conduct their business and go to bed without regular power supply. While there are many explanations to the above painted dire power situation in Nigeria, the poor maintenance culture in Nigeria to infrastructure is at the heart of it.

Whereas asset management is one of the hottest topics in contemporary society and this has been so since the inception of creation [2]. The Nigerian electrical power system has not been properly managed. If anything, the Nigerian electrical power system has without gainsaying suffered the untold neglect in terms of poor servicing and maintenance from successive governments since 1960. Many decisions concerning equipment maintenance, repair, or replacement have been made in the midst of a crisis, usually when one critical piece of equipment fails and requires immediate attention [3].

Electrical power system is an important infrastructure that creates, transmits and supplies safe and usable electrical energy to consumers. The livelihood of most people depends on it. Without adequate supply of electrical energy, the modern world economy, public health, security, and safety will suffer huge loses as has been experienced in Nigeria. References [4] – [9] reported that Nigeria's national grid failed at least once every month between 2009 and 2019, throwing the country into darkness. On the factors responsible for such low level of reliability, the report highlighted amongst others, inadequate and dilapidated transmission and distribution network, poor upkeep of transmission and distribution network and lack of investment as the principal causes of frequent interruptions.

Nigeria's transmission system has the capacity of transmitting 5,300MW but is frequently disrupted by system failures and forced outages. Most of the capacity shortfall is due to obsolete equipment and poor maintenance, or to ongoing maintenance and repair activities at existing power plants. Only about 25% of Nigeria's 12,522MW of installed capacity reaches the end user. According to [10], transmission losses across the network are high at 7.4% on average (January to July 2015), compared to emerging country benchmarks of approximately 2-6%. This situation reflects critical infrastructure and operational challenges. Against this background, Reference [11] states that ageing infrastructure of electrical energy systems has lately calls for concern and challenge to power utilities around the globe and in Nigeria particularly.

Poor electrical infrastructure causes a lot of disruption to the power supply channels. To ensure continuous service and supply of the energy to the consumers, those interruptions need to be taken care of. Reference [12] submits that when approaching the end of the service life of an overhead line, the risks of its use increase. This is due to aging, which causes more frequent defects, longer maintenance times, a greater number of replaced spare parts, and the need for more frequent maintenance and detailed inspection of overhead line condition. Overall, this results in an increase in costs for the stated overhead line. Accordingly, in order to ensure the long service life of overhead line components, monitoring of their condition should be an activity of high priority.

Calculating the asset's health index is one method for reducing interruptions in energy supply. Health Indices represent a practical method to quantify the results of operating observations, field inspections, and site and laboratory testing into an objective and quantitative index, providing the overall health of the assets [13]. The asset health index is a powerful tool for managing assets, identifying investment needs, and prioritizing capital and maintenance investments. [14].

II. Literature Review

A. Health Index

Reference [15] defined Health Index as a way of combining complex condition information to give a single numerical value

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as a comparative indication of overall condition. It can be used as an assets management tool and identifier for investment needs, such as prioritizing capital investment and maintenance programs. The purpose of health index assessment is to quantify the condition of the equipment based on various criteria related condition factors of long-term degradation that cumulatively resulted in the end of life of the operating assets [16].

A composite Health Index is a very useful tool for representing the overall health of a complex asset. The result describes the overall health condition of an asset. Health Index results differ from test results, condition-based maintenance, or diagnosis, which emphasizes the search for damage and inefficiencies. In several studies literature, the Health Index method is referring to industry standards and expert judgment [17].

Health Indices provide a basis for assessing the overall health of an asset which are based on identification of the modes of failure for the asset and its subsystems, and then developing measures of generalized degradation or degradation of key subsystems that can lead to end-of-life for the entire asset.

Transmission and distribution assets are characterized by multiple subsystems with multiple modes of degradations and failures. Depending on the nature of the asset, there may be one dominant mode of failure, or there may be several independent failure modes. In some cases, an asset may be considered to have reached end-of-life only when several subsystems have reached a state of deterioration that precludes continued service. The composite Health Index combines all of these condition factors using a multi-criteria assessment approach into a single indicator of the health of the asset [18].

To develop a Health Index for an asset, it is essential to understand the functionality of the asset, and the way the various subsystems work together to perform the main functions of the asset. With a clear understanding of asset functionality, the various condition ratings can he combined to create a condition score for the asset, and the continuum of asset scores can be subdivided into ranges of scores that represent differing degrees of asset health.

B. Assets and Assets Management

An asset is simply any resource that is critical to the operations of an organization. The assets of the organization are used to service and supply end users, or to facilitate such services. Asset owners acquire, operate, and maintain assets to support the effective delivery of services. As a result, an asset has service potential or future economic benefit. Physical assets such as transmission and distribution system equipment are commonly considered in the power delivery industry [19].

Asset management (AM) is the process of guiding the acquisition, use and disposal of assets to optimize their future economic benefit and manage the related risks and costs over their entire life cycle, It entails optimizing the life cycle of assets in order to maximize their performance, not only in a security context, but also in a social and environmentally acceptable context [20]. Asset management has shifted away from age-based assessments and toward condition-based data, which provides a more accurate picture of equipment's health and potential for failure. Individual structures and components are assigned performance ratings during routine inspection. By integrating field knowledge into the overall condition rating, these ratings drive Health Index algorithms.

C. Identification of Failure Modes of Transmission Line Components

Reference [21] submitted that four major components basically make up the condition of a transmission line; the components are the foundation, structure, insulator, and conductor. Coordinated evaluation of these components can reveal vital information relating to their health status.

The most common failure mode of steel tower is corrosion of the steel member and cracking in the case of wooden tower. Other tower failure modes are deformation, settlement and excessive deflection. Corrosion and annealing are the major contributors to conductors' failures, conductors are inclined to corrosion, especially in heavily industrialized areas which have high stages of pollutants in the atmosphere, other significant failure modes are joints and splices [22]. The insulation criteria commonly check crack of the insulator, the polluted insulator grade and the service life of the insulator. Foundation failure can occur because of foundation displacement to the ground, soil settlement, slope protection damage, or a flood disaster [22]. Environmental factors also contribute to transmission line failure and need to be included. The criteria are based on the tree barrier condition, construction nearby, vandalism, theft, vehicle approaches, thunder, strong wind and rainfall. Vandalism is an important factor for consideration in the provision of stable electricity, reported cases of vandalism of electrical facilities are on the increase. Reference [23] reported that, the 330 kV Sapele to Benin transmission line tripped off in March 2022 after several attacks that affected some towers under it. The most recent case of vandalism is tower collapse of T104 on April 8, 2022, at Oku Iboku in Akwa Ibom State, along the 330 kV Ikot-Ekpene to Odukpani transmission line, this led to a major outage for over two weeks, many communities in Akwa Ibom and some parts of Cross River states were affected. Vandalism, theft, encroachment and other such illegitimate human activities are contributing factors to the instability and unreliability of electricity supply and should not be ignored.

III. METHODOLOGY

One of the major causes of frequent interruption of power supply in developing countries and in Nigeria particularly and has been grid collapse. Grid collapse in Nigeria has become an annual event especially during the rainy season (between April to October), it usually comes with adverse effect on the transmission line infrastructure and by implication the distribution network culminating in several days of blackouts. Hence, the emphasis in this study is the utilization of artificial intelligent models for the prediction of the health index of electrical transmission line. The data used in this study was obtained from linesmen inspection report of Uyo/Itu 132 kV transmission line, which consists of 59 towers labelled from T1-T59. Ten (10) towers were sampled in erosion prone areas and communities with reported cases of transmission line components vandalism. Various methods of disruptions are considered with regards to damage to the transmission line were grouped under environmental disruption conditions, electrical

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disruption conditions, structural (tower structure) disruption conditions and vandalization of the line.

From Table 1, the major transmission line parameters considered were divided into three main subsections namely, environmental, structural and electrical with the addition of electrical components vandalism. The factors considered for the transmission line disruptive parameters were Item score (Ip), Condition level (Cl), Critical factor (CFp), Age factor (AFp) and then the health index of the parameter (Hip). Condition level is determined from physical assessment, the item score depends on the impact of that item to the integrity, stability and service reliability of the overhead transmission lines. Historical data give the service life data for determining the age factor of the parameter. The critical factor is set in relation to the frequency of occurrence of service disturbance along a specific span of transmission line, it is dictated by accessibility, environmental exposure and ground condition of the transmission tower [22].

TABLE 1: Transmission line parameters condition

Parameters	Factors
Environmental	Encroachment
	Ground clearance
	Tower footing
	Assessment of the slope
	Condition of the earth taping
	Land slope assessment
Electrical	Condition of the conductor
	Condition and availability of the damper
	Insulator type and level of insulator exposure
Structural	Bracing corrosion condition
	Cross arm
	Tower leg condition
	Immersed, Rusty and bent conditions of the stub
	Tower foundation conditions (erosion and land slide)
Vandalism	Component vandalism

The inspection team report of the operational capabilities of the transmission line components are graded based on the conditions shown in Table 2.

TABLE 2: Condition level grading.

Condition rating	Description
0.8 – 1.0	Operational/no sign of defect or deterioration
0.60 - 0.79	Still operational /minor defect or deterioration
0.40 - 0.59	Fairly operational/significant defect of deterioration
0 - 0.39	Major defect/deterioration

From Table 2, a rating of 0.8 – 1 means that there is no defect or other damage to the component and the component is like new condition, for rating between 0.6 - 0.79, there will be minor defect and/or damage to the component but does not really require corrective action as it is only very minimal deterioration, with a rating between 0.4 - 0.59, there is defect and/or damage and should be requiring planned corrective action as there are signs of significant deterioration, then there is the rating of 0 – 0.39, in this case there is major defect and/or damage requiring immediate emergency repairs.

A. Health Index Calculation Based on Field Data.

The major transmission line parameters considered were divided into three subsections namely, environmental, structural and electrical with the addition of vandalism. The factors considered for the transmission line disruptive parameters were item score of the parameter (Ip), condition level of the parameter (Cl), critical factor of the parameter (CFp), age factor of the parameter (AFp), from these, the health index of the parameter (Hip) can be calculated.

The health index is calculated based on data obtained. (1) is used for calculating the health index values from the factors and conditions of the transmission line components of Table 1.

$$HI = CI \times Ip \times CFp \times AFp \times 0.02 \quad (1)$$

Where HI is the health index, Ip is the item score, CFp is the critical factor of the parameters, CI is the condition of the parameter and AFp is the equipment age factor.

B. ANN Model

To model with ANN in MATLAB the data was imported using the disruptive parameters as the input data and the health index as the target to the ANN model. The data was split to train, test, and validation datasets in the ratio of 70:15:15 respectively. The number of hidden neurons selected for the training of the data sets in ANN was 5 hidden neurons with each neuron having a log sigmoid model. Then the data was trained with Levenberg Marquart back propagation network.

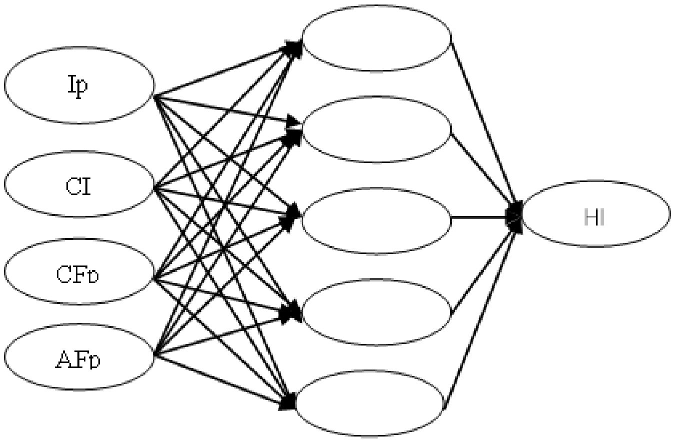

Fig. 1: ANN Model.

The ANN model is shown in Figure 1. The input layer has four input neurons which represent the four input parameters, the output layer has one output which is the HI and the hidden layer has five hidden neurons. The prediction performance of the ANN model is tested with statistical parameters.

The data was arranged as input and targets with CI, Ip, AFp, and CFp assigned to the input variable and HI the target variable. The outcome showed that the input data had 16 data points with 4 columns (each column represents the independent variables) and the target was 16 data points with 1 column which was the HI variable.

Thereafter, the data was split to percentage train, test and validate, 70% of the data was assigned for training, 15% each for testing and validation, This implies that out of the 14 data points, 12 data points were used for the training of the model and 2 data point apiece was used to test and validate the model.

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C. ANFIS Model

In ANFIS model. the input and output data were entered with their corresponding membership function. Triangular membership function was selected for the input variable and linear membership function selected for the output variable. The snapshot for the input membership function for the Ip variable is shown in Fig. 2.

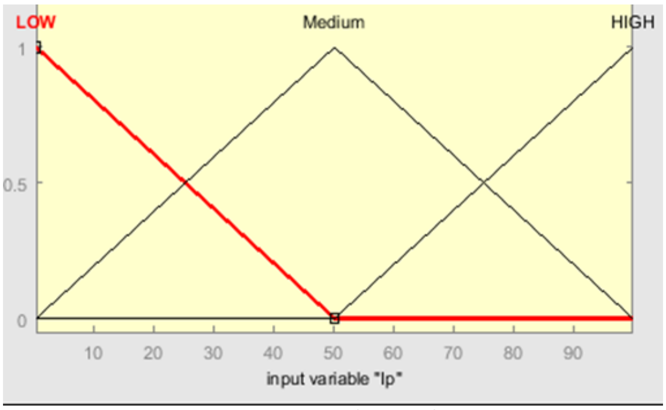

Fig. 2: Triangular membership function for the Ip variable

The triangular membership of Fig. 2 was split to Low, Medium and High, to aid in the generation of the inference rules. The linear membership function for the output variable is shown in Fig. 3, where each data point in the output variables was represented.

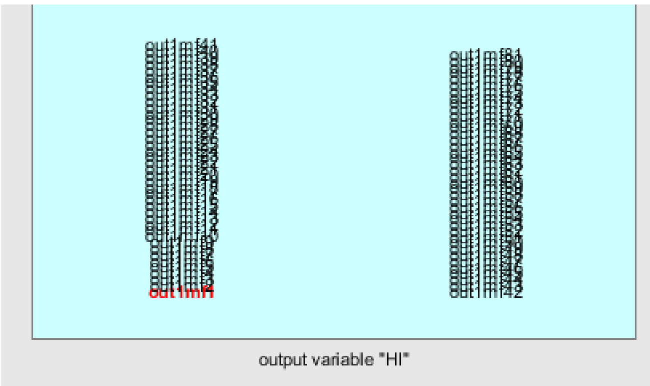

Fig. 3: Output variable membership function

The inference rules create a relationship between the input parameters and the output variable. Rule 1 of the inference simply means that if Ip is low, CI is low, CFp is low, AFP is low then HI would be out1mf1. The same pattern to all the 81 one inference rules applied. The structure for the ANFIS model is shown in Fig. 4.

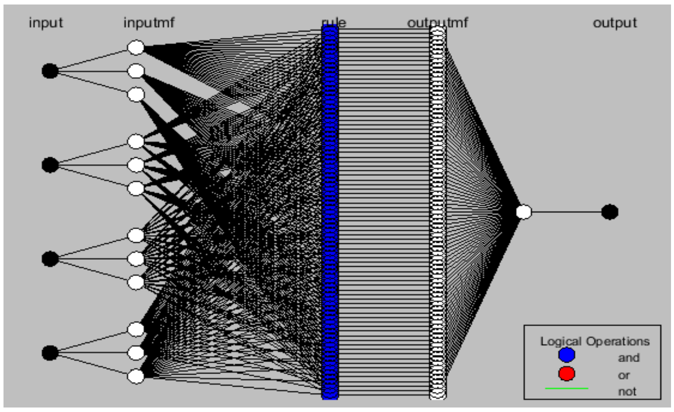

Figure 4 ANFIS structure
Source: Developed by Researcher (2023).

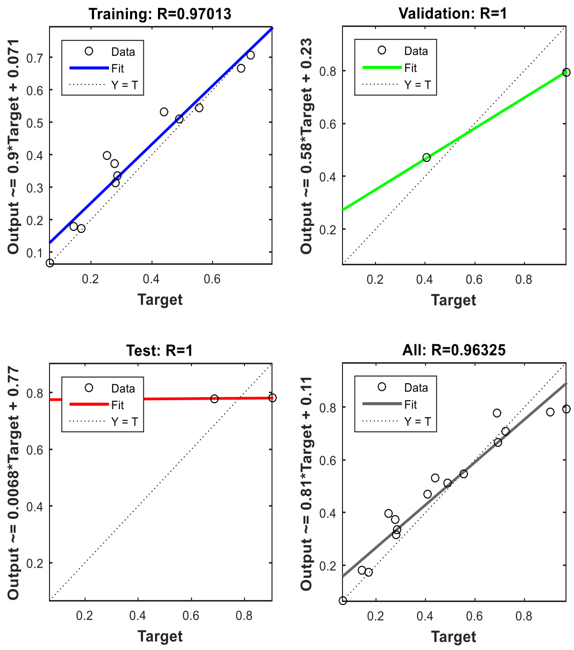

Fig. 5: Prediction performance for each and total data splits

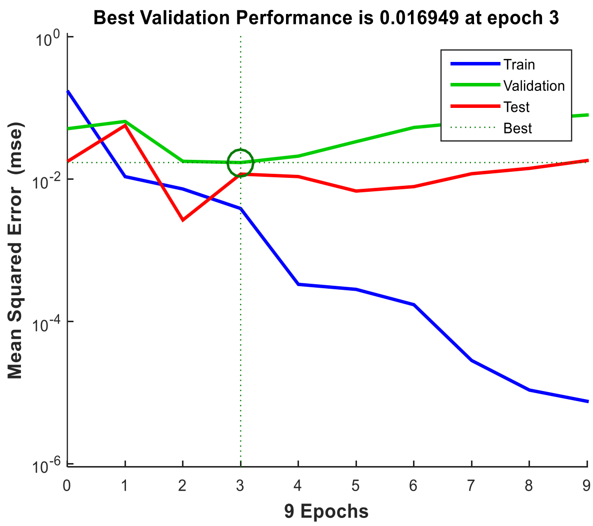

Fig. 6: Validation performance of the ANN model

IV. Result and Discussion

A. ANN Model Prediction

The prediction performance of the data splits is shown as a subplot in Fig. 5.

The total data split had a prediction performance of 0.96325 which implies that the ANN has a high model performance. The validation performance for the mean square error (mse) is shown in Fig. 6.

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Fig. 6 shows that the validation performance of the ANN mode has mse value of 0.016949 at epoch (iteration) 9. This implies that the best iteration point with the best prediction performance is at 9th iteration. The comparative plot of the ANN predicted HI and the actual HI is shown in Fig. 7.

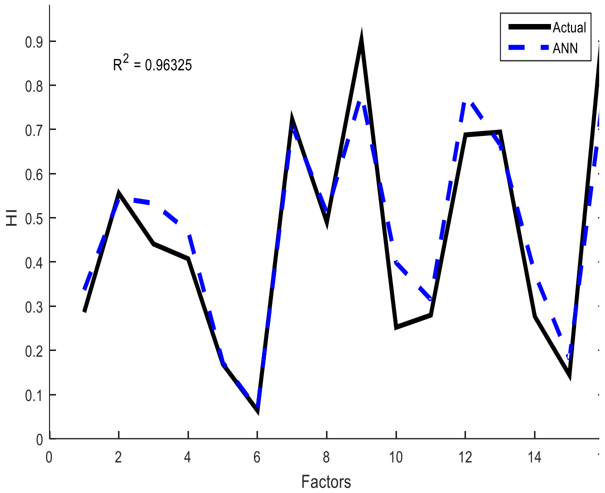

Fig. 7: Comparative analysis of actual and ANN predicted HI

The prediction performance shown with the ANN model as displayed in Fig. 7 was 0.96325 which meant the model has a high prediction performance.

B. ANFIS Model Prediction

The training for the 3rd iteration which is where the system stopped training is 0.0000001608 which is approximately zero. The rule view of the aftermath of the ANFIS model for the first 30 rules is shown in Fig. 8.

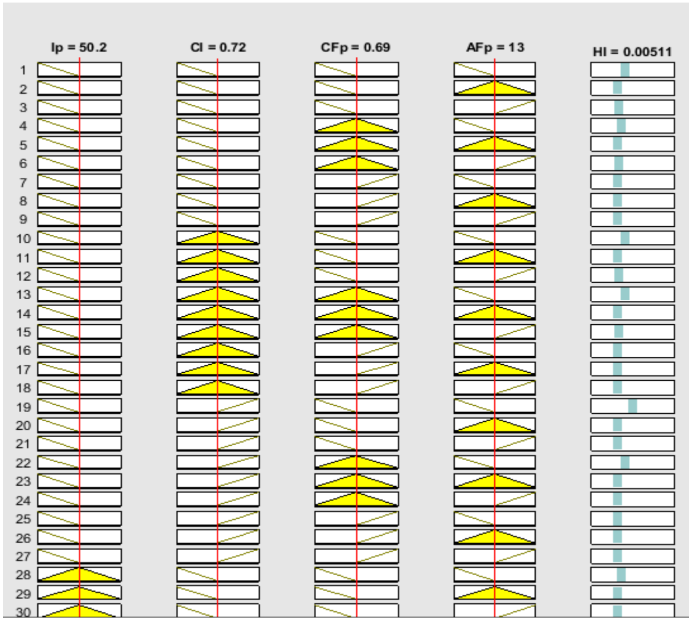

Fig. 8: Rule view for the first 30 rules

The rule view in Figure 8 is used for the prediction of HI in ANFIS model. Once the independent variable value was entered, the output values would be generated (this is evident of the inference rules generated). The comparative plot between the ANFIS predicted HI and the actual HI is shown in Fig. 9.

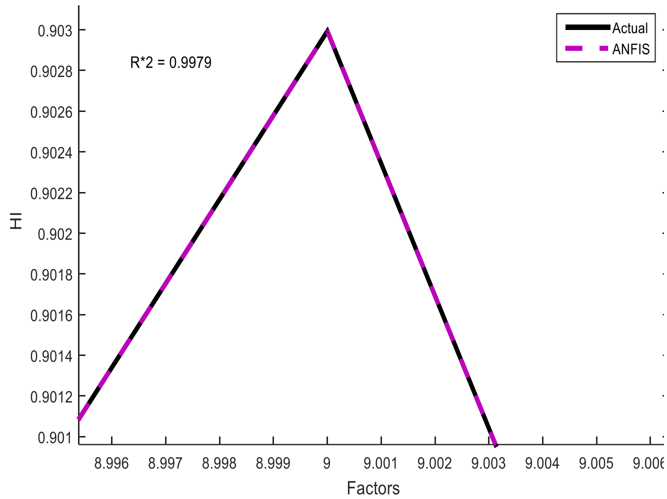

Figure 9: Comparative plot of HI actual and ANFIS predicted.

The prediction performance with ANFIS model as shown in Fig. 9 was 0.9979 which implies that ANFIS model has a high level of prediction performance.

V. Conclusion And Suggestions

In this study, artificial intelligence models; ANN and ANFIS were used in evaluating the health index of overhead transmission line assets. It was observed that environmental factors are the major degradation factors in overhead transmission line failures, contributing 40% of the entire failure events encountered in the transmission network. This model can effectively be used to predict asset health index and should be implemented instead of the time-based, visual inspection that is currently the practice in TCN.

This study is a call for a transition from preventive maintenance-based practices to a predictive maintenance approach. There are numerous benefits of predictive maintenance, its capacity to significantly reduce equipment downtime by providing the most up-to-the-minute condition data for assets is second to none. By evaluation of the health index and implementation using AI, maintenance personnel can see when problems are forming and address them early before they cause costly downtime. In general, this study helps to reduce capital, operational and maintenance expenditures.

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