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[1]**Dr. Mohammad Ahmar Khan,**

[2]**Tushar Jadhav**

[3]**Mehul Manu**

[4]**Dr. Vuda Sreenivasa Rao**

[5]**Dr. Mohammed Aref Abdul**

Investigating the Effects of Ageing on Transmission System Dependability Through the Use of an Artificial Neural Network

Abstract: - As power transmission systems age, their dependability becomes increasingly critical for maintaining reliable electricity supply. However, accurately predicting the impact of ageing on system dependability remains a challenging task due to the complex interactions among various components and environmental factors. In this study, we propose the utilization of an artificial neural network (ANN) approach to investigate the effects of ageing on transmission system dependability. The ANN model is trained on historical data encompassing a wide range of parameters including equipment age, maintenance records, environmental conditions, and system performance metrics. By capturing the nonlinear relationships within the data, the ANN can effectively model the intricate dependencies between ageing and system dependability. Through comprehensive simulations and sensitivity analyses, we demonstrate the capability of the ANN to forecast the degradation of transmission system dependability over time. Moreover, the model enables the identification of key factors driving system reliability decline, thereby facilitating proactive maintenance strategies and resource allocation.

Keywords: Power transmission systems ,Ageing,Dependability,Artificial neural network (ANN)

Introduction

A transmission line is a very important link between generation and consumer. The power required by the consumer is supplied by generation plant through a transmission line. Also to ensure that the transmission of power from generation centre to consumer remains uninterrupted the reliability of transmission line should remain intact. Since the voltage level at which the transmission occurs is much higher than the voltage at which generation and consumption of power take place. Obviously the transmission line becomes a complete system when a step up transformer is added at the sending end while a step down transformer is added at the receiving end[1]. Thus a transmission system mainly consists of transformers, transmission line conductor, electric poles and line insulators. The reliability of transmission system would therefore be assured if at no link as above the transmission of power experiences a failure. It can therefore be understood that the reliability of transmission system would be intact or assured if and only if the reliability of each of the components of the transmission system viz. line conductor, insulator and transformer is intact or assured. Thus a failure of reliability of any one of the components would render the entire transmission system unreliable[2][3]. While planning the research the idea of integrated reliability level which considers the reliability of each component and gives a cumulative

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[1] Dept. of MIS, CCBA, Dhofar University, Salalah, Sultanate of Oman

mkhan@du.edu.om

[2]Associate Professor, E and TC Vishwakarma Institute of Information Technology, Pune

email- tushar.jadhav@viit.ac.in

[3]Assistant Professor, Allied Science (Physics), Graphic Era Hill University, Bhimtal; Adjunct Professor, Graphic Era Deemed to be University, Dehradun, Uttarakhand- 248002, India

Mail id- mmanu@gehu.ac.in

[4]Associate Professor, Department of Computer Science and Engineering, Koneru Lakshmaiah Education Foundation, Green Fileds, Vaddeswaram, A.P., 522302.

vsreenivasarao@kluniversity.in

[5]Rasheed, Dept. of MIS, CCBA, Dhofar University, Salalah, Sultanate of Oman"

reliability index has been avoided. While in the present approach the reliability of individual component of transmission system has been given importance. This is because the individual component reliability if known in advance, only a component having least reliability would be required to be replaced to make the entire system fully reliable[4]. Moreover the replacement of a component facing degradation in reliability would not only be easy but most economical[5].

Efforts have been made in present work to develop mathematical models which explain the degradation in the reliability of component of transmission system due to ageing, since the date it is installed. It is possible using the mathematical model as to when a line conductor, insulator and transformer would fail or lose its reliability[6]. Also the methods have been suggested to enhance the reliability of line conductor, insulator and transformer. Here reliability means the number of years the individual component would survive without obstructing the transmission of power, whereas the enhancement of reliability means enhancement of time period of survival of individual component without obstructing the transmission of power[7]. This is the result of periodic maintenance of component of the individual component of transmission system which is in service. It is suggested that the life of transmission line conductor is enhanced or extended by making it to operate at higher voltage. Similarly life of transformer is enhanced or extended by not allowing it to work near full load rather it is made to operate at loads near 85% of full load[8]. This leads to lower currents, lower heating and longer life of insulation and therefore enhancement of reliability. Since the insulators are exposed to atmosphere they attract salt, chemicals and dust on their surface leading to high leakage of current and high frequency of arcing. To avoid high leakage current and arcing, it is proposed to clean the insulators by periodic washing. It has been observed that higher the periodicity of washing of insulator greater is the enhancement of reliability of insulator[9]. Finally the assessment of reliability in the first stage and enhancement of reliability in the second stage has been validated through artificial neural network (ANN)

The transmission system after being in service over certain number of years need to be tested for its reliability for the remaining of number of years it remains in the service. Also the maintenance engineer is to take steps to enhance the reliability of transmission system over its nominal reliability period[10].

It is therefore the objectives of this work are: (1) To assess the reliability of three components of transmission system viz. line conductor, line insulator and transformer (As it is used at sending as well as receiving end of transmission line). (2) To enhance the reliability of transmission system viz. three components of transmission system viz. line conductor, line insulator and transformer. (3) To validate the reliability enhancement of line conductor, line insulator and transformer using artificial neural network.

Artificial Neural Network

A mathematical model for simulating a network of real neurons (like the human nervous system) is defined by an artificial neural network. Intelligent information processing, distributed processing, a high degree of parallelism, the ability to learn, generalise, and adapt, and a high tolerance for incorrect information are just a few of the human brain's properties that it mimics. In order to process information, this computing system uses a dynamic state reaction to external inputs, similar to a biological neural network. It is composed of many basic, highly-connected processing units. A computer model that mimics the structure and operation of real neural networks is known as an artificial neuron network (ANN). Since a neural network adapts—or "learns"—in response to input and output, the information flowing through the network influences the ANN's structure [11]. When it comes to modelling or discovering patterns in complicated input-output interactions, ANNs are considered nonlinear statistical data modelling techniques. A computer model of a "brainlike" network of linked processing units is called an artificial neural network (ANN). Common belief is that processing units, which are likened to neurons, work in tandem with one another [12]. Here is how an ANN's behaviour might be described for a single processing unit: Prior to processing any data, the unit adds up all of the signals received by it from the other nodes in the network. Secondly, in order to achieve a certain degree of internal activity, the unit uses an activation function on this total signal. Third, depending on its internal activities, the unit communicates with other processors in the network by a signal [13]. A weighted connection is sometimes likened to a synapse because it allows one processor to communicate with another by sending a signal across it. One way to think about an ANN is as a system that takes an input stimulus and uses it to create an output that the user desires. The causal linkages between the processors in an ANN are defined by the pattern of connectivity, which is similar to a programme in a traditional computer. This pattern includes the strengths of the connections between different processing units within the network [14]. Nevertheless, unlike a traditional computer, the ANN is not provided with a detailed process to carry out a certain job. Rather, the network is trained to do the action.

Dynamic systems with one-way connections are known as neural networks. In reaction to inputs, it processes data. Directed connections serve as interconnects between the processing components, which are called nodes. There is a single output signal from each processing device, and then duplicates of that signal spread out. The extraordinary pattern-recognition and trend-detecting capabilities of neural networks make them ideal for tasks where people or other computational methods would fail to pick up on subtleties in the data [15]. One way to look at a trained neural network is as a "expert" in the field of the data it was given to examine. In light of novel circumstances, this specialist may provide predictions and address "what if" inquiries.

ANN Architecture

A single layer is the basic building block of an ANN. Because the input is processed forwards until the output, feed-forward multilayer neural networks are constructed of many hidden layers that lie between an input and an output layer. Typically, activation functions may be either a simple linear function or the sigmoid function ($1/1+e-x$). Since the sigmoid function is smooth and doesn't need an if function, it is often chosen over step functions. The bias weight is like a threshold; it shifts the function that determines when a node will fire the linear function, which in turn ensures that the output follows the expected order of response [18]. However, Hagan et al. (1996) provides a number of other activation functions that are beneficial.Based on ANN's theorems, one can determine the amount of nodes and layers. With appropriate activation functions and N>2, a two-layer neural network with 2N+1 nodes in the first layer may precisely fit every function of an N-dimensional input space, according to the strong Kolmogorov theorem. So, to reduce calculations and reaction time, most developed neural networks employ 2 hidden layers [19]. Overfitting a function, which might lead to erroneous predictions, is a potential danger, however. The most appealing aspect of ANNs is undoubtedly the difficulty of correctly assigning weights to neural networks. An ANN's usefulness lies in its capacity to learn from examples, a preexisting set of inputs and outputs, and to modify its connection and bias weights to mimic its surroundings. So, instead of assigning these weights, the user's duty is to train the network effectively using efficient techniques [20]. You won't have to worry about evaluating system attributes like mass and stiffness when you employ an artificial neural network (ANN) to manage structures; these intelligent systems can adapt via training and replicate functions. Proper network tuning and structural discretization were made possible by nonlinear behaviour. After the design is complete, the network must undergo thorough training. When it comes to supervised learning feedback schemes, back propagation training is the gold standard for training networks. The bias weight acts as a threshold in the sigmoid function, shifting the function to determine the value at which the node will activate [21]. The output may be adjusted to fit the desired order of response using the linear function. Two hidden layers are often used in constructed neural networks since they reduce processing and reaction time. Artificial neural networks (ANNs) may mimic their surroundings by learning from previous experiences with an existing set of inputs and outputs for the system and adjusting its connection and bias weights accordingly. Users should focus on training the network using efficient techniques rather than assigning weights [22]. Structure characteristics such as mass stiffness and damping do not require evaluation when using ANN.

Reliability Assessment and Enhancement Measures for Transmission System

To ensure a constant supply of electricity to the customer, it is crucial to conduct reliability assessments based on transmission system ageing studies. Loss of dependability occurs when any one of the primary components of a transmission system—the line conductor, the line insulator, and the transformers at each end of the transmission line—fails. Approaches to reliability evaluation and reliability improvement strategies of a gearbox system are the focus of the current study [23].

In addition to meeting the increasing load demand, the reliability of the transmission line conductor is of utmost importance in ensuring a steady flow of electricity to the load centre. Improving the dependability of line conductor is often required. To achieve this goal, it is necessary to investigate in detail the elements that significantly diminish the dependability of transmission line conductors [24]. Rule 77 of the 1956 Indian Electricity Rules specifies that transmission lines transmitting power at 400 kilovolts must have the following specifications: pole height= 22 metres, sag= 9.71 metres, and ground clearance= 8.84 metres [4]. When either of these values is exceeded, the reliability of the transmission line conductor is compromised. The factors that contribute to a rise in sag include (i) the constant weight of the conductor on the line conductor, (ii) the constant pressure of the wind on the line conductor, and (iii) the constant heating of the line conductor as a result of energy loss in the line conductor, which has a specific resistance per kilometre of conductor. The tensile strength of the line conductor decreases as the weight of the conductor is applied continuously. In addition to increasing the size and direction of the conductor's weight, wind pressure also determines the direction in which the combined forces of the two would act. At last, it's safe to say that line conductor tensile strength is negatively impacted by wind pressure [5]. The line conductor's tensile strength decreases as its temperature rises, its volume increases, and the energy loss it experiences contributes to this overall change. Ageing of line conductor is essentially caused by the three elements mentioned earlier, which have a cumulative impact that increases over time [7, 15]. Age, brought on by the aforementioned three variables, does, in fact, impact the dependability of transmission line conductors. Assume the gearbox system follows the schematic in Figure 1.

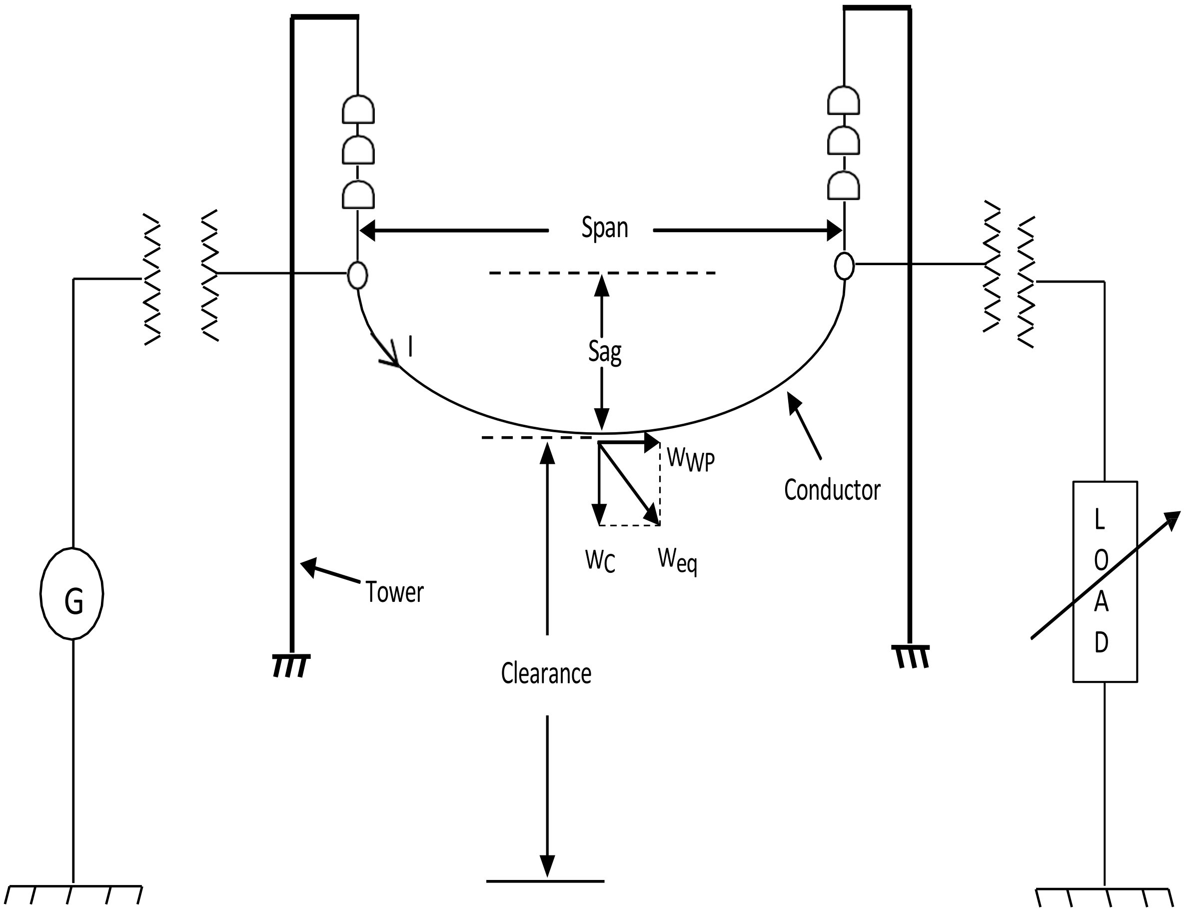

Fig. 1. Line Conductor Sag in Transmission System

The current study aims to evaluate the dependability of transmission line conductors impacted by ageing, driven by the aforementioned philosophical considerations. The next step in making things more reliable is to advise increasing the voltage of power transmission by a certain percentage. Because a smaller transmission current is needed to transmit the same amount of power at a higher voltage, smaller cross-sectional area conductors are required, which in turn decreases the volume and weight of the conductor. As a result, the rate of tensile strength degradation is slowed, sag development is slowed, and the dependability of the transmission line conductor is enhanced [25]. It should also be noted that lower current values result in decreased energy loss, dissipation of heat, and conductor temperature increase when power is transmitted. Because of this, the pace of tensile strength degradation is slowed, which in turn slows the rate of sag expansion, and the dependability of the transmission line conductor is improved. Finally, an Artificial Neural Network (ANN) is used to verify the findings. This has provided assurance that the work is worthy of receiving the reliability evaluation and further development.Thus, in order to evaluate the dependability of the line conductor, the study included the impacts of

(i) Conductor Weight

(ii) Wind Pressure and

(iii) Heating of Conductor due to energy loss.

Effect of Conductor Weight on Tensile Strength of conductor

The tensile strength of a conductor is a response to the downward force of gravity acting on its weight (wc), which in turn creates tension on the conductor [5]. Because applying weight to a conductor is an ongoing process, the conductor's tensile strength degrades with age and is provided by

$$T_{s\,w}\ (t) = T_{si} \times e^{-\alpha w c\, t}$$

where

Ts wc (t) = Working tensile strength affected by conductor weight at time „t‟,

$$\text{Tsi} = \text{Initial Tensile Strength} = \frac{\text{Ultimate Tensile Strength (U. T. S.)}}{\text{Factor of Safety (F. O. S.)}}$$

Effect of Wind Pressure on Tensile Strength of Conductor

Atmospheric pressure changes throughout the year. The underlying assumption is that it stays the same from one quarter to the next, and from one year to the next, the average of the four quarters stays the same. Thus, it is assumed that the conductor is continually subjected to the mean of pressures throughout the four quarters all year round. Equivalent constant pressure works consistently across the years, and this mean pressure is the average of the four quarters' means [5]. The effect of wind pressure in terms of weight on conductor is given as

w_{wp} = Weight on Conductor due to wind pressure = Projected Area * Wind Pressure

$= (D \times l) \times P_w$

D = Conductor diameter (mm)

l= Length of Conductor (m)

P_w =Wind Pressure on Conductor (kg/m^2)

An Analogous Relationship Between Wind Pressure and Conductor Weight as It Relates to Tensile Strength

It is considered a component of the conductor's weight as the wind is believed to exert pressure on it at a constant pace. Consequently, the initial sag is determined by taking the sag value that corresponds to the mean weight due to wind on the line conductor. The combined effects of wind pressure and the weight of the line conductor, expressed as the net weight of the line per metre of length, also contribute to the gradual worsening of the sag. Weight of conductor alone (i.e., without wind pressure) is plainly less than net conductor weight. Because of this, the conductor's tensile strength will quickly decrease, its sag will increase, and its dependability will decline sooner rather than later. So, to evaluate the rise in sag caused by a decrease in tensile strength as a consequence of wind pressure and the weight of the conductor, the combined impact of these two factors is provided by [5].

$weq = \sqrt{w2 + w2}$

Validation of Line Conductor Reliability and its Enhancement through ANN

To validate the enhancement in reliability of line conductor through ANN, MATLAB platform architecture has been organized whose flowchart is shown in Fig. 2

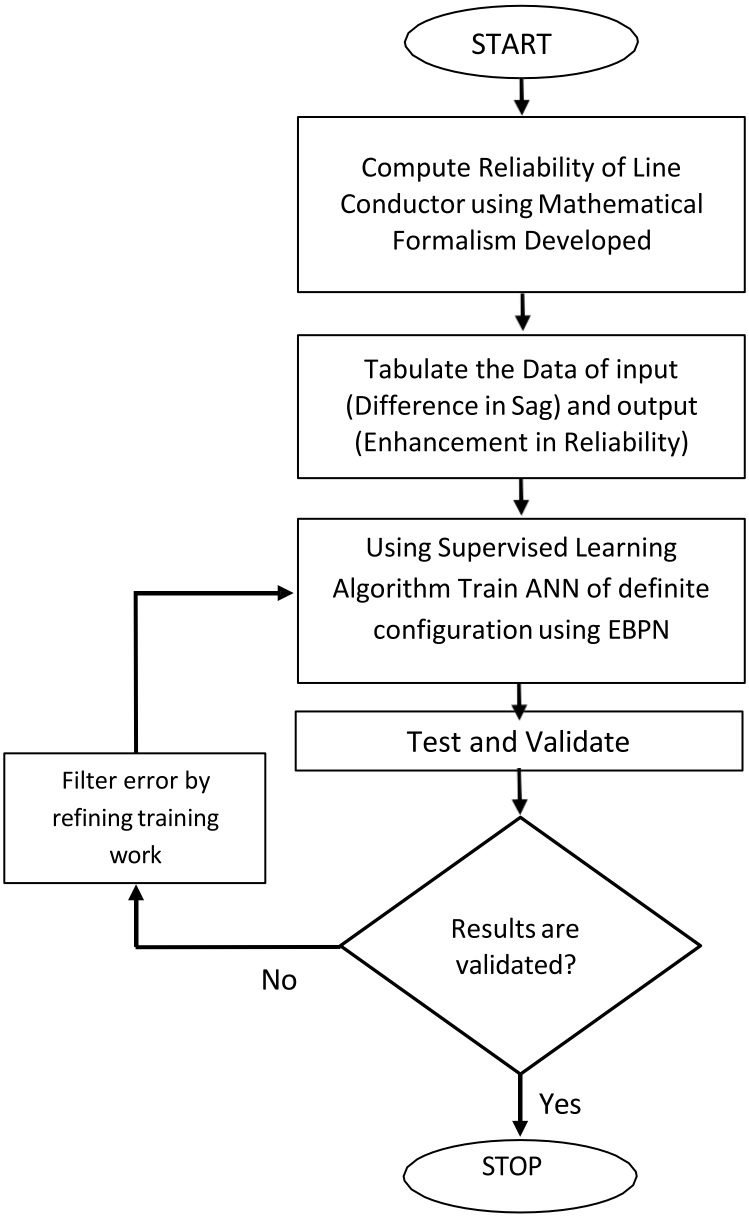

Fig.2 Flowchart for Line Conductor Reliability Enhancement Validation

The reliability assessment and enhancement has been investigated for 400kV, 50Hz, 3-phase transmission system. The present work proposes reliability assessment approaches and reliability enhancement measures for a transmission system. Mathematical models are generated for reliability assessment of line conductor, line insulator and transformer, which gave satisfactory values of the life of these components upto which they worked without failure. It therefore gave the time period upto which these equipments possessed reliability. Failure or loss of reliability of line conductor is caused by the three factors such as (i) sustained application of conductor weight (ii) sustained application of wind pressure and (iii) heating in conductor due to energy loss. All these have cumulative effect on loss of reliability of line conductor.

These factors infact cause increase in sag of line conductor and when it exceeds the threshold value of sag, the line conductor loses its reliability. Similarly the failure or loss of reliability of line insulator is caused by the factors such as due to regular deposits of salt, dust, chemicals and oil on the surface of the insulator. The growth in the thickness of such deposits affects the value of leakage path resistance. This in-turn affects the value of Tanδ the dissipation factor. Also when this value exceeds the threshold value of Tanδ, the insulator fails and it loses the reliability of being kept in service.

The dielectric strength of the winding insulation and the transformer oil degrades over time, which is another cause of transformer failure or unreliability. Continuous heating removes furan content from winding insulation, which leads to a decrease in its dielectric strength. This degradation is studied by examining the degree of polymerization, which in turn reveals the causes of this deterioration. Damage to transformer oil happens when the oil's dielectric strength decreases as a result of a rise in the accumulation of furan content, which pollutes the oil. Some of the things that might reduce dielectric strength include acidity, interfacial tension, and the amount of furan in the oil.

Conclusion

The utilization of ANNs offers a promising avenue for enhancing the understanding and management of ageing-related challenges in power transmission systems. By integrating advanced data-driven techniques into decision-making processes, utilities and operators can better anticipate and address reliability issues, ultimately contributing to the resilience and sustainability of the power infrastructure. This study demonstrates the efficacy of employing artificial neural networks (ANNs) to investigate the effects of ageing on transmission system dependability. By leveraging historical data encompassing various parameters such as equipment age, maintenance records, environmental conditions, and system performance metrics, the ANN effectively captures the nonlinear relationships underlying the intricate dependencies between ageing and system reliability.

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