Reliability Enhancement of Line Insulator of a Transmission System using Artificial Neural Network

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Abstract— The line insulators which hold the transmission line conductor suffer degradation in dielectric quality due to pollution. The pollution is caused because of the formation of layers of salt, chemicals, dust and oil etc. on the surface of dielectric. This pollution affects the resistance and capacitance of the dielectric and therefore Tanδ which increases with pollution. Also when the growth in Tanδ exceeds the threshold value of Tanδ for the insulator, it loses reliability. The aim of the present paper is to assess the reliability by monitoring growth in Tanδ. The insulators are washed with water to check the growth in pollution and to enhance the reliability of insulator. Washing controls the growth of pollution and therefore growth of Tanδ. The Tanδ therefore takes longer time to attain its threshold value. The insulator therefore loses its reliability at a later point of time thus ensuring reliability enhancement. The reliability enhancement of insulator due to control in growth of Tanδ is also confirmed through Artificial Neural Network.

Keywords— *Dissipation factor, Tanδ, Loss factor, Pollution factor, Periodic Washing, Reliability, Artificial Neural Network (ANN).*

1. Introduction

It is observed that the line insulators which are exposed to atmosphere while mechanically holding the line conductor get failure after a particular time. The reason behind failure or breakdown of the line insulator is external flashover which results in puncture of insulator later and the external flashover at line insulators are subjected to pollution caused by the deposition of dirt, pollution, salt and water on the insulator surface, which creates a resistive path across its external surface and gives rise to leakage current shown in fig. 1.

This leakage current flows from conductor to earth which causes flashover arc across the insulator. Due to this flashover arc insulator surface gets heated and weakens the dielectric strength of insulator by increasing the series resistance. Current conduction also takes place through the body of insulator. The heating due to internal current conduction and resistance (i.e. I^2R) results in the puncture of line insulator over a long period of time and it is an irreparable damage for the insulator. Both kinds of leakage currents cause damage of insulator in the form of reduction in dielectric strength.

The loss of dielectric strength of insulator can be determined by value of Tanδ (Dielectric dissipation factor). Tanδ is a measure of degradation of dielectric nature of insulation material. The insulator carries cavities and impurities which are responsible for leakage resistance and therefore leakage currents. With the ageing of insulator and being in continuous usage these cavities and impurities grow in size and lead to increase in leakage resistance. These have very insignificant effect on capacitance, which remains all the most constant.

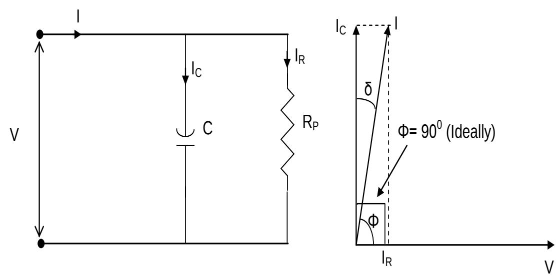

Fig.1 (a) Circuit Diagram (b) Phasor Diagram

The variation in Tanδ due to change in series resistance is shown in fig. 2. Where δ is the angle by which current fails to be in exact quadrature from voltage, dielectric loss leads to δ.

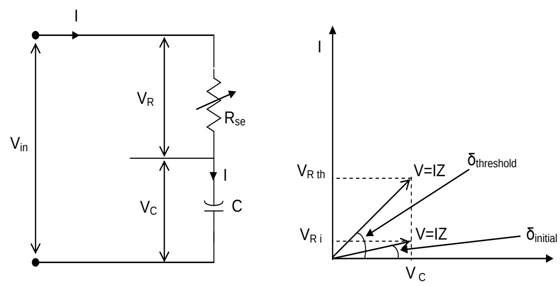

Fig.2 (a) Circuit Diagram (b) Phasor Diagram

The dielectric quality requires Tanδ to be small but if the insulators are washed with water periodically the degree of pollution can be controlled causing growth in Tanδ to slow down, thus increasing the time period in which Tanδ grows to pick up threshold value. But soon Tanδ attains threshold value either without wash or with periodic washing it loses its useful life span and therefore loses its reliability. In the present work the lifespan up to which the insulator attains threshold value of Tanδ has been formed under without wash and with six monthly periodic wash. Thus the difference between the two life spans provides the reliability enhancement of line insulator due to periodic washing.

In [1] the author has presented the variable-voltage technique through which the aging process of naturally or artificially aged and contaminated non-ceramic insulators are studied and monitored. With this technique the testing duration and cost are reduced as compared to constant voltage artificial pollution tests for similar confidence limits.

In [2] the author has described formative stage and initiation stage of breakdown and examined the aging of insulators through activation energy, field enhancement factor and threshold factor.

In [3] the authors have focused on the in service insulator failures caused by the brittle fracture as well as catastrophic in service failures of insulator through simulation.

In [4] the authors have discussed several models of brittle fracture as well as focused on different methods to prevent the failure caused by brittle fracture.

In [5] the authors have worked out to develop a model, which indicate that interaction between space charge and aging process of polymeric insulation.

In [6] authors have described the hydrothermal aging of epoxy based syntactic foam with polymeric microspheres and the effect of misopheres diameters, filling degrees and additional particles on the aging.

In [7] authors have investigated the ageing deterioration of composite insulators based on their slope angles and working positions under conditions of simulated rain and fog water precipitation.

The paper aims to provide the method to assess the reliability of line insulator and enhancement of reliability is achieved through periodic washing of insulator by water at different intervals. Further the enhancement of reliability is validated through ANN.

The paper is organized in six sections. Section 2 gives reliability assessment of line insulator affected by Tanδ, section 3 deals with approach for reliability enhancement. Section 4 deals with validation of reliability assessment and enhancement using ANN. Section 5 provides the conclusion followed by references.

2. Reliability Assessment of Insulator

The reliability of insulator is assured until its Tanδ measure is below $Tan\delta_{threshold}$. It is therefore reliability is assessed by monitoring the Tanδ level of insulator.

2.1 Assessment of the Growth in Tanδ of Insulator

The initial value of Tanδ is because of very small leakage current that takes place due to H.T. level of transmission voltage and ionization of air surrounding conductor and cross arm. The increase in δ is acceptable upto $\delta_{threshold}$ and therefore the value of Tanδ is affected. This is because at higher values of Tanδ leakage current becomes high and flashover of voltage across the insulator with associated heat generation and successive roughness of surface of insulator takes place which causes further growth of leakage resistance 'R_S'.

The rate of growth of Tanδ depends on the rate of deposits that take place on the insulator. It is therefore decided by the location of insulator. This may be industrial, deserts, sea shore, salt lake etc. The change in dissipation factor (Tanδ) with time due to increase in series/parallel resistance is given by:

$$\mathrm{Tan}\delta(t) = \mathrm{Tan}\delta_{initial} \times e^{\lambda t} \qquad (1)$$

Where,

δ = Loss angle = 90^0- Φ

Φ = Phase angle difference between voltage and current

λ = Pollution growth factor

t = Time in years

$\mathrm{Tan}\delta_{initial}$, Initial dissipation factor refers to the dissipation factor that remains in line insulator at the time of installation.

$\mathrm{Tan}\delta_{threshold}$, the threshold value of dissipation factor refers to the maximum value of dissipation factor beyond which the increase in dissipation factor is not permissible.

The initial and threshold value of dissipation factor (Tanδ) of the dielectric is given by

$$\mathrm{Tan}\delta = \omega R_S C \qquad (2)$$

Here,

C = Capacitance of insulator

R_S= Internal series resistance of insulator

ω = 2πf

f = System frequency

2.2 Assessment of Reliability of Insulator

The reliability of a line insulator is decided by Tanδ at instant 't', $\mathrm{Tan}\delta_{initial}$ and $\mathrm{Tan}\delta_{threshold}$ and is given by.

$$\mathrm{Reliability}(\%) = \left(Z_2 - \frac{\mathrm{Tan}\delta(t)}{Z_1}\right) \times 100 \qquad (3)$$

Where

$$Z_1 = \mathrm{Tan}\delta_{threshold} - \mathrm{Tan}\delta_{initial}$$

$$Z_2 = \frac{\mathrm{Tan}\delta_{threshold}}{\mathrm{Tan}\delta_{threshold} - \mathrm{Tan}\delta_{initial}} = \frac{\mathrm{Tan}\delta_{threshold}}{Z_1}$$

3. Reliability Enhancement by Periodic Washing of Insulators

The time in which the dielectric loss angle δ grows upto its threshold value i.e. $\delta_{threshold}$ depends upon the growth of leakage resistance. But the leakage resistance increases with increase in impurities that deposit on the surface of insulator. These impurities along with cavities give rise to leakage resistance which in turn grow with time and leads to flashover across the conductor and earth through the insulator surface. The flashover further causes the increase in leakage resistance. The process than becomes cumulative. The increase in leakage resistance due to increase in deposition of impurities with time can be controlled by periodic washing of insulators. This in turn controls the rate of growth in δ and elongates the time of arrival of $\delta_{threshold}$ and therefore $Tan\delta_{threshold}$. The arrival of state of insulator where its Tanδ becomes $Tan\delta_{threshold}$ marks the failure of insulator. In other words the insulator loses its reliability soon it attains $Tan\delta_{threshold}$.

Case Study

Assess the reliability of line insulator used for erecting a 400kV transmission line affected by growth in Tanδ with ageing time't', having 281 pF as capacitance, 0.05 MΩ as initial internal series resistance. The improvement in reliability is considered due to washing of insulators at different intervals of times between two successive washings. Other data are chosen as per the Indian Electricity Rules of 1956.

The growth in Tanδ and decay in reliability has been analyzed for various conditions of pollution levels with different periodic washing frequencies.

(i) For No Washing: The table 1 gives the growth of Tanδ and decay of reliability of line insulator with time, when insulators are not washed (λ = 0.1026).

Table 1
Assessment of Tanδ and Reliability w.r.t. time for no washing

Years (t)	Tanδ(t)	Reliability (%)
0	0.0042	100
4	0.0063	98.77
8	0.0095	96.92
12	0.0143	94.13
16	0.0215	89.92
20	0.0325	83.58
24	0.0489	74.03
28	0.0738	59.62
32	0.1112	37.90
36	0.1676	5.16
36.5	0.1764	0.04
40	0.2526	-44.19

The manner in which the Tanδ and reliability of line insulator varies for pollution no washing with ageing time't' is graphically shown in Fig.3.

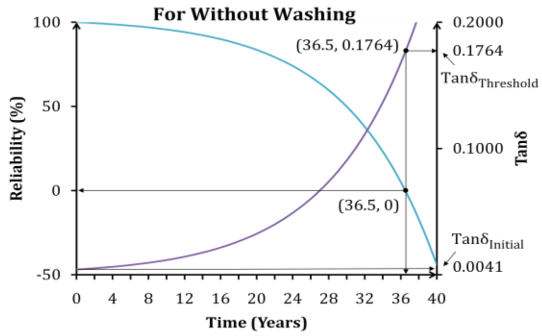

Fig.3. Assessment of Reliability and Tanδ for Line Insulator no washing with ageing time t

It is obvious "from the calculation and graphical analysis for assessment of Tanδ and reliability of line insulator varies naturally with ageing time't'" that dissipation factor reaches to its threshold value and reliability reaches to 0% after 36.5 years.

(ii) For Yearly Washing: The table 2 gives the growth in Tanδ and decay in Reliability of line insulator when washed yearly (λ = 0.0967) at successive intervals of four years.

Table 2
Assessment of Tanδ and Reliability w.r.t. time for yearly washing

Years (t)	Tanδ(t)	Reliability (%)
0	0.0042	100.00
4	0.0061	98.86
8	0.0090	97.17
12	0.0133	94.70
16	0.0196	91.05
20	0.0288	85.68
24	0.0425	77.77
28	0.0625	66.14
32	0.0920	49.00
36	0.1355	23.77
39	0.1811	-2.70

The manner in which the Tanδ and reliability of line insulator varies after yearly washing with ageing time't' is graphically shown in Fig.4.

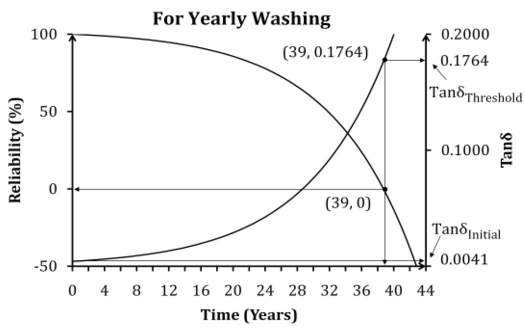

Fig.4. Assessment of Reliability and Tanδ for Line Insulator for yearly washing with ageing time t

It is obvious "from the calculation and graphical analysis that Tanδ and reliability of line insulator gets improved when washed yearly by 2.5 years i.e. reliability attains 0% level at t=39 years viz-a viz t= 36.5 years when no washing was done of insulators.

(iii) For half yearly washing: The table 3 gives the growth in Tanδ and decay in Reliability of line insulator when washed half yearly ($\lambda = 0.0895$).

Table 3
Estimation of Tanδ and Reliability with time for half yearly washing

Years (t)	Tanδ(t)	Reliability (%)
0	0.0042	100.00
4	0.0060	98.96
8	0.0085	97.47
12	0.0122	95.34
16	0.0175	92.29
20	0.0250	87.93
24	0.0357	81.69
28	0.0511	72.76
32	0.0731	59.99
36	0.1046	41.73
40	0.1496	15.60
42	0.1789	-1.41
44	0.2140	-21.77

The manner in which the Tanδ and reliability of line insulator varies after half yearly washing with ageing time't' is graphically shown in Fig.5.

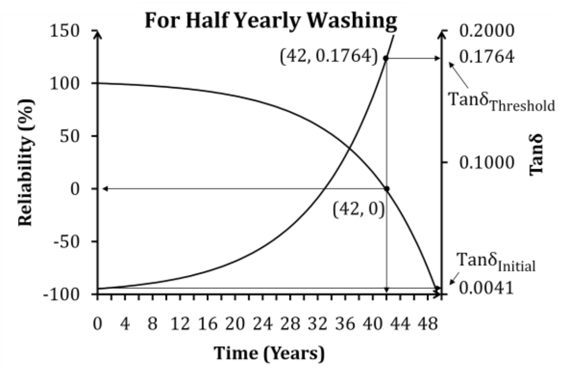

Fig.5. Assessment of Reliability and Tanδ for Line Insulator for half yearly washing with ageing time t

It is obvious "from the calculation and graphical analysis that Tanδ and reliability of line insulator gets improved when washed half yearly by 5.5 years i.e. reliability attains 0% level at t=42 years viz-a viz t= 36.5 years when no washing was done of insulators.

(iv) For quarterly wahing: The table 4 gives the growth in Tanδ and decay in Reliability of line insulator when washed quarterly ($\lambda = 0.0827$) at successive intervals of six months.

Table 4
Estimation of Tanδ and Reliability with time for quarterly washing

Years (t)	Tanδ(t)	Reliability (%)
0	0.0042	100.00
4	0.0058	99.05
8	0.0081	97.73
12	0.0112	95.89
16	0.0157	93.33
20	0.0218	89.77
24	0.0303	84.81
28	0.0422	77.90
32	0.0588	68.29
36	0.0819	54.91
40	0.1140	36.28
44	0.1587	10.35
45.5	0.1796	-1.81
48	0.2209	-25.75

The manner in which the Tanδ and reliability of line insulator varies after quarterly washing with ageing time't' is graphically shown in Fig.6.

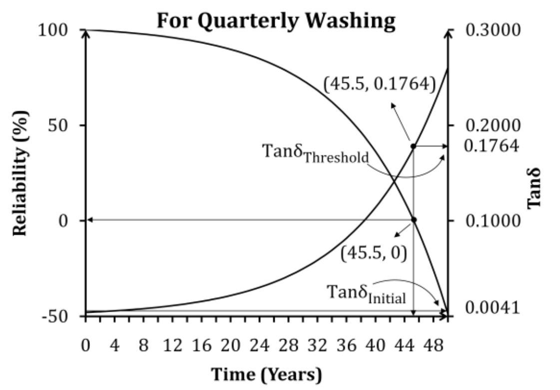

Fig.6. Assessment of Reliability and Tanδ for Line Insulator for quarterly washing with ageing time t

It is obvious "from the calculation and graphical analysis that Tanδ and reliability of line insulator gets improved when washed half yearly by 9 years i.e. reliability attains 0% level at t=45.5 years viz-a viz t= 36.5 years when no washing was done of insulators.

(v) For monthly washing: The table 5 gives the growth in Tanδ and decay in Reliability of line insulator when washed quarterly ($\lambda_M = 0.0783$) at successive intervals of four year.

Table 5
Estimation of Tanδ and Reliability with time for monthly washing

Years (t)	Tanδ(t)	Reliability (%)
0	0.0042	100.00
4	0.0056	99.17
8	0.0075	98.05
12	0.0101	96.55
16	0.0136	94.54
20	0.0182	91.83
24	0.0245	88.20
28	0.0329	83.31
32	0.0442	76.75
36	0.0594	67.93
40	0.0798	56.09
44	0.1072	40.18
48	0.1441	18.81
51	0.1798	-1.91
52	0.1935	-9.90

The manner in which the Tanδ and reliability of line insulator varies after monthly washing with ageing time't' (as the time grows) is graphically shown in Fig.7.

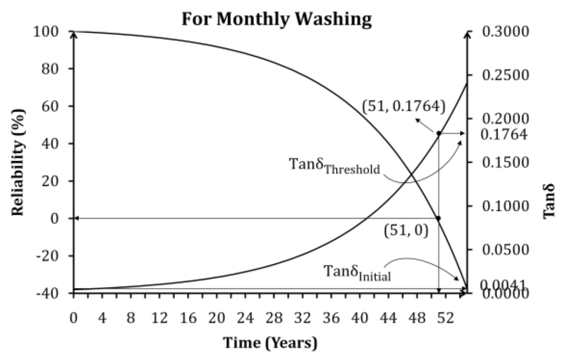

Fig.7. Assessment of Reliability and Tanδ for Line Insulator for monthly washing with ageing time t

It is obvious "from the calculation and graphical analysis that Tanδ and reliability of line insulator gets improved when washed half yearly by 14.5 years i.e. reliability attains 0% level at t=51 years viz-a viz t= 36.5 years when no washing was done of insulators.

Result

Fig.8 shows the comparative analysis of enhancement in reliability of line insulator.

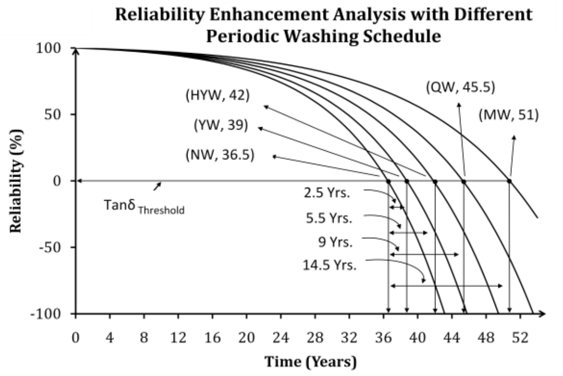

Fig.8. Enhancement in Reliability of Line Insulator in term of Age

Since the washing of insulator is associated with cost and consumer annoyance due to interruption of power supply, it cannot be taken as a measure to improve reliability with increased frequency of washing. The best periodic washing can be six monthly washing. Thus by adopting periodic washing frequency to be every six month good results of reliability enhancement could be seen.

4. Validation of Reliability and its Enhancement through ANN

The architecture of ANN has been organized on MATLAB platform and its training has been shown in the training window as in figure 9.

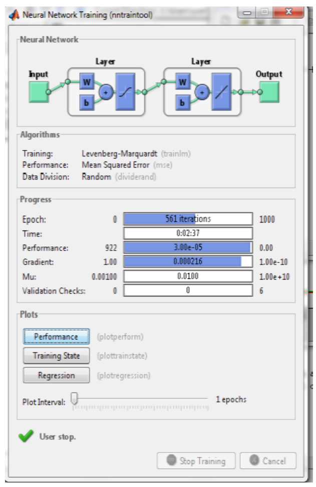

Fig.9 Training of ANN

After training Neural Network (NN) is then validated and tested for its standardization shown in figure 9 so that the NN can be used for testing the reliability enhancement for the change in Tanδ ($Tan\delta_{Unwashed}$-$Tan\delta_{HYwashed}$) corresponding to threshold value of Tanδ ($Tan\delta_{threshold}$) when the insulator is washed half yearly.

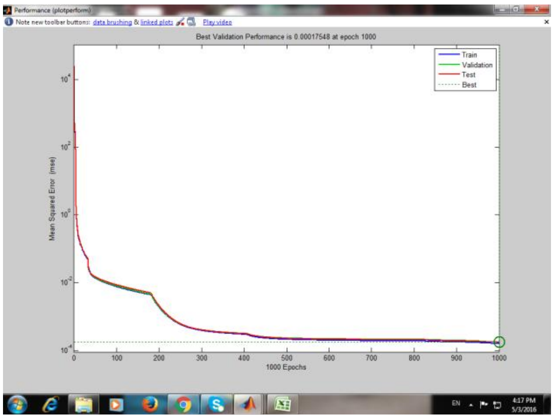

Fig.10 Testing and Validation of ANN

The output of ANN corresponding to difference in Tanδ ($Tan\delta_{Unwashed}$-$Tan\delta_{HYwashed}$) at threshold value of Tanδ refers to reliability enhancement for $Tan\delta_{Unwashed}$-$Tan\delta_{HYwashed}$ = 0.1472 at $Tan\delta_{HYwashed}$ = 0.1793 the value of reliability enhancement is equal to 84.3% shown in figure 11.

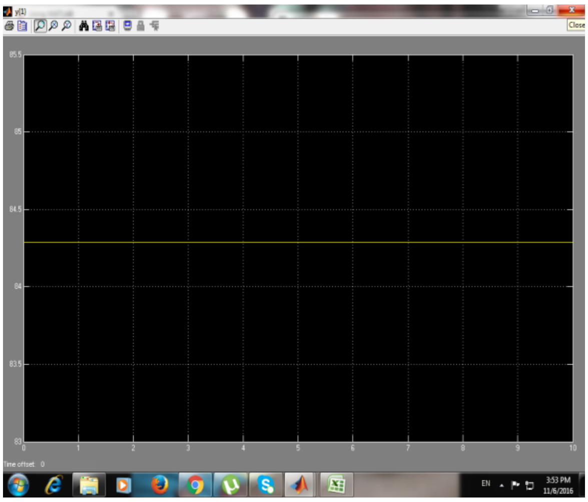

Fig.11 Reliability Enhancement Output for Difference in $Tan\delta_{Unwashed}$-$Tan\delta_{HYwashed}$ = 0.1472

Result

It is observed that the reliability due to half yearly periodic washing is enhanced by 5.5 years when worked out by mathematical model. This result is validated by ANN and that also shows the enhancement of reliability by 5.5 years.

5. Conclusion

The dielectric quality of the insulator is affected by pollution of insulator because it is exposed to atmosphere. The pollution is caused due to the deposition of layers of salt, chemical, dust and oil on the surface of insulators. It causes the resistance to increase and capacitance to decrease, thus causing Tanδ $= \frac{V_R}{V_C}$ to increase. The increase or growth in Tanδ marks the degradation of dielectric. When the growth in Tanδ exceeds the threshold value the insulator loses its reliability. It is suggested that the periodic washing of insulator reduces the rate of pollution and the growth in Tanδ is delayed which leads to reliability enhancement. This is noticed that viz-a viz without washing a six monthly periodic washing of insulator controls the growth in Tanδ such that the reliability enhancement by 5.5 years takes place. If the periodicity of washing is increased it would give higher reliability enhancement but would cost high. The results have been confirmed by ANN which also shows analogous reliability enhancement.

6. References

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