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Performance Characteristics of a 11kv High Tension Side Transformer Bushing Under Different Polluted Conditions

Smt. N. Sumathi M.Tech., (Ph.d)[1], **P. Kishore Kumar**[2]

[1]Assistant Professor, EEE Department, JNTU Kakinada, Andhra Pradesh, India
[2]Student, M.Tech (EEE) in High voltage Engineering, JNTU Kakinada, Andhra Pradesh, India

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Abstract - ***In Power systems the most critical component is the transformers. Transformer bushings are the insulation devices that allow power to flow into and out of the transformer. To a large extent, bushings are significantly affected by the type of environmental conditions and the performance characteristics of the bushings were also affected by exposure to different polluted cases. In this work, the performance characteristics of 11kV high tension side bushings were obtained during three different conditions. For this 3-samples of identical 11kV H.T bushings were tested. During the first case clean bushings were tested in both dry and wet condition and the second case is for salt contamination in dry and wet condition and during the last case the samples are tested under urea contamination in dry and wet condition. From the experimental tests, the leakage current is observed with respect to applied voltage using measuring meters in the laboratory in all conditions and is then analyzed. From the experimental results, an increase in leakage current and decrease in flashover voltage of the samples is observed during salt and urea polluted condition. When compared to salt and urea pollution, urea pollution has more affect on the bushings which shows that proper maintenance to be taken in agricultural areas.***

Key Words: *Transformer bushings, characteristics, salt moisture, urea moisture, flashover voltage, leakage current.*

1. INTRODUCTION

Power generation from different sources is increasing due to several reasons including energy security and environmental conditions. Operational reliability and maintenance are the important factors that control the operation of power systems. In power system, transformers perform the essential function of transferring power between circuits operating at various voltages. From the statistics of National power systems, bushing defects were one of the main causes for multiple determined damages of transformer. In the view of operating point the most visible part on the transformer that is affected by pollution is the bushing. In India, there is an agricultural area of 394.6 million acres[1] and it plays an important role of surviving. The transformers locate in and near these agricultural areas can be exposed to fertilizer pollution mostly urea. The India is having a coastline of 7517km [1], the transformers located near the coastal areas can be exposed to salt moisture or breeze. When the transformer bushings are exposed to this salt or urea pollution, a pollution layer is formed on the bushing which causes the surface to become conductive having a value of leakage current[2] that is responsible for flashover at low voltages. To study the effect of pollution contamination different researchers made various types of testing such as the effect of salt moisture and cement dust on 20kV porcelain suspension insulator[3], artificial pollution tests on an 800-KV composite bushing for coastal conditions [4], flashover characteristics of insulator surface during contamination [7]-[8] and rain and pollution contamination tests on HVDC wall bushings[9]-[10]. So the testing of transformer bushings during salt or urea contamination is to be considered as the flashover on the bushings can be responsible for catastrophic failures[5]. These may cause cascading failures in which system recovery is impossible.

In all the above working data on bushings in salt and urea contamination conditions is not that much informative. This paper concerns the tests on salt and urea contaminated bushings in dry and wet conditions, the results are compared between urea and salt pollution conditions. These results are used as bench mark in manufacturing and installation of transformer bushings and also as reference in academics.

2. EXPERIMENTS

2.1 Test setup and circuit diagram

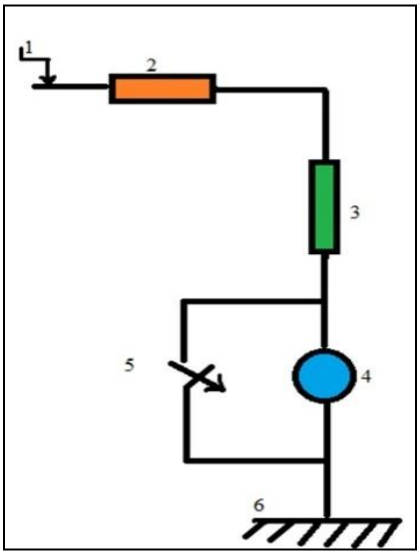
The experiments on the bushings are conducted in High Voltage Laboratory at University College of Engineering, JNTU Kakinada. The measurement of the Leakage current set up consisted of cascading transformer, HV bus bar, bushings, control panel with required metering. The total voltage generated by the 2-stage cascaded transformer is 500 kV with 100 KVA rating. The circuit diagram shown in Fig.1 is used for leakage measurement of the bushing. Fig-2 shows the flashover of the bushing. During the measurement of leakage current the ammeter switch is opened and then again it is closed on increase of applied voltage.

2.2 Pollution

For salt pollution, a solution is prepared by mixing 200 grams of crystal salt in 1litre of sea water. Similarly for urea pollution, a solution is prepared by mixing 200 grams of fertilizer urea in 1litre of sea water. These salt or urea solutions is applied independently on the bushings for seven days so that a pollution layer is formed and are tested independently for salt and urea pollution conditions.

2.3 Bushing specifications

The three H.T bushings are denoted as B1, B2, B3. The Operating voltage of these bushings is 11kV with the creepage distance[6] of 425mm and an arc length of 321mm.



1. HV terminal
2. High resistance
3. Test specimen
4. Ammeter
5. Switch
6. Ground

Fig-1: Circuit diagram

3. RESULTS AND ANALYSIS

The three bushing samples are tested under three different cases. In the first case, the healthy bushing samples are tested in both dry and wet conditions. In the second case, salt pollution is applied on the bushings by spraying and are tested in both salt dry and salt wet conditions. In the third case, urea pollution is applied on the cleaned bushings by spraying and are tested in both urea dry and urea wet conditions. The results are tabulated and are analysed.

Fig.-2: Bushing Flashover

3.1 Results during testing

3.1.1. Case-1: During the first case the healthy H.T bushing samples are tested in both dry and wet condition.

i) Healthy dry condition: The three bushing samples B1, B2, B3 without any pollution are connected as shown in the Fig.1.The leakage current is measured at every test voltage and the flashover voltage is also recorded from the meters connected in the circuit. The variation of corresponding values are shown in Table-1 and Fig-3 respectively.

Table-1: Leakage current values of healthy bushing samples during dry test

Applied Voltage(kV)	LC of B1(μA)	LC of B2(μA)	LC of B3(μA)	Avg. LC (μA)
11	4.3	3.3	4.1	3.9
20	7.8	7.3	7.8	7.63
30	11.8	11.3	12.5	11.87
40	15.8	15.5	17.3	16.2
50	20.7	20	22.5	21.07
60	26.4	25.7	28.9	27
70	33.5	32.4	36.1	34
80	42.8	40.6	45.2	42.87
90	52.1	48.6	57.4	52.7
FOV (kV)	**100**	**100**	**97**	**99**

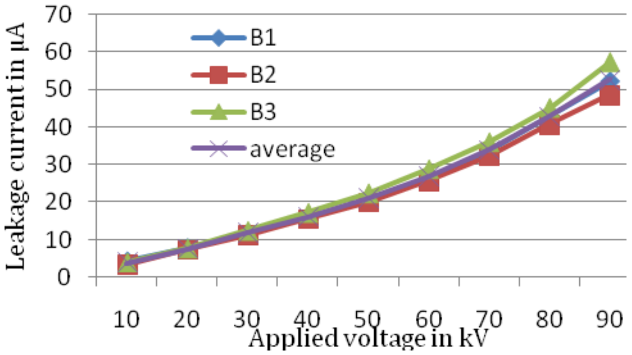


Fig-3: Variation of leakage current with applied voltage during Healthy Dry condition

ii) Healthy wet condition: The three bushing samples B1, B2, B3 without any pollution are dipped in clean water and are connected as shown in the Fig.1. The leakage current is measured at every test voltage and the flashover voltage is also recorded from the meters connected in the circuit. The variation of corresponding values are shown in Table-2 and Fig-4 respectively.

Table-2: Leakage current values of healthy bushing samples during wet test

Applied voltage (kv)	LC of B1 (µA)	LC of B2 (µA)	LC of B3 (µA)	Avg LC (µA)
11	7.6	6.6	3.3	5.83
20	18.6	14.4	7	13.3
30	43.2	27.3	11.5	27.33
40	63.7	33.1	18.3	38.33
50	76	44.5	26.4	52.3
60	--	69.8	34.9	54.2
70	--	--	58.5	58.5
80	--	--	65.3	65.3
FOV(KV)	**57**	**61**	**85**	**67.66**

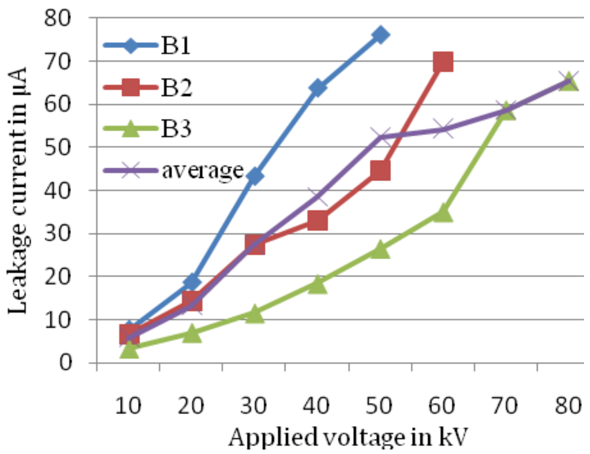


Fig-4: Variation of leakage current with applied voltage during Healthy Wet condition.

3.1.2. Case-2: In the second case, salt pollution is applied on the H.T bushing samples and are tested in both salt dry and salt wet condition.

i) Salt dry condition: The salt solution formed by mixing crystal salt in sea water is sprayed on the bushing samples and is dried such that a visible salt layer is formed. The three bushing samples B1, B2, B3 with salt dry pollution are connected as shown in the Fig.1. The leakage current is measured at every test voltage and the flashover voltage is also recorded from the meters connected in the circuit. The variation of corresponding values are shown in Table-3 and Fig-5 respectively.

Table-3: Salt dry test values of leakage currents with applied voltage under salt pollution

Applied Voltage (kV)	LC of B1 (µA)	LC of B2 (µA)	LC of B3 (µA)	Avg LC (µA)
11	4.9	6.6	2.9	4.8
20	9.7	13.9	7.1	10.23
30	14.1	22.9	10.1	15.7
40	18.9	34.2	14.4	22.5
50	23.4	44.2	19.6	29.067
60	28.2	60	24.6	37.6
70	34.8	74.5	32.2	47.16
80	41.8	96.1	41.4	59.7
90	50.2	121.6	52.9	74.9
FOV (KV)	**92**	**94**	**96**	**94**

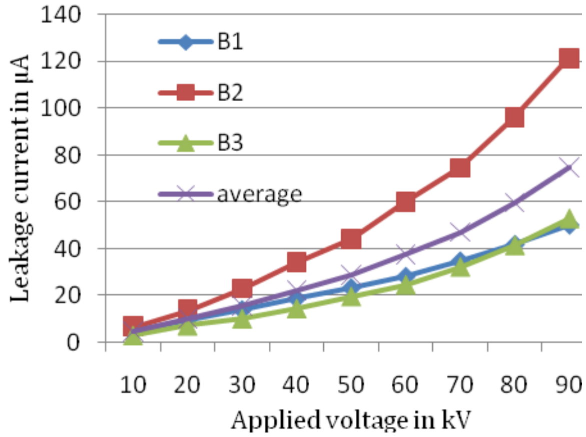


Fig-5: Variation of leakage current with applied voltage during Salt Dry condition.

ii) Salt wet condition: During this condition, the salt solution is sprayed on the salt dried bushing samples at the instance of testing such that the bushings are in wet condition with salt pollution. These bushing samples B1, B2, B3 with salt wet pollution are connected as shown in the Fig.1. The leakage current is measured at every test voltage and the flashover voltage is also recorded from the meters connected in the circuit. The variation of corresponding values are shown in Table-4 and Fig-6 respectively.

Table-4: Salt wet test values of leakage currents with applied voltage under salt pollution

Applied Voltage(kV)	LC of B1(μA)	LC of B2(μA)	LC of B3(μA)	Avg. LC (μA)
5	8.4	27.1	7.9	14.47
11	14.3	45.7	13.5	24.5
15	20.6	63.9	18.4	34.3
20	24.9	86.5	24.1	45.16
25	33.4	109.8	31.9	58.37
30	190	153.4	39.4	127.6
35	230	182.8	48.9	153.9
40	251	220.8	60.4	177.4
FOV(KV)	**45**	**45**	**45**	**45**

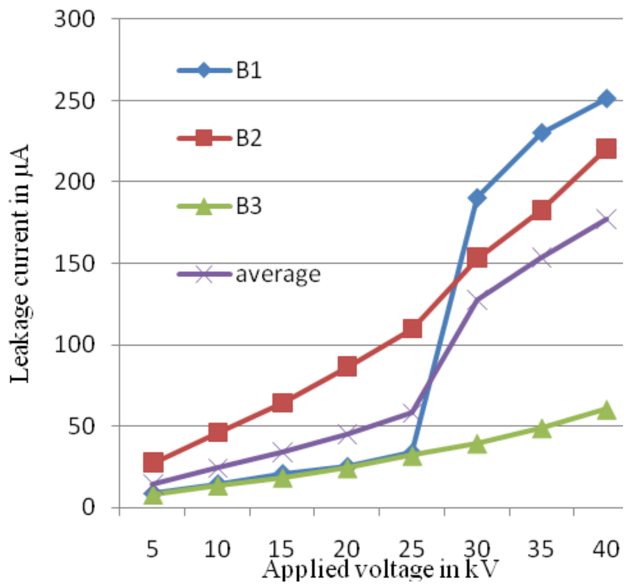


Fig.-6: Variation of leakage current with applied voltage during Salt Wet condition.

3.1.3. Case-3: In the third case, urea pollution is applied on the H.T bushing samples are tested in both urea dry and urea wet condition.

i) Urea dry condition: The urea solution formed by mixing fertilizer urea in sea water is sprayed on the cleaned bushing samples and is dried such that a visible urea layer is formed. The three bushing samples B1, B2, B3 with urea dry pollution are connected as shown in the Fig.1. The leakage current is measured at every test voltage and the flashover voltage is also recorded from the meters connected in the circuit. The variation of corresponding values are shown in Table-5 and Fig-7 respectively.

Table-5: Urea dry test values of leakage currents with applied voltage under urea pollution.

Applied voltage(kV)	LC of B1(mA)	LC of B2 (mA)	LC of B3(mA)	Avg. LC (mA)
5	1.97	1.63	1.79	1.796
11	2.87	2.14	2.04	2.350
15	3.29	2.21	2.16	2.680
20	3.74	2.49	2.75	2.993
25	3.99	2.59	3.21	3.263
30	4.06	2.83	3.27	3.386
35	4.25	2.98	3.43	3.553
40	4.40	3.02	3.49	3.636
45	4.57	3.12	3.60	3.763
50	5.25	3.16	4.05	4.150
55	5.29	--	4.12	4.705
FOV (KV)	**57**	**55**	**60**	**57.33**

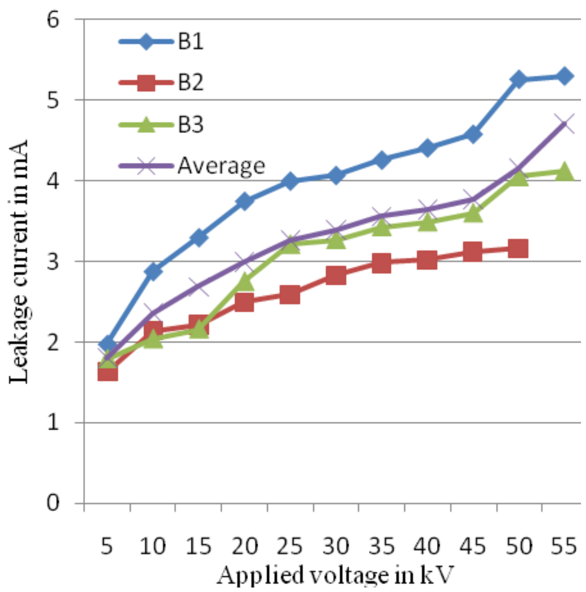


Fig.-7: Variation of leakage current with applied voltage during Urea Dry condition.

ii) Urea wet condition: During this condition, the urea solution is sprayed on the urea dried bushing samples at the instance of testing such that the bushings are in wet condition with urea pollution. These bushing samples B1, B2, B3 with urea wet pollution are connected as shown in the Fig.1. The leakage current is measured at every test voltage and the flashover voltage is also recorded from the meters connected in the circuit. The variation of corresponding values are shown in Table-6 and Fig-8 respectively.

Table-6: Urea dry test values of leakage currents with applied voltage under urea pollution.

Applied voltage (kV)	LC of B1 (mA)	LC of B2 (mA)	LC of B3 (mA)	Avg. LC (mA)
5	5.29	5.23	2.47	4.33
11	18.85	18.54	11.28	16.22
15	19.45	19.52	16.52	18.496
20	20.49	20.82	20.81	20.706
25	23.28	21.22	25.62	23.373
30	25.80	24.08	30.03	26.63
FOV(KV)	**36**	**37**	**35**	**36.33**

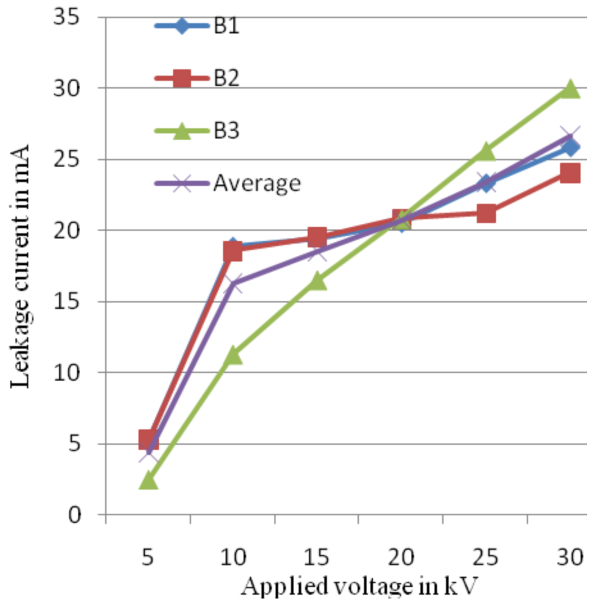


Fig-8: Variation of leakage current with applied voltage during Urea Wet condition.

Table-7: Maximum leakage current and flashover voltages of bushing samples at different cases.

Case	B1		B2		B3	
	FOV	LC	FOV	LC	FOV	LC
Dry	100	52.1	100	48.6	97	57.4
Wet	57	76	61	69.8	85	65.3
Salt-Dry	92	50.2	94	121.6	96	52.9
Salt-Wet	45	251	45	220.8	45	60.4
Urea-Dry	57	5290	55	3160	60	4120
Urea-Wet	36	25800	37	24080	35	26630

FOV is the flashover voltage in kV(kilo Volts) and LC is the leakage current in µA(micro amperes).

3.2. Analysis

From the results as shown in TABLE VII, In healthy condition the maximum value of leakage current for virgin sample in dry condition was 57.4µA and wet condition was 78.4µA which shows that for wet condition there is a 36.5% increase in leakage current compared to dry condition. The flashover voltage for virgin sample in dry condition was 100kV and wet condition was 85kV which shows that for wet condition there is a 15% decrease in breakdown strength compared to dry condition. Under application of salt pollution the maximum value of leakage current for salt contaminated sample in dry condition was 121.6µA and wet condition was 251µA which shows that for wet condition there is a 106.4% increase in leakage current compared to dry condition. The breakdown voltage in Salt dry condition was 96kV and wet condition was 45kV which shows that for wet condition there is a 53.12% decrease in breakdown strength compared to dry condition. Under application of urea pollution the maximum value of leakage current for urea contaminated sample in dry condition was 5.29mA and wet condition was 30.03mA which shows that for wet condition there is a 467.67% or 5.6 times increase in leakage current compared to dry condition. The breakdown voltage in Urea dry condition was 60kV and wet condition was 37kV which shows that for wet condition there is a 38.33% decrease in breakdown strength compared to dry condition. In any pollution contamination the flashover voltages of bushings under wet condition is very less when compared to its dry condition and is shown in the Fig-9.

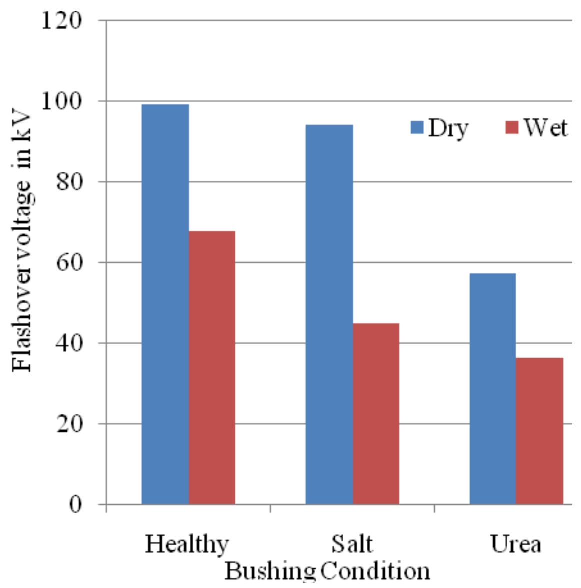


Fig-9: Variation of Average Bushing flashover voltage under different conditions.

Table-8: Leakage currents of the bushings at operating voltage during different conditions.

Condition	Healthy	Salt	Urea
Dry	4.3µA	6.6 µA	2870µA
wet	7.6 µA	27.1 µA	18850µA

From the results as shown in TABLE VIII, In healthy condition the magnitude of maximum leakage currents at operating voltage 11kV are 4.3µA and 7.6µA in dry and wet conditions respectively In salt pollution contamination the magnitude of maximum leakage currents at operating voltage 11kV are 6.6µA and 27.1µA in salt dry and salt wet conditions respectively. In urea pollution contamination the magnitude of maximum leakage currents at operating voltage 11kV are 2.87mA and 18.85mA in urea dry and urea wet conditions respectively. This also shows that the effect of salt and urea pollution contamination is more during wet condition. Since contamination on the surface of the bushings amplify the chances of flashover. Under dry conditions the contaminated surfaces do not conduct, and thus contamination is of little importance in dry periods but considerable. In cases of dry conditions such as light rain, fog or dew, the contamination on the surface dissolves. This build up a conducting film on the surface of the bushing and the operating voltage admits the leakage current. High current density near the bushing electrodes results in the heating and drying of the pollution film. An arc will be triggered when the voltage stress across the dry band go beyond the withstand capability. The extension of this arc across the bushing finally results in flashover.

4. CONCLUSION

From the results it was concluded that salt and urea pollution contamination can have considerable effects on the performance characteristics of the transformer bushings. It was evidently seen that salt and urea pollution contamination on the bushings could increase the magnitude of leakage current in wet contaminated condition when compared to dry pollution condition. As urea has high moisture absorption capability the effect of urea pollution contamination is to be considered in both dry and wet conditions since the magnitude of leakage currents obtained are very high. Proper maintenance is to be taken to the transformer bushings located near coastal and agricultural areas as the leakage currents can have a probability of causing flashover which finally leads to cascading system failures.

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