Influence of Arc Flash Performance and ESDD Measurement of Bushings Tainted by Nitrates

R.Nikkitha, L.Kalaivani

Abstract: ***Tainting devastate the feat of bushings. Conductors are insulated inside the bushing that carry a high voltage current through a grounded enclosure. An aspiration is to study the pollution performance of bushings tainted by Nitrates.Arc flash tests of 1kV,11kV,17.5kV bushings are tainted by three types of salts such as NaCl, $NaNO_3$, KNO_3. The morsels are negotiated under habitual environment as per IEC 60507. The impact of tainting salts with their solubility on Equivalent Salt Deposit Density (ESDD) and bushings arc flash voltage are scrutinized. The effect of tainted salts on arc flash fruition, the sway of volume conductivity and Equivalent Salt Deposit Density (ESDD) under different percentages are also scrutinized. The research upshot reveals that the Equivalent Salt Deposit Density (ESDD) rate escalated with escalating salt content. When salt concentration gets escalated then conductivity also get escalated. When Equivalent Salt Deposit Density (ESDD) get Escalated then the arc flash voltage and leakage current get slacken. Finally, the graphs are drawn between ESDD and Arc flash voltage, Conductivity and Salt concentration, Arc flash voltage and Leakage current are obtained using MATLAB software.***

Keywords:Bushing, Tainted, Pollution arc flash, ESDD.

I. INTRODUCTION

In wattage, a bushing is comrade in nursing caulking device that enables comrade in nursing electrical conductor to pass safely through a grounded conducting barrier like the case of an electrical device or circuit breaker. Bushings area unit usually made of porcelain[1]; although alternative caulking materials are attainable, typically ceramic ware is employed. A bushing should be designed to resist the electrical intensity made within the caulking. Once any earthed material is gift, because the strength of the electrical field will increase, escape methods could develop inside the insulation. If the energy of the escape path overcomes the caulking strength of the insulation, it's going to puncture the insulation and permit the voltage to conduct to the closest earthed material inflicting burning and arcing.

A typical bushing style contains a 'conductor', (usually of copper or metallic element, sometimes of different conductive materials), encir cled by insulation, apart from the terminal ends. Caulked bushings are often put in either indoor, or outdoor, and also the choice of caulking is going to be determined by the locale of the installation and also the electrical service duty on the bushing.

Ceramic ware was originally used because of its properties of being runproof to wetness [4]once sealed by laid-off glaze, and low producing price. A basic ceramic ware bushing may be a hollow ceramic ware form that matches through a hole during a wall or metal case, permitting a conductor to pass through its center, and connect at each end to different instrumentation. Bushings of this sort area unit usually product of wet-process laid-off ceramic ware, that is then glazed. A semi-conducting glaze could also be accustomed assist in equalizing the electrical potential gradient on the length of the bushing. Once pollution is wetted by rain[5] or fog, there's an unsought flow of current over the surface of the insulation of bushing is named run current. A discharge happens between the live finish of the bushing and another finish of the bushing that cause slacken of Arc flash voltage within the bushing.

II. MORELS, TENTATIVE SETUP AND PROCEDURE

A. Morels

The morels taken were three porcelain type of bushings such as 1kV, 11kV and 17.5kVrespectively.

B. Tentative Setup

An ac artificial pollution[6], [7]feat takes a look at with non-uniform pollution distribution was administrated in bushings.The power supply is given as per Fig. 1. Fig. 1 shows the tentative setuphaving coupling capacitance, high voltage test transformer, and set up to hold a bushing. The transformer rated voltage is 2×0.22/100/0.22kV, rated current 2×22.8/0.1A, rated output is 10kVA. A testing transformer is employed to provide AC, DC, and impulse voltage. Supply is given to bushing by suggests that of the transformer. The management table is employed to regulate and operate high voltage AC equipment. The test setup is controlled by means of management table. The Arc flash voltage and leakage current may be noted from the management table.

C. Test Procedure

The transformer yieldextreme is connected to the top notch of the bushing. Before the test, all the test morels were cleaned and desiccatedspontaneously. The bushings were contaminated nonuniformly by suggests thatof conditional brushing methodology.

Revised Manuscript Received on December 30, 2019.
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The required quantity of NaCl or Nitrates and china stone were reckonedconsistence with the ratios by means that of electronic weight balancer. NaCl or Nitrates and china stone mixed with neededpure water and coated on the facial of the bushing by brushing methodology. When twenty-four hours of natural drying, the bushing is subjected to pollution performance check. The bushing used for testing is dangledupright on

the test setup and wetted by pure water. The high voltage is enforced slowly from zero voltage tillwhole Arc flash stumbles on the bushing surface. At Arc flash, the voltage is filed.The technique used for pollution could be a solid layer method[8], [9]. Brushing technique is finished, before beginning of pollution check, the load of NaCl (Sodium Chloride) and china stone is weighedby suggests that of weighing balance.The brush used for coating should be washed and cleaned with the pure water and artefact.

Fig. 1. Tentative setup for pollution testing

III. EVALUATED PARAMETERS

A. Conductivity Measurement

Conductivity of associate degree solution resolution could be a live of its endowment to charge electricity. The SI unit of conduction is Siemens per meter (S/m).Conductivity measurements are used most often in several industrial aura operation as a quick, cheap and reliable manner of mensuration the ionic during a solution.The electrical conduction of a solution of an electrolyte is measured by determinant the resistance of the answer between 2 flat or cylindrical electrodes separated by a hard and fast distance. Associate alternating voltage is hired so as to avoid electrolysis.The resistance is deliberated by a conductivity meter where Equation (2) shows the volume conductivity at 20℃.

The specific conductance (conductivity), κ (kappa) is the reciprocal of the specific resistance are shown in Equation (1).

$$K = \frac{1}{\rho} = \frac{C}{R} (1)$$

$$\sigma_{20℃} = \sigma_{\theta℃}[1 - b(\theta - 20)] (2)$$

where,

θ is the solution temperature (C), σ_θ is the volume conductivity[2], [3] at the temperature of θ⁰C (S/m), σ_{20} is the volume conductivity at the temperature of 20⁰C (S/m).

B. ESDD Measurement

Pollution degree is determined by an equivalent salt deposit density which is detached from the insulating shoal of the bushing. After Arc flash examining, the contaminated bushings were desiccated under dazzling sunlight and the torrid granules of salts and china stone are assembled from the elite and basic surface of the bushing independently was assembled by brushing them off with a miniature paintbrush. The assembled salt deposits were then softening in 40ml of pure water. The conductivity measuring instrument was used to quota the conductivity of each assembled salt solutionwhere Equation (3) shows ESDD value [10].

$$\boldsymbol{ESDD} = (\boldsymbol{Sa} \times \boldsymbol{Vol} \, \boldsymbol{in} \, \text{cm}^3) / \boldsymbol{Area} \, \boldsymbol{in} \, \text{cm}^2 (3)$$

Vol - is the volume of the solution in cm^3,

Area - is the area of the cleaned surface in cm^2,

Sa - Salinity of the solution,

$$Sa = (5.7 \times \sigma_{20℃})^{1.03} (4)$$

$$b = -3.200\times10^{-8} (\theta)^3 + 1.032\times10^{-5} (\theta)^2 + -8.272\times10^{-4} (\theta) + 3.544\times10^{-2} (5)$$

where Equation (5) shows the factor depending on the temperature of θ and Equation (4) shows the salinity of the solution.

C. Voltage at Standard Room Temperature and Pressure

Classic action for temperature and pressure are classic sets of action for empirical measurements to be authorize to permit comparisons to be created betwixt different sets of instruction. The foremost used standards are those of the International Union of Pure and Applied Chemistry (IUPAC) and also the National Institute of Standards and Technology (NIST), although these are not universally accepted standards. Hence the Equation (6) and (7) shows the Voltage at standard temperature and pressure and Equation (7) shows the air density correction factor.

$$V_{STP} = V_{RTP} * (HCF/ADCF) (6)$$

$$ADCF = (0.293*760) / (273+T) (7)$$

V_{STP} = Voltage at standard temperature pressure

V_{RTP} = Voltage at Room temperature pressure

HCF = 1, Humidity correction factor

ADCF = Air density correction factor

T = Room Temperature

Retrieval Number: B3836129219/2019©BEIESP
DOI: 10.35940/ijeat.B3836.129219
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
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IV. RESULTS AND DISCUSSION

A. Arc Flash Test on Sodium Chloride

NaCl salt is taken with different combinations like 5g, 10g, 15g,20g, 30g with Kaolin at constant 10g.Then the mixture is mixed with 15ml distilled water. The mixture is coated on the bushings using brushing method[10], [11] and then dried for 24hrs.After 24hrs drying Arc flash voltage and Leakage current is obtained by testing the test objects.Table. I - V shows 5,10,15,20,30g NaCl with

10g Kaolin.Depending upon the temperature variations dry and wet conditions changes simultaneously with respect to atmospheric condition. So, the Arc flash voltage at room temperature also get changed. Hence the Arc flash voltage is converted into standard temperature and pressure and it is listed in table, table. VI – X shows Arc flash voltage at standard room temperature and pressure for 5,10,15,20,30g NaCl.

B.Arc Flash Test on Potassium Nitrate

KNO_3 salt is taken with different combinations like 5g, 10g, 15g,20g, 30g with Kaolin at constant 10g.Then the mixture is mixed with 15ml distilled water. The mixture is coated on the bushings using brushing method and then dried for 24hrs. After 24hrs drying Arc flash voltage and Leakage current is obtained by testing the test objects. Table. XI – XV shows 5,10,15,20,30g KNO3 with 10g Kaolin.
Depending upon the temperature variations dry and wet conditions changes simultaneously with respect to atmospheric condition. So, the Arc flash voltage at room temperature also get changed. Hence the Arc flash voltage is converted into standard temperature and pressure and it is shown in table, table. XVI – XX shows Arc flash voltage at standard room temperature and pressure for 5,10,15,20,30g KNO_3.

C. Arc Flash Test on Sodium Nitrate

$NaNO_3$ salt is taken with different combinations like 5g, 10g, 15g,20g, 30g with Kaolin at constant 10g.Then the mixture is mixed with 15ml distilled water. The mixture is coated on the bushings using brushing method and then dried for 24hrs.After 24hrs drying Arc flash voltage and Leakage current is obtained by testing the test objects. Table. XXI – XXV shows 5,10,15,20,30g $NaNO_3$ with 10g Kaolin.
Depending upon the temperature variations dry and wet conditions changes simultaneously with respect to atmospheric condition. So, the Arc flash voltage at room temperature also get changed. Hence the Arc flash voltage is converted into standard temperature and pressure and it is listed in table, table. XVI – XXX shows Arc flash voltage at standard room temperature and pressure for 5,10,15,20,30g KNO_3.

Table- I: 5g NaCl with 10g Kaolin at 31°C

Rating of bushing in kV	Primary voltage (kV)	Arc Flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	56	28.5	15.3	0.6	0.856	0.01486
11	193	91.5	48	0.2	0.342	0.00577
17.5	217	110	60	0.1	0.215	0.00204

Table- II: 10g NaCl with 10g Kaolin at 36°C

Rating of bushing in kV	Primary voltage (kV)	Arc Flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	50	23.5	11.5	1	1.473	0.026
11	156	73	35.5	0.3	0.428	0.0072
17.5	180.5	84.5	43.5	0.2	0.457	0.0077

Table- III: 15g NaCl with 10g Kaolin at 44°C

Rating of bushing in kV	Primary voltage (kV)	Arc Flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	30	17	7.5	1.2	1.947	0.0353
11	149.5	71.5	39.5	0.4	0.882	0.0153
17.5	167.5	80.8	45	0.3	1.114	0.0195

Table- IV: 20g NaCl with 10g Kaolin at 36°C

Rating of bushing in kV	Primary voltage (kV)	Arc Flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	18.5	11	6.6	1.4	1.962	0.0349
11	148	69.5	38.5	0.5	1.362	0.0233
17.5	163.5	77.25	35.6	0.6	1.591	0.0281

Table- V: 30g NaCl with 10g Kaolin at 31°C

Rating of bushing in kV	Primary voltage (kV)	Arc Flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	12.5	6.8	3.35	1.8	2.266	0.0405
11	139.5	67	34.9	0.7	1.743	0.0309
17.5	146.5	70.8	39.4	0.8	1.617	0.0286

Table- VI: Arc flash voltage at standard room temperature and pressure for 5g NaCl

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	31	38.9
11	31	124.9
17.5	31	150.2

Table- VII: Arc flash voltage at standard room temperature and pressure for 10g NaCl

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	36	32.61
11	36	101.3
17.5	36	117.3

Table- VIII: Arc flash voltage at standard room temperature and pressure for 15g NaCl

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	44	24.2
11	44	101
17.5	44	115.1

Table- IX: Arc flash voltage at standard room temperature and pressure for 20g NaCl

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	36	15.3
11	36	92.6
17.5	36	107.2

Table- X: Arc flash voltage at standard room temperature and pressure for 30g NaCl

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	31	9.3
11	31	91.5
17.5	31	96.7

Retrieval Number: B3836129219/2019©BEIESP
DOI: 10.35940/ijeat.B3836.129219
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
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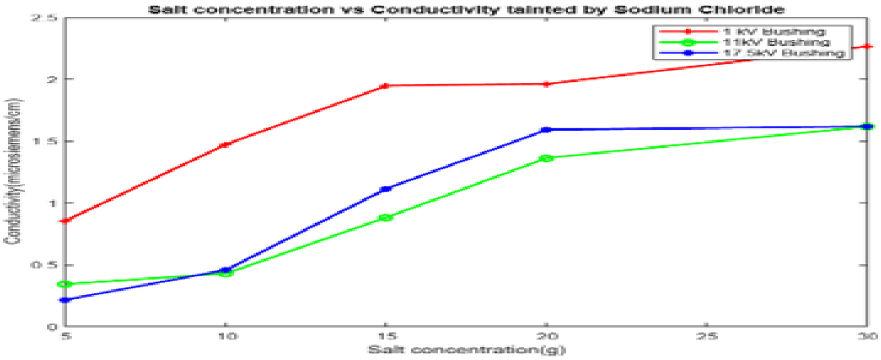

Fig. 2. Salt concentration and conductivity tainted by sodium chloride

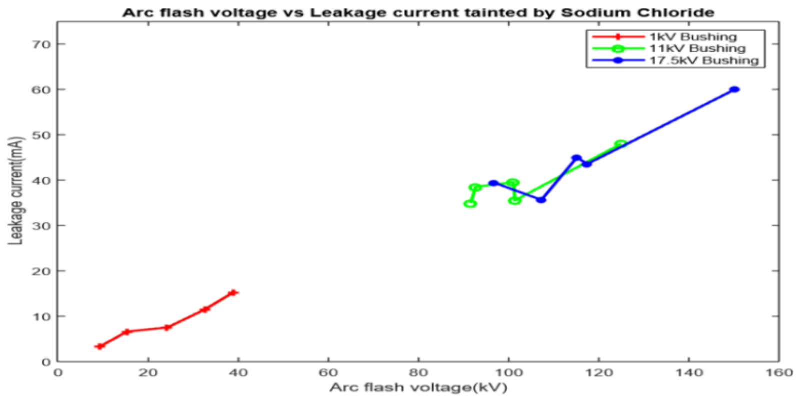

Figure. 3. Arc flash voltage and leakage current tainted by sodium chloride

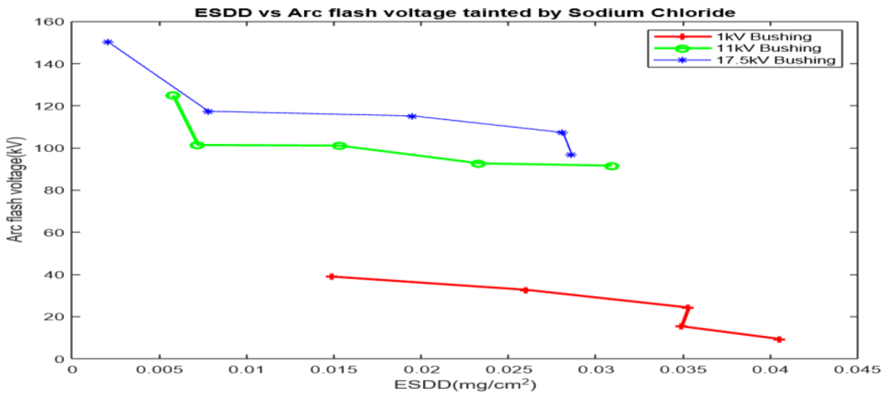

Fig. 4. ESDD and arc flash voltage tainted by sodium chloride

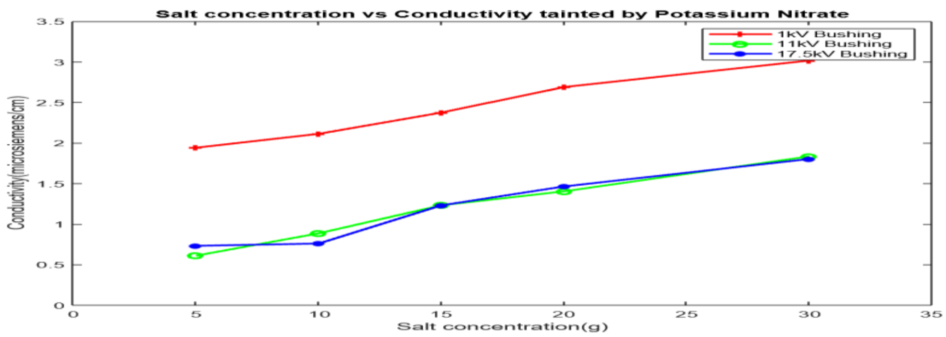

Fig. 5. Salt concentration and conductivity tainted by potassium nitrate

Table- XI: 5g KNO3 with 10g Kaolin at 32°C

Rating of bushing in kV	Primary voltage (kV)	Arc Flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	23	14.5	9.35	0.2	1.941	0.0345
11	151.5	71.5	43.05	0.1	0.610	0.01048
17.5	191.5	91.5	55	0.1	0.731	0.01263

Table- XII: 10g KNO_3 with 10g Kaolin at 32°C

Rating of bushing in kV	Primary voltage (kV)	Arc flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	22.5	11.5	6.25	0.7	2.112	0.0376
11	149.5	69	40.9	0.1	0.885	0.01538
17.5	161	76	40.1	0.1	0.759	0.01313

Table- XIII: 15g KNO_3 with 10g Kaolin at 34°C

Rating of bushing in kV	Primary voltage (kV)	Arc flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	11	6.9	4.7	1.7	2.374	0.0425
11	118.5	61.5	35	0.2	1.231	0.02161
17.5	134.5	65.5	34.3	0.2	1.230	0.0215

Table- XIV: 20g KNO_3 with 10g Kaolin at 33°C

Rating of bushing in kV	Primary voltage (kV)	Arc flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	12	7	3.75	2.7	2.689	0.0483
11	130	61	34.1	0.3	1.403	0.02473
17.5	135	63.5	33.5	0.3	1.463	0.0258

Table- XV: 30g KNO_3 with 10g Kaolin at 30°C

Rating of bushing in kV	Primary voltage (kV)	Arc flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	8	3.85	0.25	3.3	3.016	0.054
11	98	50.532	33.65	0.8	1.834	0.0325
17.5	122.5	58.532	32	0.7	1.802	0.0320

Table- XVI: Arc flash voltage at standard room temperature and pressure for 5g KNO3

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	32	19.860
11	32	97.93
17.5	32	125.32

Table- XVII: Arc flash voltage at standard room temperature and pressure for 10g KNO_3

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	32	15.751
11	32	94.507
17.5	32	104.09

Table- XVIII: Arc flash voltage at standard room temperature and pressure for 15g KNO_3

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	34	9.513
11	34	85
17.5	34	90.3

Table- XIX: Arc flash voltage at standard room temperature and pressure for 20g KNO_3

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	33	9.619
11	33	83.82
17.5	33	87.259

Table- XX: Arc flash voltage at standard room temperature and pressure for 30g KNO_3

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	30	5.2386
11	30	68.715
17.5	30	79.600

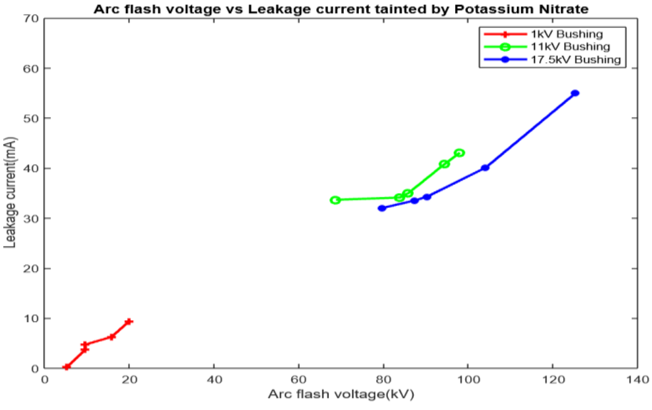

Fig. 6. Arc flash voltage and leakage current tainted by potassium nitrate

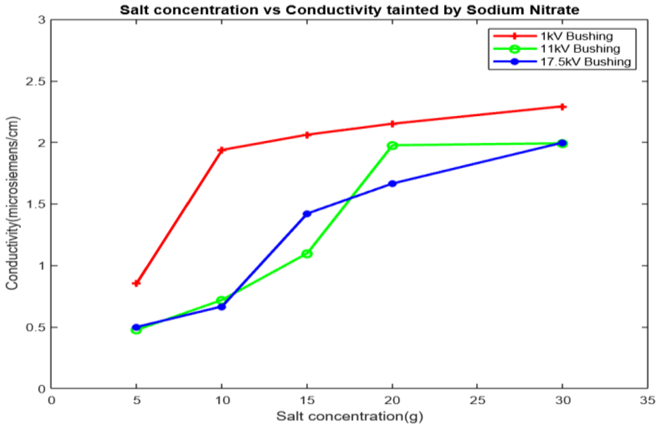

Fig. 8. Salt concentration and conductivity tainted by sodium nitrate

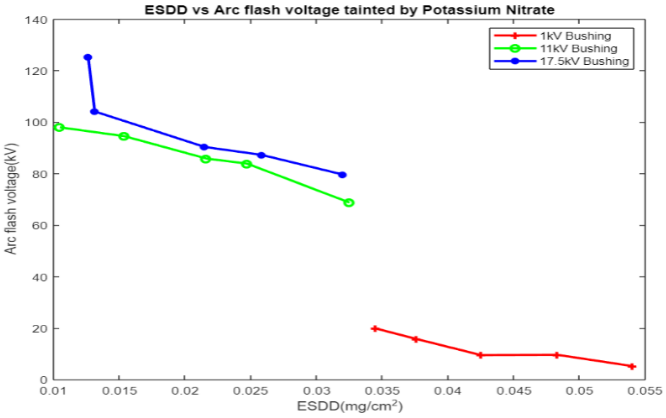

Fig. 7. ESDD and arc flash voltage tainted by potassium nitrate

Table- XXI: 5g $NaNO_3$ with 10g Kaolin at 33°C

Rating of bushing in kV	Primary voltage (kV)	Arc flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	10	6.25	2.8	0.4	0.854	0.01483
11	150	72	44	0.1	0.474	0.00808
17.5	186.5	88.5	50.5	0.2	0.498	0.008511

Table- XXII: 10g $NaNO_3$ with 10g Kaolin at 35°C

Rating of bushing in kV	Primary voltage (kV)	Arc flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	10.5	5.5	2.9	0.8	1.937	0.03448
11	171.5	80	49.8	0.1	0.718	0.0124
17.5	175	82	50.9	0.1	0.655	0.0112

Table- XXIII: 15g $NaNO_3$ with 10g Kaolin at 35°C

Rating of bushing in kV	Primary voltage (kV)	Arc flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	6.5	5.25	2.65	1.2	2.061	0.0367
11	167.5	80	46.65	0.2	1.097	0.01919
17.5	173	81.5	47.9	0.3	1.420	0.02504

Table- XXIV: 20g $NaNO_3$ with 10g Kaolin at 33°C

Rating of bushing in kV	Primary voltage (kV)	Arc flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	10	6.45	2.8	1.4	2.150	0.03839
11	168	79.5	47.15	0.3	1.975	0.03512
17.5	185.5	89.5	53.3	0.2	1.664	0.02948

Table- XXV: 30g $NaNO_3$ with 10g Kaolin at 34°C

Rating of bushing in kV	Primary voltage (kV)	Arc flash voltage (kV)	Leakage current (mA)	Weight (g)	Conductivity (µs/cm)	ESDD (mg/cm^2)
1	5.5	3.95	2.85	1.6	2.292	0.04100
11	125.5	60.45	33	0.6	1.991	0.03547
17.5	156.5	76	44.45	0.7	1.997	0.0355

Table- XVI: Arc flash voltage at standard room temperature and pressure for 5g $NaNO_3$

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	33	8.588
11	33	98.94
17.5	33	121.613

Table- XVII: Arc flash voltage at standard room temperature and pressure for 10g $NaNO_3$

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	35	7.067
11	35	110.652
17.5	35	113.418

Table- XVIII: Arc flash voltage at standard room temperature and pressure for 15g $NaNO_3$

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	35	7.2615
11	35	110.65
17.5	35	112.72

Table- XIX: Arc flash voltage at standard room temperature and pressure for 20g NaNO3

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	33	8.863
11	33	109.25
17.5	33	122.98

Table- XXX: Arc flash voltage at standard room temperature and pressure for 30g $NaNO_3$

Rating of Bushing in kV	Room temperature°C	V_{STP}
1	34	5.445
11	34	83.33
17.5	34	104.778

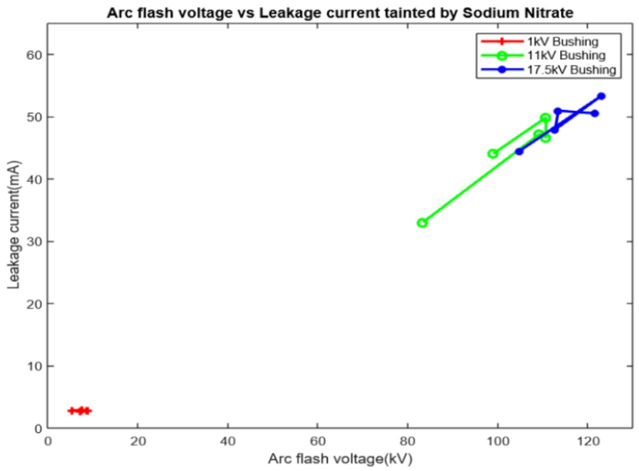

Fig. 9. Arc flash voltage and leakage current tainted by sodium nitrate

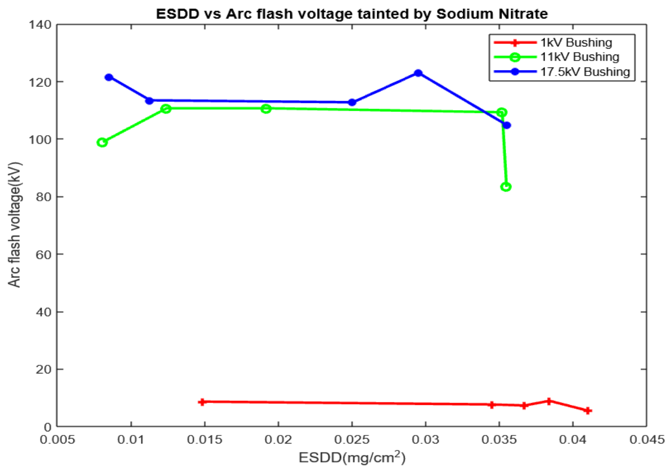

Fig. 10. ESDD and arc flash voltage tainted by sodium nitrate

From fig.2, 5 and 8 shows that the salt concentration in water determines its physical phenomenon. The larger the salt concentration, the upper the physical phenomenon. The physical phenomenon of an answer depends on the quantity of charge carriers (the concentrations of the ions), the quality of the charge carriers and their charge. In theory, conductivity ought to increase in direct proportion to concentration. Some ionic compounds aresoluble, which implies they dissolve in water. once these compounds dissolve, they dissociate, or break into their respective ions. As a category of compounds, salts are chemicals comprised of a metal and a nonmetal. The metal assumes a positive charge and is a cation whereas the nonmetal assumes a negative charge and is an anion.Fig. 3, 6 and 9 normally shows that when voltage get increases then current get decreases (minimum or zero), both are inversely proportional. At the same time, high voltage is passed on the pollution shoal of the bushing, then conducting channel is model on the shoal due to stress and it forms contamination layer due to the presence of salts. At this condition, leakage current flows on the shoal of the bushing and the amount of leak current flows on the shoal is expressed in terms of milliampere. So, flash over occurs on the shoal of bushing and the leak current get escalated.

When the applied voltage gets escalated then the leak current passes through the pollution shoal also get escalated and form a conducting channel.

From fig. 4, 7 and 10 shows that when ESDD values get increases then arc flash voltage gets decreases. When salt concentration get increases then the flashover occurs earlier.

Arc flash occurs quickly in 1kV bushing when compare to 11kV, 17.5kV bushing because it has shortest creepage distance hence the ESDD value get increases. Creepage distance is the shortest distance between two live conductors. 11kV and 17.5kV bushing has long creepage distance so the formation of conduction layer is discontinuing and the arc flash voltage get increases.

V. CONCLUSION

This work is positioned on the AC unrealcontamination test with non-uniform contamination on bushings, some conclusions are obtained as follows,

- When salt concentration get increases then the conductivity also get increases drastically.
- The Equivalent Salt Deposit Density increases with increased salt concentration.
- The arc flash voltage decreases gradually when the Equivalent Salt Deposit Density rate increases.
- The arc flash voltage gets escalated and the leakage current also get escalated gradually.
- When comparing to clean bushings, the arc flash voltage for 1kV,11kV,17.5kV bushings decreases very rapidly when the bushings are tainted with NaCl, KNO_3 and $NaNO_3$.
- From the above obtained results, the arc flash voltage for KNO_3> $NaNO_3$> NaCl respectively.

From this the conclusion can be made that the reaction of nitrates degrades the performance of bushings very quickly when comparing to NaCl.

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