Novel Approach for Condition Monitoring of Metal Oxide Surge Arresters Based on Frequency Variation Technique

Anil S. Khopkar and Kartik S. Pandya

[1]Research Scholar, Dept. of Electrical Engg. CSPIT, Charotar University of Science and Technology, Changa, India & Electrical Research and Development Association (ERDA), Vadodara, India [2]Senior Member IEEE, Associate Professor, Electrical Engg. Dept. Faculty of Engg & Technology, Parul Institute of Engg and Technology, Parul University, Vadodara, India
anil.khopkar@erda.org, a.s.khopkar@gmail.com

Abstract: Metal Oxide Surge Arresters (MOSA) is device which protects electrical power system against surge voltage. ZnO blocks degrades due to ageing effect under various operating conditions. Premature failure of surge arresters observed due to ageing. To avoid premature failure condition monitoring required at periodic intervals. Offline condition monitoring techniques required system shutdown and required costly equipment hence not preferred technique. Online condition monitoring techniques based on measurement 3rd Harmonic leakage current flowing through surge arrester. This method effected by presence of harmonics in the supply which needs to be compensated. Novel technique of leakage current measurement with frequency variation approach is proposed in this paper. Measurement of total leakage current and resistive leakage current at frequency range from 20 Hz to 200 Hz has been proposed in this paper. The experiments with frequency variation from 20 Hz to 200 Hz is carried out in the laboratory on 30 kV fresh and aged MOSA. Measurement of total leakage current and Resistive leakage current has been carried out. The data base of leakage current at frequency range from 20 Hz to 200 Hz in steps of 10 Hz is created. The results of current components at different frequency, I-F characteristics of MOSA are considered to verify its healthiness. The proposed technique has been proven useful to check healthiness of MOSA. The obtained results are analyzed and validated using other diagnostic techniques which is useful for instruments manufacturer, utility and manufacturers.

Keywords: Metal oxide Surges arrester, Condition monitoring, Leakage currents, Frequency,

1. Introduction

MOSA is one of the most important equipment applied in power system for protection against over voltage. While over voltage appears in the system, a surge arrester is functioning as an over voltage limiting device. It is expected to behave as an insulator with very low current under normal operating condition. The insulating properties are essential for the arrester life expectancy and for the power system operation reliability [1]. The working of MOSA is affected by ageing and insulation breakdown inside the arrester. Therefore it is necessary to protect the MOSA from further damage and deterioration, which may cause interruption in electricity transmission and distribution. [2]. The equivalent circuit of MOSA constructed with zinc oxide (ZnO) element is given in Fig. 1. Where, voltage applied across surge arrester is V, equivalent capacitance denoted by C and non-linear resistor is denoted by R. Total leakage current (I_T) is flowing through surge arrester. Due to the non-linear characteristics of ZnO element a current in the range of 1 mA flows through the surge arrester under normal service condition [3].

The total leakage current is divided into capacitive component I_C and resistive component I_R. The total Current (I_T) of flowing through MOSA is given by a vector sum of a capacitive current component (I_C) and Resistive current component (I_R).

$$I_T = I_R + I_C \tag{1}$$

Received: Nopvember 26th, 2024. Accepted: December 31st, 2024
DOI: 10.15676/ijeei.2024.16.4.7

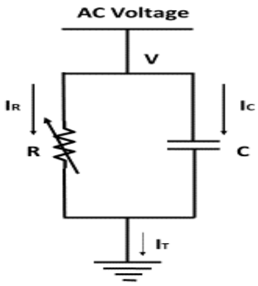

Fig. 1. Equivalent Circuit of MOSA

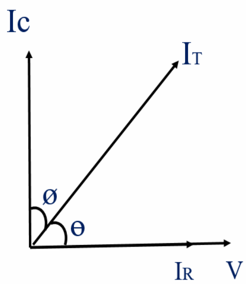

Fig. 2. Phasor diagram of leakage current

Fig. 2 shows phasor diagram of Capacitive Leakage Current (I_C), total leakage current (I_T), Resistive leakage current (I_R) and applied voltage (V). It can be seen that I_R lag I_T by angle ϴ and I_C lead I_T by an angle ø. The resistive components of leakage current exceeds from its capacitive component with the rise in applied voltage [4]. Ideally the capacitance of a ZnO element in the range of 60 pF.kV/cm^2 to 150 pF.kV/cm^2 [5]. The capacitive current (I_C) can be computed from its capacitance value C.

$$Ic = V\omega C \tag{2}$$

where, $\omega = 2\pi f$

Resistive component of leakage current is sensitive indicator of change in voltage-current characteristics of metal oxide resistors. Therefore, resistive current is use as effective tool to ascertain condition of metal oxide surge arrester [5]. The capacitive current is attributed to the grading capacitance of MOSA housing and permittivity of metal oxide element [6]. The power loss measurement is frequently used in the laboratories but is rarely used online because simultaneous leakage current and operating voltage measurements are required [7]. The power loss in the surge arrester can be computed based on the leakage current and applied voltage data the following formula can be use to calculate active power loss [8].

$$P = \frac{1}{T}\int_{t}^{t+T} v(t)\, i(t)\, dt \tag{3}$$

The power loss measurement method has some advantage such as being a good indicator for the MOSA's condition evaluation and giving a realistic picture of MOSA's electrical characteristics and changes due to various types of degradation. [9] [10]. As a results, although it is insensitive to the operating voltage harmonic, even under direct or non-sinusoidal voltage it provides reliable results and is another benefit of the power loss measurement [11]. A leakage current based condition assessment is most extensively opted method to monitor the ageing and deterioration of zinc oxide surge arrester [12]. Many offline and online approaches have been presented for condition monitoring of surge arresters. Such as measurement of power loss, V-I characteristics, leakage current measurement, temperature measurement, partial discharge measurement etc. Leakage current measurement is the most commonly applied for condition assessment of MOSA. [13]-[16]. Research indicated that if the maximum voltage of V-I characteristics decreased by 10 % then a surge arrester is classified as "aged

[17]. The previous research studies have illustrated that the magnitude of leakage current is mainly affected by the ageing and deterioration of MOSA. [18] [19]. There are method such as arrester temperature and electromagnetic field measurements are used for online testing of arresters [20],[21],[22]. Earlier, measurement of fifth harmonic resistive current as ageing indicator is proposed [23]. Ratios of third to fifth resistive harmonic components and ratio of resistive to total leakage current fundamental components have been also proposed [24]. The U-I characteristics with and without harmonic distortion has been compared to check healthiness MOA blocks [25]. Accurate results may be obtained by using the offline methods compared to online methods which are based on leakage current measurement. Offline methods required expensive equipment for experimentation and also need for disconnection of surge arrester from the system. This is the major drawback of the offline methods.

In this paper new approach for the condition monitoring of MOSA has been proposed. The proposed technique is based leakage current measurement at different frequency range from 20 Hz to 200 Hz. Variation of total leakage current and resistive leakage current with different frequency (I-F characteristics) has been considered as condition monitoring tool of MOSA. This proposed technique of I-F characteristics is novel method and not used by any researcher earlier which can be implemented offline measurement mode. The results of the proposed techniques is validated by tan δ and partial discharge values. Research is continue on measurement of I-F characteristic with further higher frequency i.e up to 500 Hz. The ageing process of lightning impulse current, temperature, voltage application under salt fog and water immersion has been adopted, which has not been followed by earlier researcher. The proposed method has been explained in section 2. The experimental set-up is illustrated in section 3. Results of the proposed method has been discussed in section 5. The proposed method to check healthiness of the surge arresters has been validated by the obtained experimental results.

2. Proposed Method

In this paper, condition monitoring and diagnostics method to identify the healthiness of MOSA has been proposed which is I-F characteristics of MOSA. Leakage current measurement at different frequency range from 20 Hz to 200 Hz has been proposed. The major advantage of the proposed technique is the since the measurement is carried out at wide range of frequency the effect of the harmonic present in the supply gets nullified. In this proposed techniques measurement of total leakage current and resistive leakage current has been carried out at different frequency. F-I characters obtained from the results for the new MOSA. Similarly, F-I characteristics obtained for aged MOSAs. Hence, F-I characteristics of MOSA has been considered as health index of MOSA. As per proposed techniques measurement of leakage current is carried out from 20 Hz to 200 Hz frequency in steps of 10 Hz on new & aged 30 kV MOSA. The measurement of leakage current is carried out at voltage level of 15 kV. The F-I characteristics, ageing process and experimental results of the condition monitoring are explained further. The data base of measurement results has been prepared. After initial measurement MOSA has been kept for various ageing process. For this research work 30 kV MOSA has been chosen for the laboratory experiments. The healthiness of the MOSA and proposed novel method has been verified by performing condition monitoring tests and rigorous ageing process followed. Details of experiments have been explained in detail at section 3. Ageing process followed has been explained in detail at section 4.

3. Laboratory Experiments

Experiments carried out on 30 kV MOSA in the high voltage partial discharge laboratory. Initially, following tests have been carried out on both the MOSAs.

1. Partial discharge measurement
2. Measurement of reference voltage at reference current at fundamental frequency
3. Measurement of capacitance and Tan δ

The technical specifications of the MOSA used for experiment are given in table 1.

Table 1. Specification of MOSA

Rated Voltage (Ur)	30 kV
Maximum Continuous Operating Voltage	24 kV
Nominal Discharge Current	10 kA
Maximum Residual Voltage	90 kVp
Frequency	50 Hz
Basic Insulation Level (BIL)	170 kVp
External Creepage distance	845 mm

80 kV PD free high voltage source, Coupling capacitor (CC), PD detector having sensitivity less than 0.1 pC has been used for measurement of partial discharge. PD calibrator of 5 pC & 100 pC has been used for calibration of PD circuit The measurement has been carried out in double shielded high voltage lab with background PD less than 0.1 pC. . The test set-up of PD measurement has been shown in figure 3. The PD measurement circuit has been shown in figure 4.

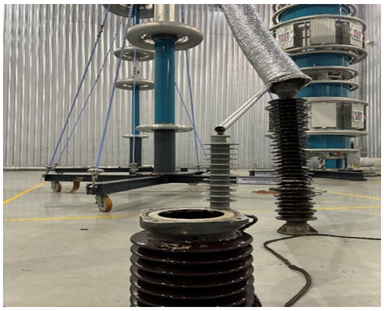

Fig. 3. Experimental set-up for PD measurement

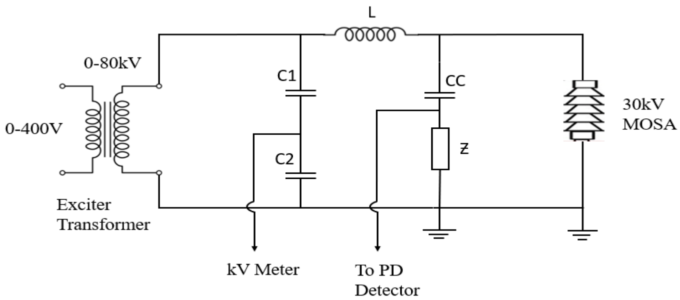

Fig. 4. Experimental circuit for PD measurement

Measurement of reference voltage at reference current of 1 mA has been carried out with same high voltage source of 80 kV. The MOSA has been earthed through 10 kΩ non inductive resistance. The voltage and current measurement has been done on digital oscilloscope (DSO). Capacitance and tan delta measurement has been done at 1 kV, 5 kV and 10 kV. For the measurement of total leakage current and resistive leakage current at frequency ranging from 20 Hz to 200 Hz, 33 kV, single phase high voltage source has been used for voltage application. Grid simulator of 30 kVA having output frequency range of 16 Hz to 400 Hz has been used for variation of frequency from 20 Hz to 200 Hz is steps of 10 Hz. The applied voltage measured using AC/DC High voltage probe. The output of the HV probe has been connected to digital oscilloscope for voltage and frequency measurement. For the measurement of leakage current FFT analysis on digital oscilloscope was used in earlier research [26]. In this research Leakage current (I_R & I_T) of surge arrester has been measured using accurate Leakage Current Analyser (LCA). The measurement has been carried out at voltage level of 15 kV. This measurement has been carried out on both 30 kV MOSA before and after ageing and database of F-I characteristics has been created. The experimental set-up for the leakage current measurement has been shown in figure 5 and experimental circuit has been given in figure 6. The obtained results has been discussed in results and discussion section 5. After conducting above tests, both MOSAs has been kept for ageing process.

Fig. 5. Experimental set-up for leakage current measurement.

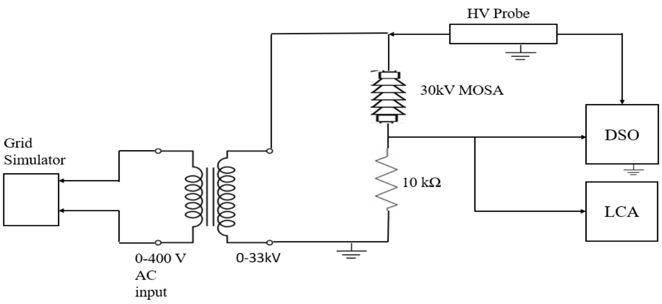

Fig. 6. Experimental circuit for leakage current measurement

4. Ageing Process

The accelerated ageing process for MOSA has been shown in figure 7. Ageing oven of sufficient capacity used for temperature ageing at 150 °C of MOSA.

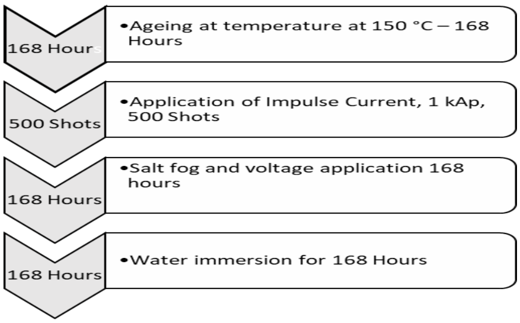

Fig. 7. Ageing Process of 30 kV MOSA

First MOSA has been kept ageing oven for temperature ageing process at 150 °C for 168 Hours. The MOSAs under temperature ageing has been shown in figure 8(a). After temperature ageing, the MOSA has been aged for application of impulse current of 1 kA. Lightning impulse current of 8/20 µS applied on MOSA. 800 kVp, 40 kJ Impulse voltage system used for Impulse current application. Non-inductive current shunt of 1 Ω used for measurement of impulse current shunt.

(a) MOSA kept on Oven for temperature

(b) Set-up for Impulse current application ageing at 150 °C

(c) MOSA kept inside salt-fog chamber

(d) MOSA immersed in water

Fig. 8. MOSA Ageing Process

Capacitive voltage divider used for the voltage measurement. High resolution impulse analyser used for waveform recording and analysis. The test set-up for ageing by impulse current application has been shown in figure 8(b). After Impulse current application MOSA kept inside the salt fog chamber for 168 hours. Salt fog chamber having volumetric dimension of 15 M^3 used for salt fog for 168 hrs. For voltage application 50 kV, 1 Amp high voltage source has been used. MOSA under salt fog ageing has been shown in figure 8(c). Test parameters maintained in the salt fog chamber is given below,

Applied voltage : 20 kV
Ageing duration : 168 hrs
Water flow rate : 0,4 l/h/m3 ± 0,1 l/h/m3
Size of droplets : 5 µm to 10 µm
Temperature : 20 °C ± 5 K
NaCl content of water: Between 1 kg/m3 to 10 kg/m3

After salt fog ageing MOSA has been immersed in normal water at room temperature for 168 hours. Normal tap water used for immersion and kept at room temperature. The water immersion ageing is shown in figure 8(d). After ageing process, the aged MOSA has been again evaluated for the similar test. The leakage current at frequency range from 20 Hz to 150 Hz has been measured. The power loss at the same frequency range has also been measured and data base has been created for the results. The results of leakage current at various frequency range "I-F characteristics" has been compared for condition monitoring of MOSA. Additionally, partial discharge measurement, reference voltage at reference current has been measured to validate the ageing effect of MOSA. The obtained results are discussed in further in next section.

5. Results and Discussion

Initially, healthiness of both the MOSAs have been verified by conducting various offline tests. It has been seen that the value of partial discharges increased to very high value. The reference voltage also increased 9.97 % & 11.37 % after ageing process. The values of capacitance has not changed significantly but value of tan δ increased significantly. The increased value of tan δ indicates moisture penetration inside MOSA. These results indicates degradation of both the MOSAs after ageing process. The test results of condition monitoring tests before and after ageing process has been given in table 2, table 3 and table 4. The variation in capacitance has been given in figure 9 and variation in tan δ value has been shown in figure 10.

Table 2. Measurement of Partial discharges

30 kV MOSA	Applied voltage	Measured PD (pC)	
		Before Ageing	After Ageing
Sample 1	25.2	2.6	1590
Sample 2	25.2	1.2	1230

Table 3. Measurement of Reference voltage at reference current

30 kV MOSA	Ref. Current (mA)	Measured Ref. Voltage (kV)	
		Before Ageing	After Ageing
Sample 1	1.01	30.1 kV	27.1 kV
Sample 2	1.01	29.9 kV	26.5 kV

Table 4. Measurement of capacitance and tan δ

30 kV MOSA	Applied Voltage	Before Ageing		After Ageing	
		Measured capacitance	Measured Tan δ	Measured capacitance	Measured Tan δ
Sample 1	1 kV	61.60 pF	0.002519	61.02 pF	0.04529
	5 kV	60.75 pF	0.007136	61.15 pF	0.04736
	10 kV	59.38 pF	0.005360	60.38 pF	0.05460
Sample 2	1 kV	62.40 pF	0.005216	62.11 pF	0.05886
	5 kV	61.55 pF	0.005657	61.95 pF	0.06157
	10 kV	60.18 pF	0.004256	60.75 pF	0.06742

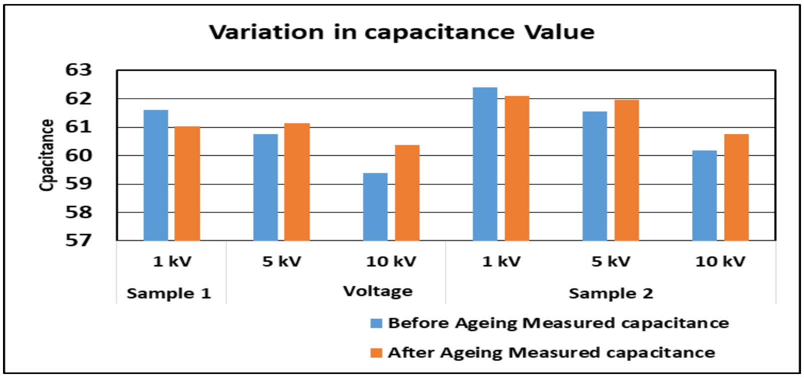

Fig 9. Variation in capacitance

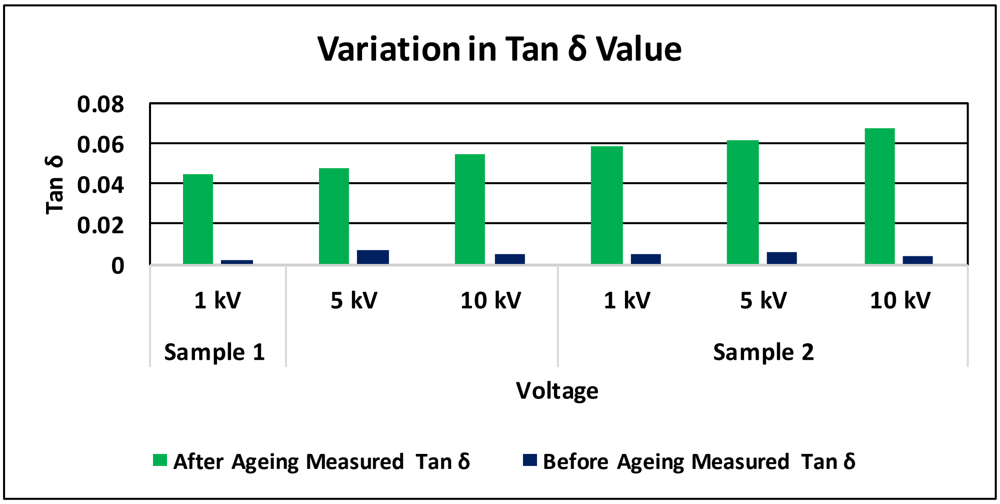

Fig 10. Variation in tan δ

As per proposed method results of measurement of total leakage current and resistive leakage current at different frequency before and after ageing has been given in table 5. The measurement has been carried out at 15 kV voltage level with variation in frequency from 20 Hz to 200 Hz.

Table 5. Measured leakage current at different frequency

f (Hz)	F-I characteristics for sample 1					
	Before ageing		After ageing		% variation	
	I_T (μA)	I_R (μA)	I_T (μA)	I_R (μA)	I_T	I_R
20	55.4	11.1	105.4	11.5	90.25	3.60
30	97.2	29.6	142.9	32.2	47.02	8.78
40	137.7	31.2	198.4	35.2	44.08	12.82
50	178.1	36.5	251.7	38.4	41.33	5.21
60	213.3	40.2	306.1	40.5	43.51	0.75
70	250.6	41.2	358.4	52.3	43.02	26.94
80	277.3	43.2	409.6	64.5	47.71	49.31
90	324.6	45.5	460.8	68.9	41.96	51.43
100	361.6	48.1	516.2	73.2	42.75	52.18
110	397.8	50.1	568.5	82.4	42.91	64.47
120	436.2	53.2	622.9	86.5	42.80	62.59
130	472.5	58.6	675.2	91.2	42.90	55.63
140	510.9	259.1	729.6	368.7	42.81	42.30
150	548.2	368.7	784	522.1	43.01	41.61
160	586.6	390.6	837.3	562.2	42.74	43.93
170	624.2	112.9	892.8	160.5	43.03	42.16
180	662.4	80.1	943.2	112.9	42.39	40.95
190	701.8	61.9	1003.7	91.8	43.02	48.30
200	740.2	54.7	1058.1	72.9	42.95	33.27

It can be seen that the total leakage current of MOSA increase linearly with increased frequency. Resistive leakage current increased linearly up to frequency of 130 Hz, then increased exponentially up to frequency of 160 Hz, and decreased linearly above frequency 160Hz. The I-F characteristics for MOSA sample-1 has given in Fig 11.

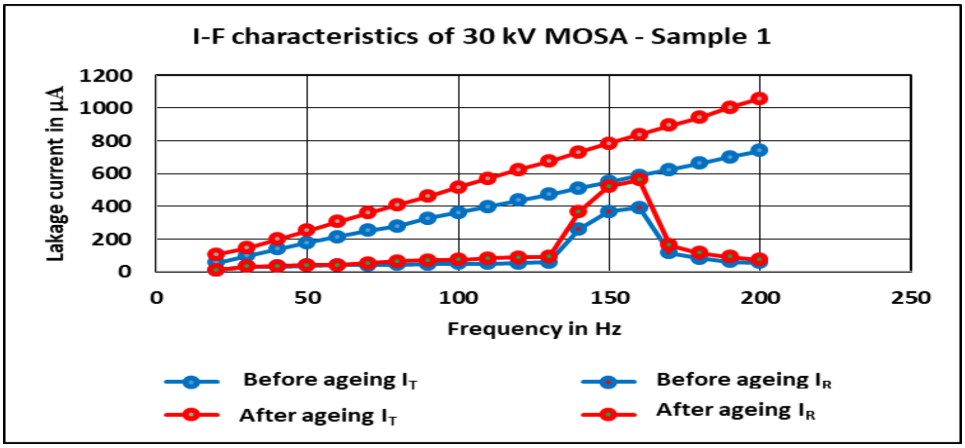

Fig. 11. I-F characteristics of 30 kV MOSA, Sample -1.

The results of measurement of total leakage current and resistive leakage current at different frequency at 15 kV before and after ageing for sample – 2 has been given in table 6.

Table 6 Measured leakage current at different frequency

f (Hz)	F-I characteristics for sample 2					
	Before ageing		After ageing		% variation	
	I_T (μA)	I_R (μA)	I_T (μA)	I_R (μA)	I_T	I_R
20	55.4	11.1	81.2	12.2	46.57	9.91
30	99.2	25.8	135.4	30.8	36.49	19.38
40	139.7	29.1	200.5	37.2	43.52	27.84
50	181.3	31.2	256.5	38.3	41.48	22.76
60	216.5	32.5	310.4	42.1	43.37	29.54
70	252.8	34.5	361.6	55.2	43.04	60.00
80	291.2	45.1	416.5	68.1	43.03	51.00
90	328.5	46.3	470.4	72.3	43.20	56.16
100	364.8	52.3	524.8	74.5	43.86	42.45
110	403.2	54.1	578.1	78.3	43.38	44.73
120	440.5	55.2	632.5	82.3	43.59	49.09
130	480.2	63.1	686.9	96.6	43.04	53.09
140	514.1	249.2	741.3	390.6	44.19	56.74
150	555.7	379.4	795.7	543.2	43.19	43.17
160	594.1	405.3	851.2	583.8	43.28	44.04
170	636.7	118.9	905.6	170.9	42.23	43.73
180	672.2	81.6	961.5	115.1	43.04	41.05
190	709.3	70.4	1018.6	96.6	43.61	37.22
200	749.8	51.9	1073.2	81.6	43.13	57.23

Here similar pattern has been observed i.e. Total leakage current of MOSA increase linearly with increased frequency and resistive leakage current increase up to 130 Hz than restive leakage current exponentially for 150 Hz and above 160 Hz frequency resistive current decreased. The I-F characteristics for MOSA sample-2 has given in Fig 12.

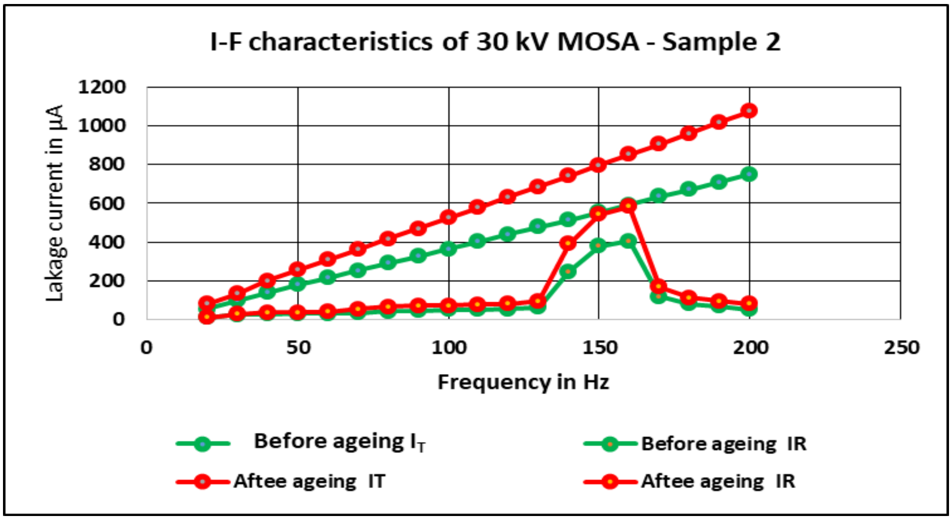

Fig. 12. I-F characteristics of 30 kV MOSA, Sample 2.

For Sample -1 after ageing process it can be seen that the total leakage current (I_T) at 20 Hz increased by 90.25 %, at 50 Hz increased by 41.33 %, at 100 Hz increased by 42.75 %, at 150 Hz increased by 43.01 % and at 200 Hz it is increased by 42.95. After ageing process resistive leakage current (I_R) at 20 Hz increased by 3.60 %, at 50 Hz increased by 5.21 %, at 100 Hz increased by 52.18 %, at 150 Hz increased by 41.61 % and at 200 Hz it is increased by 33.27%. For sample – 2, after ageing process it can be seen that the total leakage current (I_T) at 20 Hz increased by 46.57 %, at 50 Hz increased by 46.57 %, at 100 Hz increased by 43.86 %, at 150 Hz increased by 43.19 % and at 200 Hz it is increased by 43.13. After ageing process resistive leakage current (I_R) at 20 Hz increased by 9.91 %, at 50 Hz increased by 22.76 %, at 100 Hz increased by 42.45 %, at 150 Hz increased by 43.17 % and at 200 Hz it is increased by 57.23%. There is major increased observed in total leakage current and resistive leakage current after ageing, it indicates degradation of MOSAs. The results of Partial discharges and tan δ measurement also indicates degradation of both the MOSAs. Hence, proposed technique in useful tool to verify the healthiness of MOSA. The F-I characteristics with further higher frequency i.e. up to 500 Hz and different voltage level is further scope of research.

6. Conclusion

In this paper new criteria based on I-F characteristics has been proposed, as condition monitoring tool for metal oxide surge arrester. The results are as follows. It has been observed that total leakage current increased with increased in frequency however resistive leakage current observed maximum between frequency of 140 Hz to 160 Hz. Similar results obtained for both the samples for new and aged MOSAs. It can be seen that the surge arrester degradation effects on residual voltage and reference voltage of surge arrester. The value of capacitance does not indicate variation, however value of dissipation factor i.e. tan δ considerably increased after ageing. The F-I characteristics with further higher frequency i.e. up to 500 Hz and different voltage level is further scope of research.

7. Acknowledgements

The authors wish to thank Dept. of Electrical Engg. CSPIT, Charotar University of Science and Technology, Changa, India for their support for publication of this paper. Authors also wish to thank the Management of Electrical Research and Development Association (ERDA), Vadodara – India for permission to publish this paper.

8. References

[1]. Metal-oxide surge arresters without gaps for ac system, IEC : 60099-5 2014..

[2]. Syeda S. Haider, Hania A. Umme A, Syeda K. Shakeel and A Munir, "Online condition monitoring of 120 kV zinc oxide surge arrester using correlation method", Eng. Proc. 2023, 46,41 https:// doi.org/10.3390/engproc2023046041.

[3]. Turgut Taskin, "Introduction of a measurement system to monitor the condition of ZnO surge arresters," 0-7803-5935-6/00, 2000 IEEE pp 1553-1557.

[4]. Abdullah Munir, Z. Abdul Malek and Rai Naved Arshad, "Resistive component extraction of leakage current in metal oxide surge arrester: A hybrid method". Elsevier *Journal, Measurement* 173 (2021) 108588.

[5]. Surge Arresters – Selection and Application Recommendation", IEC Standard 60099-5, 2018.

[6]. Abdullah Munir, Z. Abdul-Malek, Umbrin Sultana and Rai Naveed Arshad. "A novel technique for condition monitoring of metal oxide surge arrester based on fifth harmonic resistive current", Elsevier, *Electric power systems research* 202(2022) 107576.

[7]. Behnam Rajbar, Ali Darvishi, Rahman Dashti and Hamid Reza Shaker, "A survey of diagnostic and condition monitoring of metal oxide surge arrester in the power distribution network", *MDPI, Energies* 2022, 15, 8091. 2022.

[8]. Dobric, G.; Stojkovic, Z.; Stojanovic, Z. "Experimental Verification of Monitoring Techniques for Metal-Oxide Surge Arrester", *IET Gener. Transm. Distrib*. 2020, 14, 1021–1030.

[9]. He, J.; Zeng, R.; Chen, S.; Tu, Y. "Thermal Characteristics of High-Voltage Whole-Solid-Insulated Polymeric ZnO Surge Arrester", *IEEE Power Eng. Rev*. 2008, 22, 62.

[10]. Seyyedbarzegar, S.M.; Mirzaie, M. “Heat Transfer analysis of Metal Oxide Surge Arrester under Power Frequency Applied Voltage”, *Energy* 2015, 93, 141–153.

[11]. Heinrich, C.; Hinrichsen, V. “Diagnostics and Monitoring of Metal-Oxide Surge Arresters in High-Voltage Networks-Comparison of Existing and Newly Developed Procedures” *IEEE Trans. Power Deliv.* 2001, 16, 138–143.

[12]. Abdullah Munir, Z. Abdul-Malek, Rai Naveed Arshad. “Resistive leakage current based condition assessment of zinc oxide surge arrester: A review”, 13th I*nternational conference on the properties and application of dielectric materials (ICPADM 2021), IEEE* pp183-186, 2021.

[13]. P. Pali´nski, and J. Wa´nkowicz, “Application of leakage current parameters for technical diagnostics of surge arresters,” *IEEE Transactions on Dielectrics and Electrical Insulation*, 23(6), December 2016, 3458-3465.

[14]. W.Doorsamy and P. Bokaro, “Online monitoring of metal-oxide surge arresters using improved equivalent model with evolutionary optimization algorithm”, 978-1-5090-1412-5/17, 2017 IEEE, pp135-139.

[15]. M. Khodsuz, M. Mirzaie, and S. Seyyedbarzegar, “Metal oxide surge arrester condition monitoring based on analysis of leakage current components,” *International Journal of Electrical Power and Energy Systems*, 12 (6), 2014, 188-193.

[16]. P. Bokoro, M. Hove, and I. Jandrell, “Statistical analysis of MOV leakage current under distorted supply voltage conditions,” *IEEE Electrical Insulation Conference, Philadelphia, USA*, June 2014.

[17]. M. Khodsuz, M. Mirzaie and S. Seyyedbarzegar’ “Metal oxide surge arrester condition monitoring based on analysis of leakage current component”, *Elsevier Journal, Electrical Power and Energy systems* 66, pp. 188-193, 2015.

[18]. Z.Abdul Malek, A.Khavari, C.Wool, M.Moradi, A. Naderipour, “A review of modeling ageing behavior and condition monitoring of Zinc Oxide surge arrester”, Int. Research and Development (SCOReD), 2015 *IEEE student conference on IEEE*, 2015 pp. 733-738.

[19]. G.Dobric, Z.Stojanovic, Z.Stojkovic, “The application of genetic algorithm in diagnostics of metal oxide surge arrester”, Electrical power system Res. 119, (2015)pp. 76-82.

[20]. M.Khodsuz and M. Mirzaie, “Monitoring and identification of metal-oxide Surge Arrester conditions using multi-layer support vector machine.” *IET Journal*, Vol 15 iss 16, pp.2501-2508, 2015.

[21]. Stojanovi´c, Z.N.; Stojkovi´c, Z.M. “Evaluation of MOSA Condition Using Leakage Current Method”, Int. J. Electr. Power Energy Syst.2013, 52, 87–95.

[22]. Christodoulou, C.A.; Avgerinos, M.V.; Ekonomou, L.; Gonos, I.F.; Stathopulos, I.A., “Measurement of the Resistive Leakage Current in Surge Arresters under Artificial Rain Test and Impulse Voltage Subjection”,. *IET Sci. Meas. Technol.* 2009, 3, 256–262.

[23]. A.Munir, Z. Abdul Malek, U.Sultana and R. Naved Arshad, “A novel techniques for condition monitoring of metal oxide surge arrester based on fifth harmonic resistive current”, Elsevier, Electric Power System Research 202 (2022) 107576.

[24]. M.Khodsuz and Mohammad Mirzaie, “Harmonic ratios of resistive leakage current as metal oxide surge arresters diagnostic tools”, Elsevier, Measurement 70 (2015) 148-155.

[25]. P. Bokaro and I.Jandrell, “Failure analysis of metal oxide arresters under harmonic distortion”, south African institute of electrical engineers, Vol 107, pp 167 – 176, September 2016.

[26]. S.Das, R.Ghosh, S.Dalai, B. Chatterjee, “Study of the effect of moisture ingression into metal oxide surge arrester using leakage current analysis”, 2017, *3rd international conference on condition assessment technique in electrical system (CATCON),* 2017, PP330-334.

Anil S. Khopkar is Working as “Asst. Director & Head of Division – R&D and Expert Services at Electrical Research and Development Association (ERDA), Vadodara. He is responsible for various research activities and technology development in areas of Power Systems, Renewable Energy, Product Development and Advanced Materials in field of electrical engineering. He also headed, High voltage Impulse laboratory, Extra High Voltage Partial Discharge laboratory, Cable laboratory, Instrument Transformer Laboratory, Transformer Laboratory as well as calibration laboratory. He has established various test laboratory like, HV Impulse, HV PD lab, Transformer test laboratory etc. He is Member of BIS technical committee of India for High Voltage Testing techniques (ETD 19) and chairman of BIS technical committee of India for Surge Arrester (ETD 30). He is also a member of IEC Technical committee “TC 99/JWG 13 – Insulation co-ordination for HVDC System”. He is pursuing his PhD from “Charotar University of Science and Technology (Charusat)” CSPIT, Changa, Gujarat, India. He can be contacted at email: anil.khopkar@erda.org and a.s.khopkar@gmail.com.

Kartik S. Pandya is working as an Associate Professor in Electrical Engineering Department at Parul Institute of Engineering and Technology (PIET), Parul University, INDIA. His research area includes Computational Intelligence methods, Power System Optimization, Smart Grid, and Renewable integrations. He can be contacted at email: kartik.pandya30364@paruluniversity.ac.in