FORENSIC ANALYSIS OF FAILED SURGE ARRESTORS

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Presentation Flow:

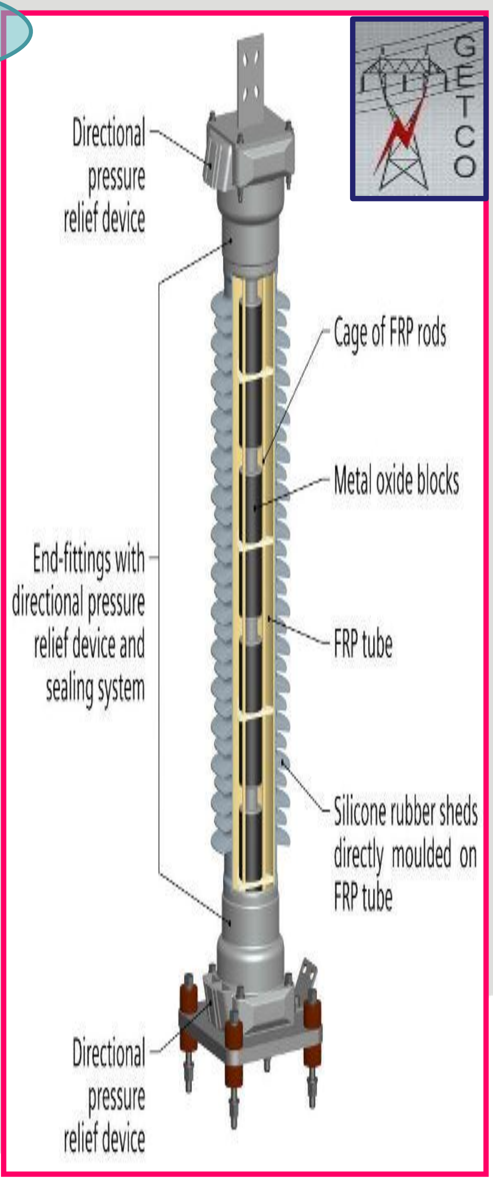
- Introduction
- Concept Behind Analysis
- GETCO Approach
- Forensic Analysis of Failed SAs
- Various Case Studies
- Remedial Measures
- Conclusion

Introduction :

Surge Arrester

"Important" Equipment of the Grid

- Protects electrical power systems from Lighting/Switching surges
- Main component of SA: Semiconductor ZnO discs
  - highly voltage sensible
  - Insulating at low voltage
  - Conducting at high voltage



"MUST" conditions for Surge Arrester:

- ✓ Conducts only during over voltages/surges
- ✓ Minimal surge clearing Time
- ✓ Low power loss under normal operating conditions
- ✓ High resistance to power current
- ✓ High energy handling capability.
- ✓ No system disturbance while operation.
- ✓ Economical, reliable and having long life

Concept behind Analysis:

- Any failure, if analyzed, is useful to improve upon design, quality and operational aspects.

- **Forensic analysis**:
  - Allow to determine cause of end of life of arrestor, whether it is,
    - Normal or expected (i.e. while performing protecting function)
    - Or any other issue related to
      - Design
      - Manufacturing or
      - Maintenance

- This exercise is useful for continuous improvement to build up efficient , safe & uninterrupted power system.

- It is also important for OEM to become consistent in quality while design & manufacturing.

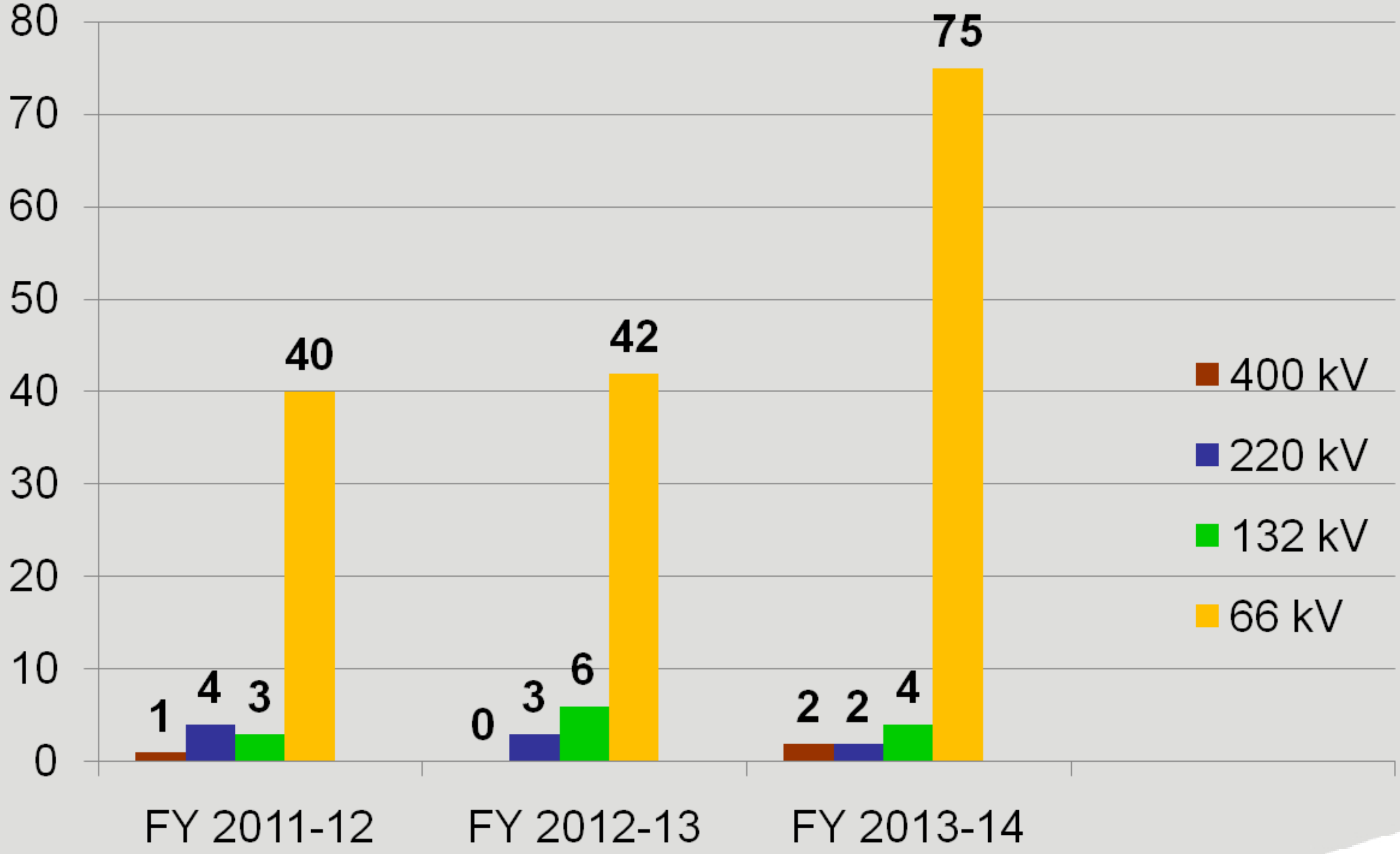
GETCO Approach:

Class	400 kV	220 kV	132 kV	66 kV	TOTAL
Population	313	2600	1491	16196	**20600**

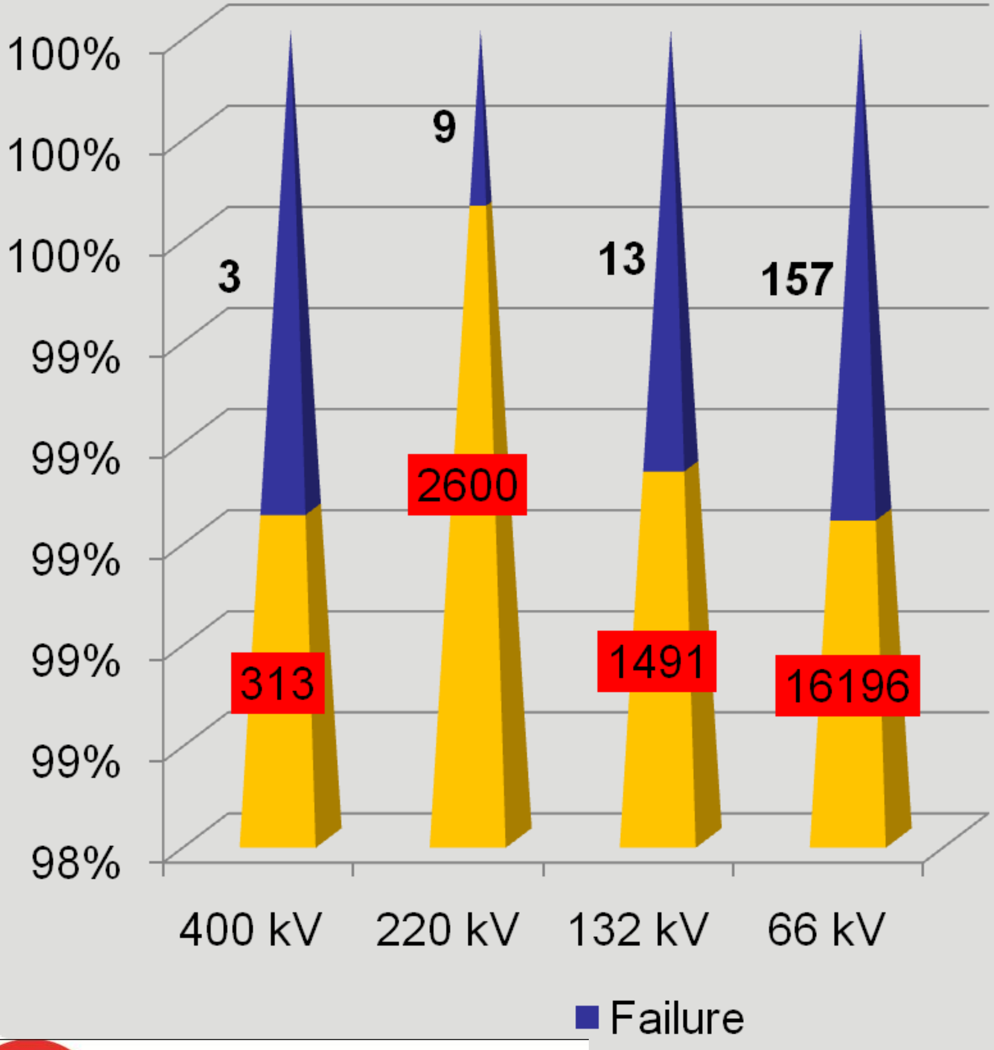
- Increasing failure rates observed in recent years (Year: 2011-12, 2012-13, 2013-14).
- Monitoring of leakage current of each and every SA is already in place.
- Knowing the reason of failure, we can identify areas of improvement like design, manufacturing, quality or service conditions.
- To identify the reason of failure, root cause analysis of each failure is essential.

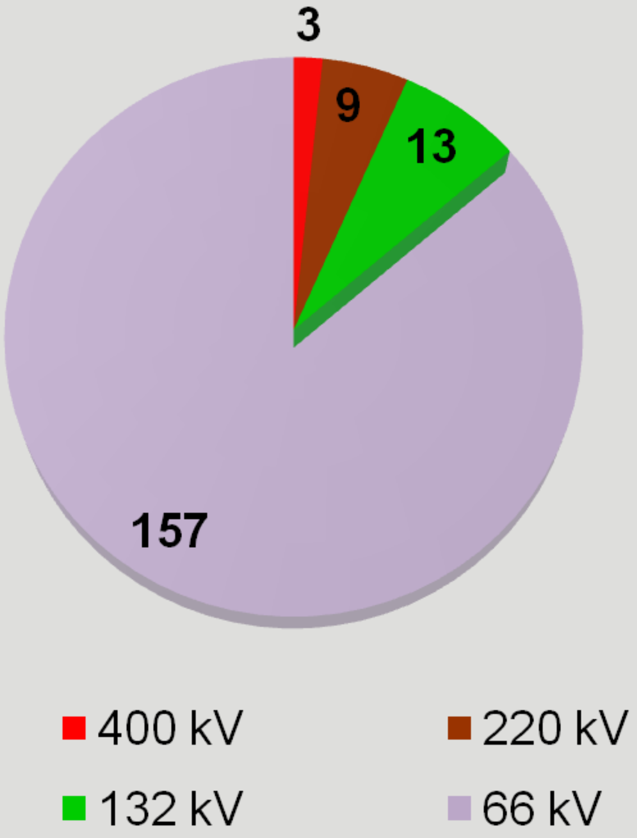
Class	400 kV	220 kV	132 kV	66 kV	TOTAL
No. of failures	3	9	13	157	**182**
Rate of failure out of total population	1 %	0.35 %	0.9 %	1 %	0.9 **%**

Year wise Failure



Voltage class wise Failures





Total **182** SAs failed during 3 years

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Forensic Analysis of Failed Surge Arrestors:

Out of 182 nos. of failures, preliminarily 20 nos. of SAs were selected randomly for study & analysis, considering practical as well as theoretical facets.

Failure Analysis Strategy

Analysis of the failure report submitted by the field

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Standard check list of site verification

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Standard format for carrying out failure investigation

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Collection of system data and input from field related to situation

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Inspection of failed arrestor by dismantling actual arrestor & correlate with the above three

↓

Preparation of forensic report and listing out potential root cause

1. Analysis of preliminary field reports

Preliminary field failure reports comprise of

- Name plate data
- Date of commissioning
- Application (Line, Transformer or Capacitor bank)
- System conditions at the time of failure
- Weather conditions at the time of failure
- Any other specific data

2. Standard Check list for site verification

Standard

The standard check list/format, describing post failure condition of SA, was prepared to maintain uniformity & precision in data collection during site visits.

:: CHECK LIST FOR LIGHTNING ARRESTER ::

1] LA Details:		
a)	a) Make of Lightning arresters	
b)	Rating of LA.	
c)	MCOV of LA.	
d)	Sl. No. of LA.	
e)	Year of manufacturing.	
f)	No. of units per arrester.	
g)	Rating of each unit.	
h)	Date of Commissioning	
i)	Date of Failure	

2] PHYSICAL VERIFICATION OF ARRESTER:-

S. N.	ITEM	YES / NO	REMARKS.
	EXTERNAL VERIFICATION.		
1.	BUSHING. (SHORT CIRCUIT MARKS, FLASHOVER MARKS		
2.	BUSHING BROKEN.		
3.	FLASHOVER MARKS ON CASTINGS		
	• TOP		
	• BOTTOM		
4.	FLASHOVER MARKS ON LINE TERMINAL CONNECTOR.		
5.	FLASHOVER MARKS ON LINE TERMINALBRACKET.		
	INTERNAL VERIFICATION AFTER OPENING.		
1.	CONDITION OF END COVER PLATES		
	• TOP		
	• BOTTOM		
2.	CONDITION OF PRESSURE RELEASE DEVICE OPERATED		
	• TOP		
	• BOTTOM		
3.	GASKET CONDITION		
	• TOP		
	• BOTTOM		
	MOISTURE INGRESS		
4.	STACK POSITION, CARBON CONTAMINATION.		
5.	NO. OF BLOCKS PER STACK / UNIT.		
6.	BLOCK DETAILS IF ANY (PRINTED ON BLOCK)		
7.	NO. OF BLOCKS DAMAGED.		
8.	NO. OF FRP RODS PER UNIT/STACK.		
9.	FLASHOVER MARK/DAMAGE OF FRP ROD.		
10.	MELTING OF STACK SEPARATERS.		
11.	FLASHOVER OF STACK SUPPORTERS.		
12.	SPRING CONDITION		
	SURGE MONITOR.		
1.	SERIAL NO.		
2.	FLASH OVER.		
3.	NO. OF IMPULSES COUNTED.		
4.	IMPULSE MARKS ON SURGE MONITOR.		

3] Remarks if any:-

3. Standard format for carrying out failure investigation

Matrix of Root cause, Failure mechanism and Symptoms

Matrix

1. External Flashover	
Typical reasons	Lightning.
	Severe contamination with presence of moist atmosphere
	Caused by animals, like monkey, snake etc.
Failure mechanism	Due to electrocution of animal, external arc can be created over the external housing of LA. However, LA may not always get affected due to external flashover if the protection system is properly operated
Indicators	Marking of arcs on HV side of LA or on housing and base

2. Moisture Ingress	
Typical reasons	Manufacturing defect
	Mishandling
	External flashover damaging seal
Failure mechanism	Due to entry of moisture, relative humidity reaches inside same as outside. With low temperature condensation occurred along electrically stressed, components leads to dry band arcing & dielectric tracking along wet surface and eventually results in a short circuit of unit.
Indicators	Brown rust on metal parts
	White rust on aluminum parts
	Increased watt loss at operating voltage
	Tracking along electrically stressed components
	Increased temperature in infrared image
	Green copper oxidation
	Hardened rubber seal left with lower compressive strength
	Old rust covered by carbon by-products of arcing which indicates rust was there prior to failure
	Tracking inside
	Cracks and damp on discs

3. Excessive Internal Partial Discharge	
Typical reasons	Excessive PD lead to degradation of ZnO discs as well as dielectric capability.
	Happened in significant internal air space.
	Manufacturing defects, moisture ingress, mishandling, excessive contamination & moisture on external surfaces.
Failure mechanism	Minor PD activity starts & then grows. After long exposure, the dielectric in this area of arrester degrades & leads to flashover of electrically stressed parts.
	PD can also reduce the oxygen content of the air around the discs and in some cases changes characteristics of disc.
Indicators	PD is indicated by high freq spikes near edges & corners, discoloration of components & contact points etc.
	Multi colored growths on rubber components
	Corroded internal parts, oxidization etc.

4. Lightning	
Typical reasons	Terminal overload occur due to lightning stroke above designed value.
	However, failure can occur later if the damage due to this is minimal.
	Excessive single current surge or a significant multi-stroke surge
	Improper lightning duty specified
	Successive strokes on same unit
	TOV followed by a surge due to fault on that circuit exceeding SA's capability
Failure mechanism	This minor damage triggers PD in turn leads to tracking and causes electrical failure. If capability is exceeded by LI stroke, the ZnO discs will initially take surge, heat up, may get cracked and then flashover. If minor damage is there, it may fail later on.
Indicators	ZnO discs get punctured
	Porcelain gets cracked or broken

5. Temporary Over Voltages (TOV)

Typical reasons	Terminal overload caused by PF voltage beyond design capability.
	A TOV overload can be immediate but, it can also occur a long term failure triggered by unrelated other issues.
	Excessive voltage rise in healthy (un-faulted) phase
	Misapplication of arrester
	Change in neutral configuration, loss of neutral on system
	Ferro resonance
	Ageing of ZnO discs
Failure mechanism	During TOV overload, the voltage across the arrester rises to a level where the disks conduct much more than during the steady state condition.
	Discs get heated up significantly in turn lowers its resistance and leads to more conduction and ultimately fails.
Indicators	Change in disc characteristics
	Cracking of few discs in stack
	Flashover of discs
	Opening of vent

6. Switching Surge Overload	
Typical reasons	It may occur due to surges generated from switching of capacitor banks, long lines, exceeding design limits of arresters.
	Re-strike or prestrike of breakers and/ or pre strike of capacitor switches.
Failure mechanism	Same as for lightning mechanisms.
Indicators	Numerous small holes in the aluminum electrode of the discs generally around circumference of disc electrode.
	Polarization of disc at low levels
Remarks	Damage due to fault current after the initial overload can disguise the real cause.

7. Ageing of Discs	
Typical reasons	Due to ageing, long term changes are observed in MOV arresters.
	More losses due to ageing occur.
	Improper manufacturing of disc.
Failure mechanism	At normal operating voltage, losses gradually increase leading to internal heating. When this heat exceeds arrester's ability to dissipate in to environment, this leads to dielectric failure and a fault on system.
	Thermal run away
Indicators	Hot arrester at normal operating temperature
	Excessive electrical losses at operating voltage

8. Other Causes	
External contamination	Lead to external flashover and excessive internal partial discharge
Improper selection of U_c or TOV rating	U_c value lower than steady state value of system voltage.
Unbalance electric field	Clearance between each phase and with ground, overheating of discs due to voltage imbalance and inappropriate grading ring can cause this type of failure.
Misalignment of disc column	Off centered column of discs along the length of housing, physical damage to edges of disc, misalignment during transport & handling, improper spring pressure can lead to PD and ultimately failure.
Mechanical stress	Excessive mechanical stress due to jumper, failure of seals due to mechanical load on one side etc.
Burrs	Sharp points on conductive parts used inside lead to internal discharge.Design or manufacturing defects also can contribute to this.
Insufficient Dielectric strength	Any of the material used inside having inadequate dielectric strength to withstand steady or impulse states can track or flashover. And it will worsen with surge event.
Assembly	Improper verification of internal arrangement as per drawings.

4. Collection of system data and input from field related to situation

- Any additional information like brief history of equipment, last LCM readings, maintenance records etc. were asked from field and final database prepared.

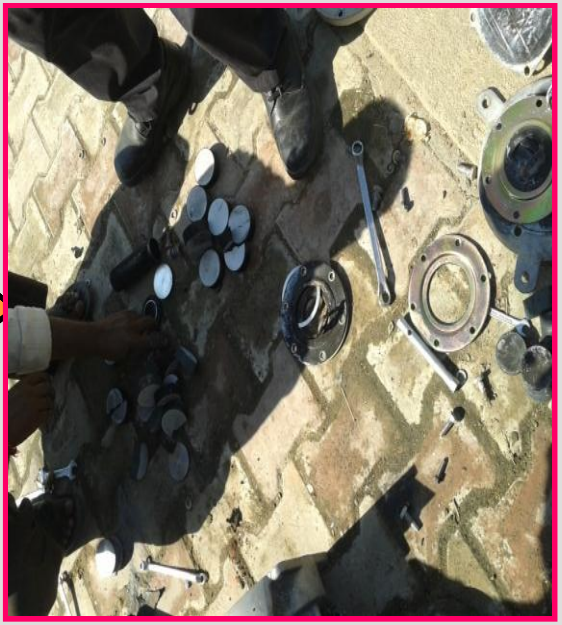
5. Inspection of failed arrestor by dismantling actual arrestor

- During site visit each failed SA was dismantled.
- Photographs of various internal & external parts of SA were taken.
- The condition of various parts of SA is matched with the indicators or symptoms given in matrix.
- Some of the photographs of dismantled SAs, pointing out their root causes of failures are shown here.

Moisture Ingress

Green Copper Oxidation

Cracked Discs



Excessive Internal PD

Multicolor Growth

Corroded Internal Parts

Broken edges & corners

Discoloration of internal parts

Lightning

Cracked & broken porcelain

Punctured ZnO discs

External Flashover

Flashover Marks

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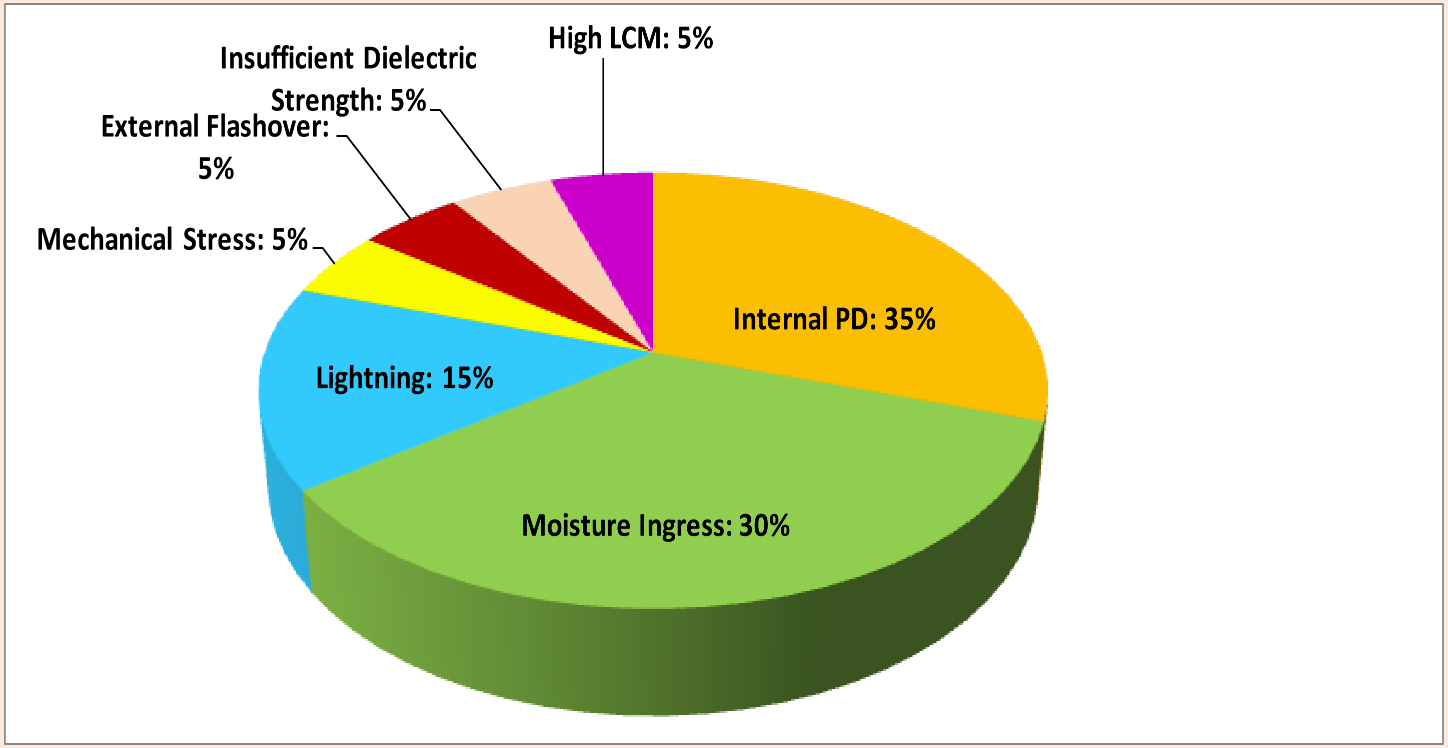
6. Preparation of forensic report and listing out potential root cause

After matching the conditions of failed SA with indicators or symptoms given in the matrix, the potential root causes of 20 nos. of Surge Arrestors are concluded as follows:

[Analysis](#)



Various Case Studies:

Case Study -1

60 kV Line SA at 66 kV Chhaya Substation,
Year of Manu.-2010, Failed on 06.09.2013

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(A)External Inspection

1) Condition of components:

- Bushing & casting found intake.
- No any flashover marks observed .
- Top end cover plate found open.
- Seal damaged.

2)Indicators of failure:

Sealing at top flange found damaged which indicates possibility of moisture ingress inside surge arrester.

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Case Study-1

(B)Internal Inspection:

1) Condition of components:

- ZnO discs found flashover.
- Carbon contamination observed at stack.
- FRP rod found damaged.
- Stack separators and supporters melt partially.
- Spring corroded slightly.
- Gasket found damaged.

2) Indicators of failure:

- Brown rust on metal parts, white rust on aluminium parts, corroded spring and damaged gasket denote entrance of moisture inside.
- Discoloration on some of the discs, multi colored growths on rubber components and colored internal parts were observed which points out possibility of Partial Discharge.

Case Study-1

(C) Root Cause:

Rusting on metal parts and carbon contamination confirm presence of moisture inside surge arrestor. Due to this moisture, partial discharge activity accelerated and finally resulted in thermal runaway of surge arrestor.

Case Study-2

60 KV Line SA at 220 kV Shivlakha Substation,

Year of Manu.-2007, Failed on 24.09.2013:

(A)External Inspection

1) Condition of components:

- Bushing completely broken in pieces
- Both end cover plates damaged

2) Indicators of failure:

Totally broken bushing and end cover plates designate heavy pressure produced inside the surge arrestor.

Case Study-2

(B) Internal Inspection:

1) Condition of components:

- Gaskets totally damaged
- Stack found displaced
- All discs damaged
- Presence of flashover marks on FRP rod
- Stack supporters and few of stack separators partially melted

(C) Root Cause:

There was no lightning stroke at the time of failure but the atmosphere was rainy and humid.

So it is certain that there was an exchange of moist air between atmosphere and surge arrestor which resulted in internal flashover with heavy pressure developed inside.

Due to this acute pressure, bushing was broken into pieces with blast.

Case Study-3

120 KV Capacitor Bank SA at 220 kV Gondal Substation, *Year of Manu.-1999, Failed on 02.04.2013*:

1) Condition of components:

- Flashover marks on bushing
- Castings ,Terminal connectors and terminal bracket & Support insulators broken.
- Bottom portion of surge arrestor damaged completely.

2) Indicators of failure:

Marking of arcs on housing & base envisage possibility of external flashover.

Case Study-3

Root Cause:

As per field report, the surge arrestor was having high leakage current (LCM reading- **444 µA**) which indicates degrading of property of ZnO discs at rated voltage.

Moreover, this surge arrestor was installed at 132 kV **capacitor bank,** so it is prone to frequent switching surges.

In view of this, it can be concluded that during any switching operation the surge arrestor might get failed while withstanding voltage swing and consequently flashed.

Remedial Measures:

Majority of the Surge Arrestors, in quantity, have failed in 66 kV class.
So utilities have to focus on manufacturing, quality and system operation aspects, as the 66 kV Surge Arrestors are closed to distribution system.

The following remedial actions are planned by GETCO:

1) Condition monitoring data shall be recorded in a **live asset management module** and such in built analysis should bring out defective SAs for replacement.
2) Detailed engineering exercise to **select gasket as well as sealing arrangement** is required to be done to improve design.
3) GETCO will carry out this exercise **in association with OEMs & material experts**.
4) The approach will also be to compare 66 kV SA design with 400/220 kV SA designs, with respect to sealing arrangements, constructional features, gasket material etc.

5) It is intended to revise the acceptable limit of Partial Discharge level, measured at 1.05 times Continuous Operating Voltage, from 50 pC to 10 pC.

6) GETCO is also looking forward to implement online leakage current monitoring **(Digital Surge Monitoring)** and to integrate the same with substation automation system.

Conclusion:

The high failure rate of Surge Arrestor has been a matter of concern for GETCO in spite of condition monitoring system in place.

This exercise is useful not only to utilities, but also important to OEM to improve upon design & manufacturing process and become consistent in quality.

Thank You !

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