



Investigation of VLF Test Parameters

Joshua Perkel

Jorge Altamirano

Nigel Hampton

Introduction - why

- IEEE400.2 is in use with recommendations of test times and test voltages
- At the start of the CDFI project there was considerable discussion concerning:
 - Appropriateness of test parameters – how close are the parameters to the “cliff edge”
 - How likely are these parameters to cause subsequent failures in service
- Objective was to examine the effects of test voltage and duration of VLF withstand tests on cable performance.

Introduction – test program

- Field aged cable samples
- Cables from one area within one utility.
 - 15 kV XLPE unjacketed cable
 - 1970 vintage
 - triplex
 - Total length: 1,680 ft
- Test program combines aging at U_0 (1 year) and $2U_0$ (1 year) with multiple applications of high voltage VLF or 60 Hz AC.

Performance Evaluation

Primary Metric

- Survival during ageing and testing

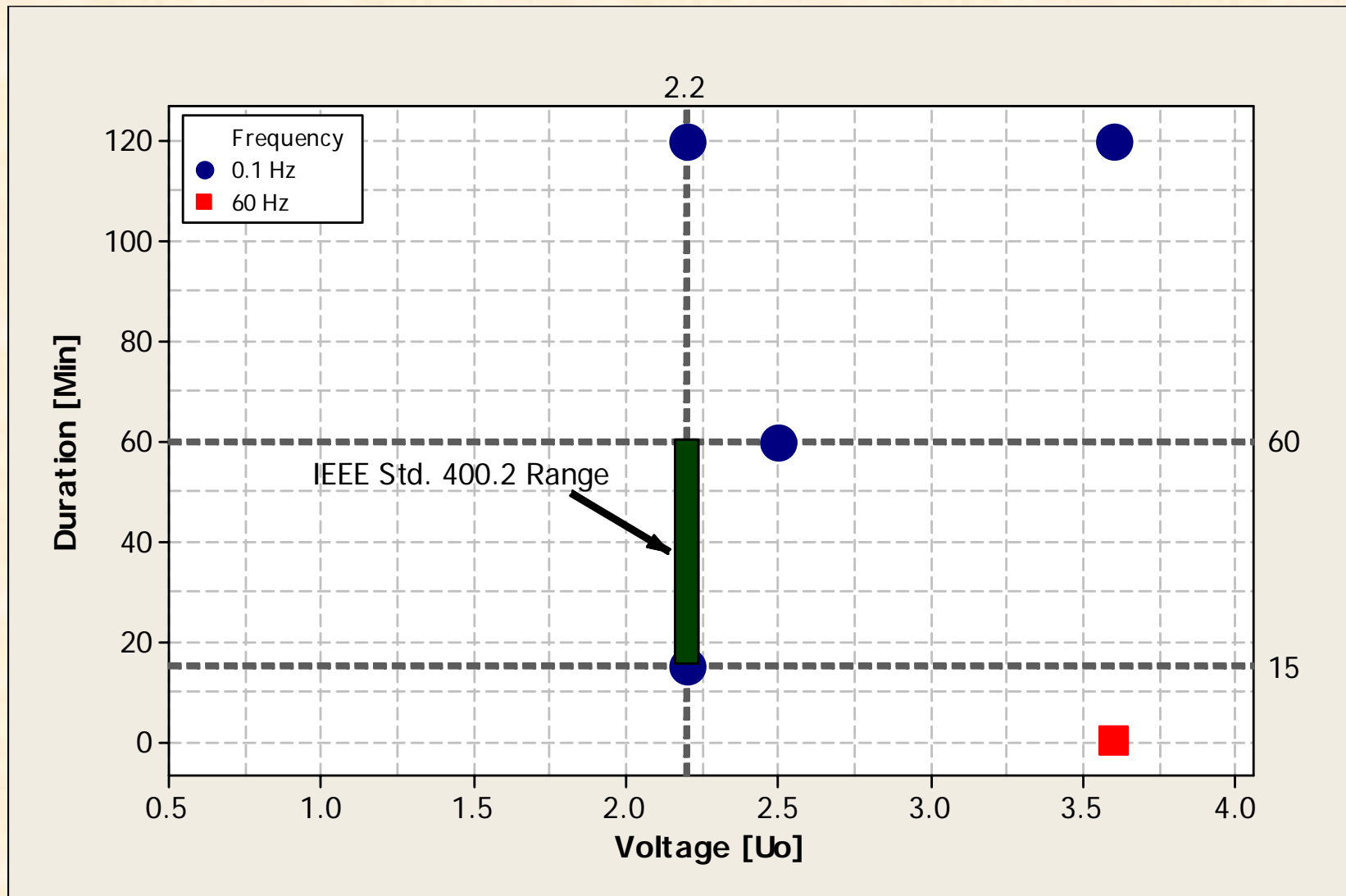
Secondary Metrics

- Before and after each VLF application 60 Hz PD measurement at the ageing voltage (U_0 or $2 U_0$)
- Between Phase A & B IRC, PD (AC $2.2 U_0$, DAC), Tan δ

Test Program Phases

	Phase A	Phase B
Samples	Service Aged XLPE	Phase A Survivors
Ageing Voltage	U_0	$2U_0$
Ageing Temperature	Ambient	45 °C
VLF Voltage Type	Sine 0.1Hz	Cosine-Rectangular 0.1Hz

Test Matrix – Voltages & Times



Laboratory Setup



VLF Units



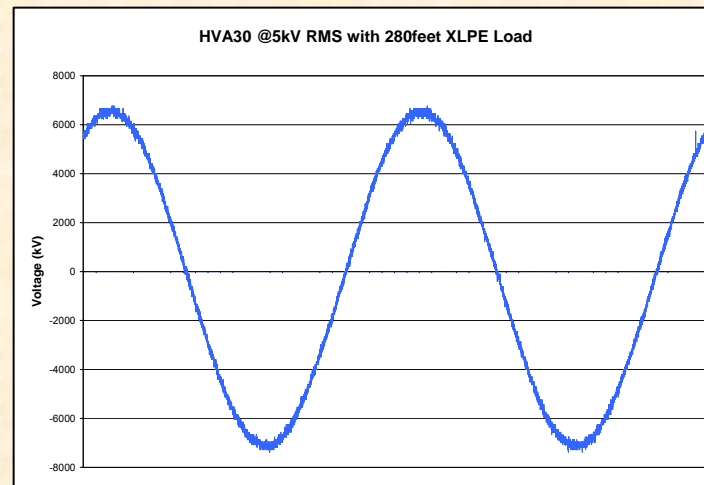
Sinusoidal

Cosine-Rectangular

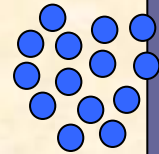


Phase A

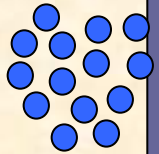
U_0 & Ambient Temp Aging Sinusoidal VLF



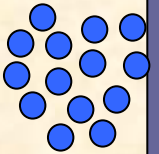
**1: No
Withstand**



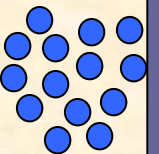
2: VLF
2.2U0
15 Min



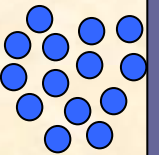
3: VLF
3.6U0
120 Min



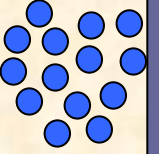
4: VLF
2.5U0
60 Min



5: VLF
2.2U0
120 Min



6: 60 Hz
3.6U0
0.25 Min



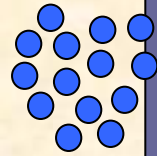
**Withstand Testing Periods
(variable durations)**

**Failures are the
primary metric
for evaluation**

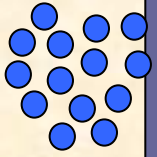
**Phase
A
End**

Conditioning

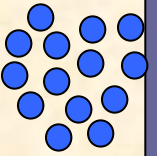
1: No Withstand



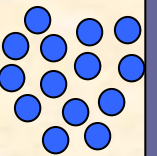
2: VLF
2.2U0
15 Min



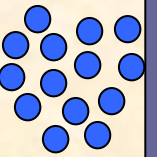
3: VLF
3.6U0
120 Min



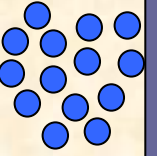
4: VLF
2.5U0
60 Min



5: VLF
2.2U0
120 Min



6: 60 Hz
3.6U0
0.25 Min



T1

T2

T3

T4

1: No Withstand

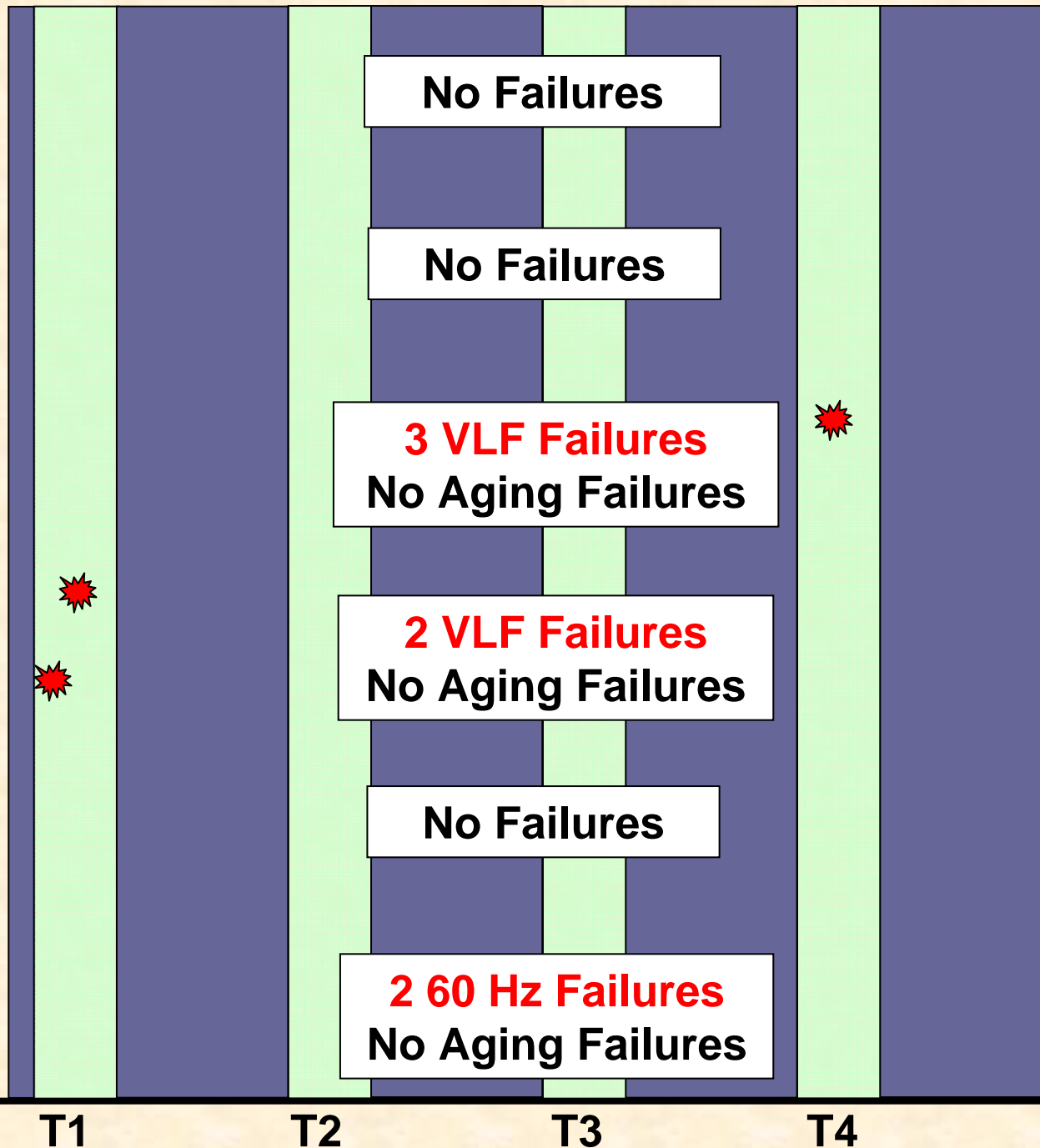
2: VLF
2.2U0
15 Min

3: VLF
3.6U0
120 Min

4: VLF
2.5U0
60 Min

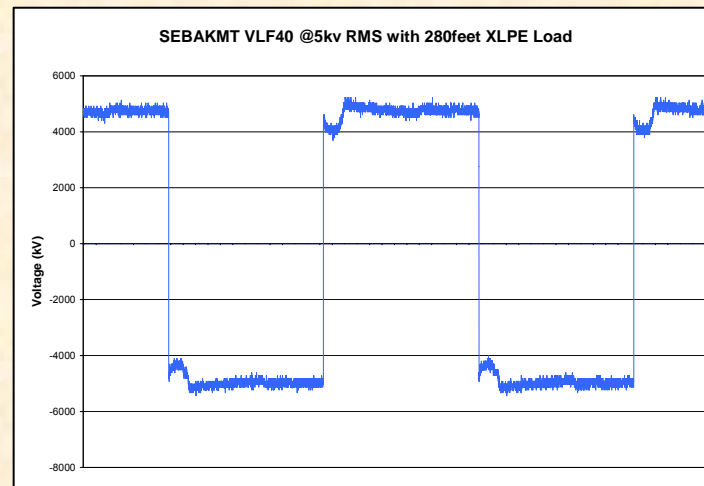
5: VLF
2.2U0
120 Min

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3.6U0
0.25 Min

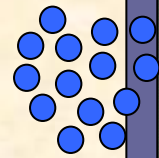


Phase B

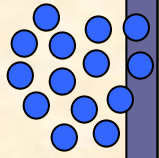
2U₀ & 45 °C Aging
Cosine-Rectangular VLF



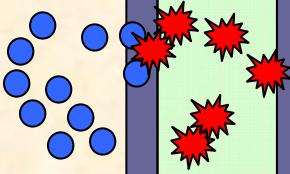
1: No Withstand



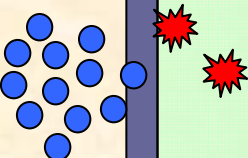
2: VLF
2.2U0
15 Min



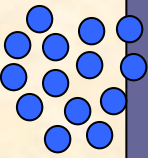
3: VLF
3.6U0
120 Min



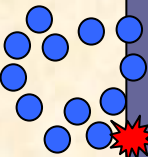
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2.5U0
60 Min



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2.2U0
120 Min



6: 60 Hz
3.6U0
0.25 Min



T1

T2

T3

T4

**Phase
B
End**

1: No Withstand

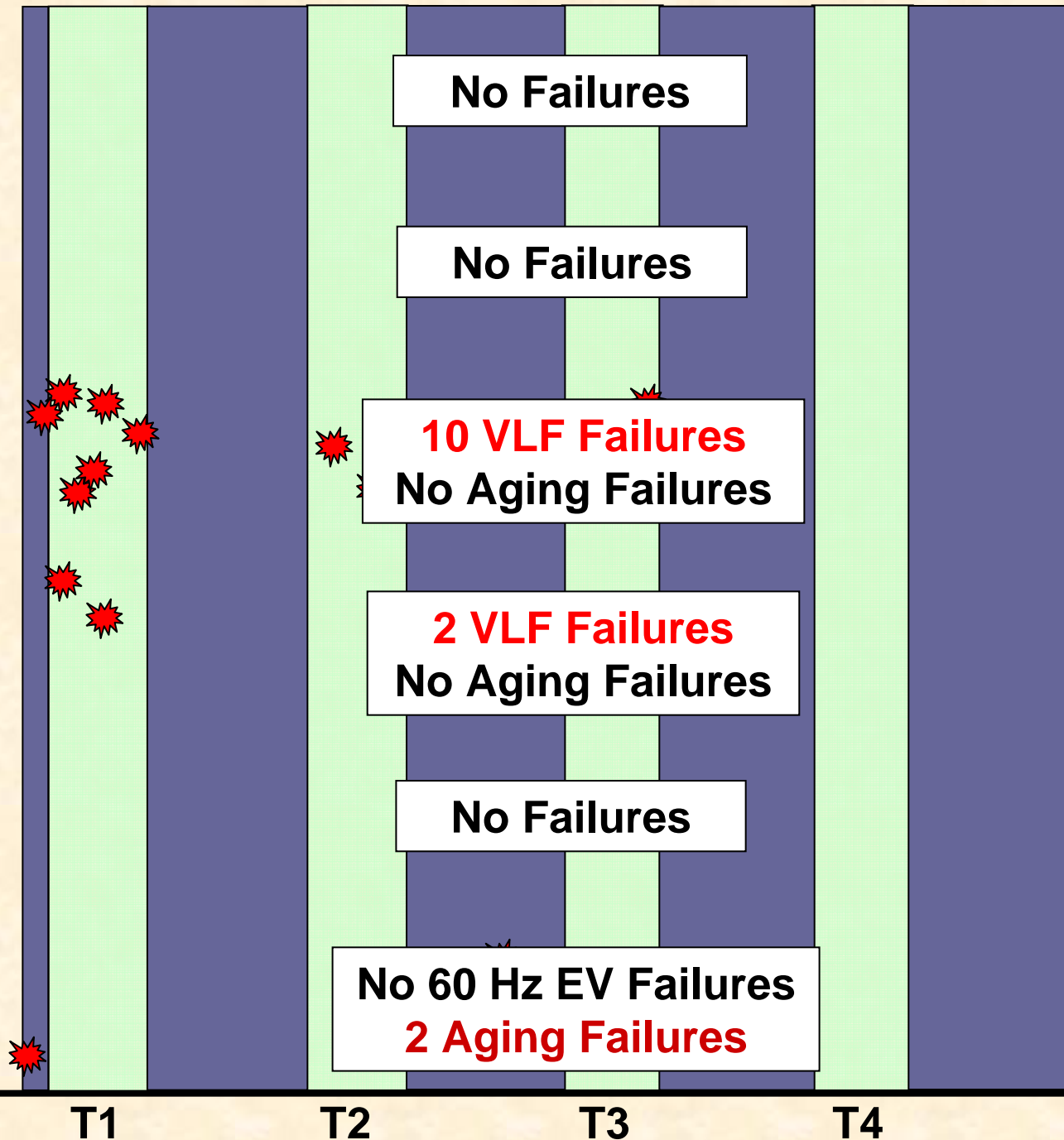
2: VLF
2.2U0
15 Min

3: VLF
3.6U0
120 Min

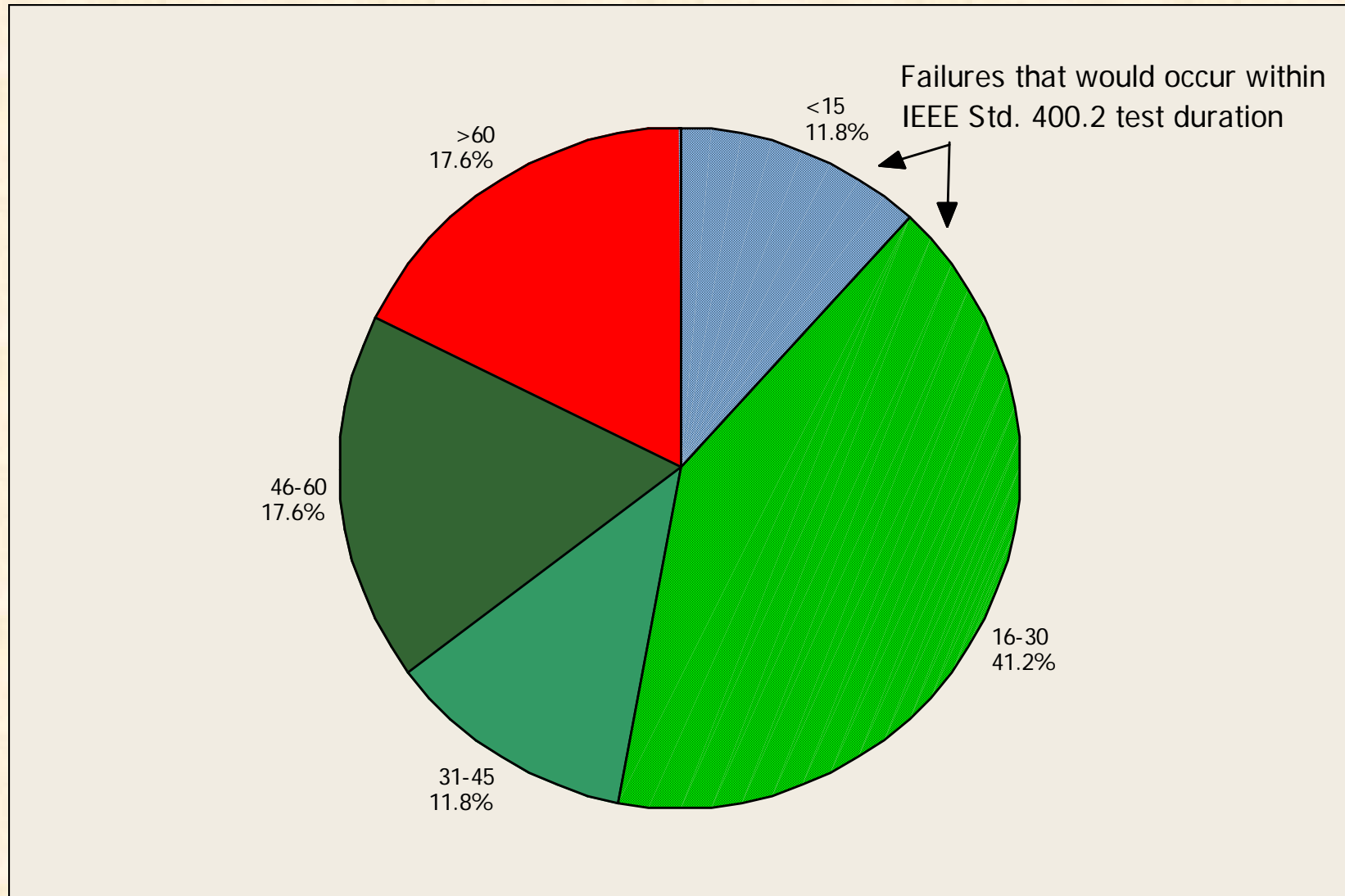
4: VLF
2.5U0
60 Min

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2.2U0
120 Min

6: 60 Hz
3.6U0
0.25 Min



Failures on Test – When do they happen?



**1: No
Withstand**

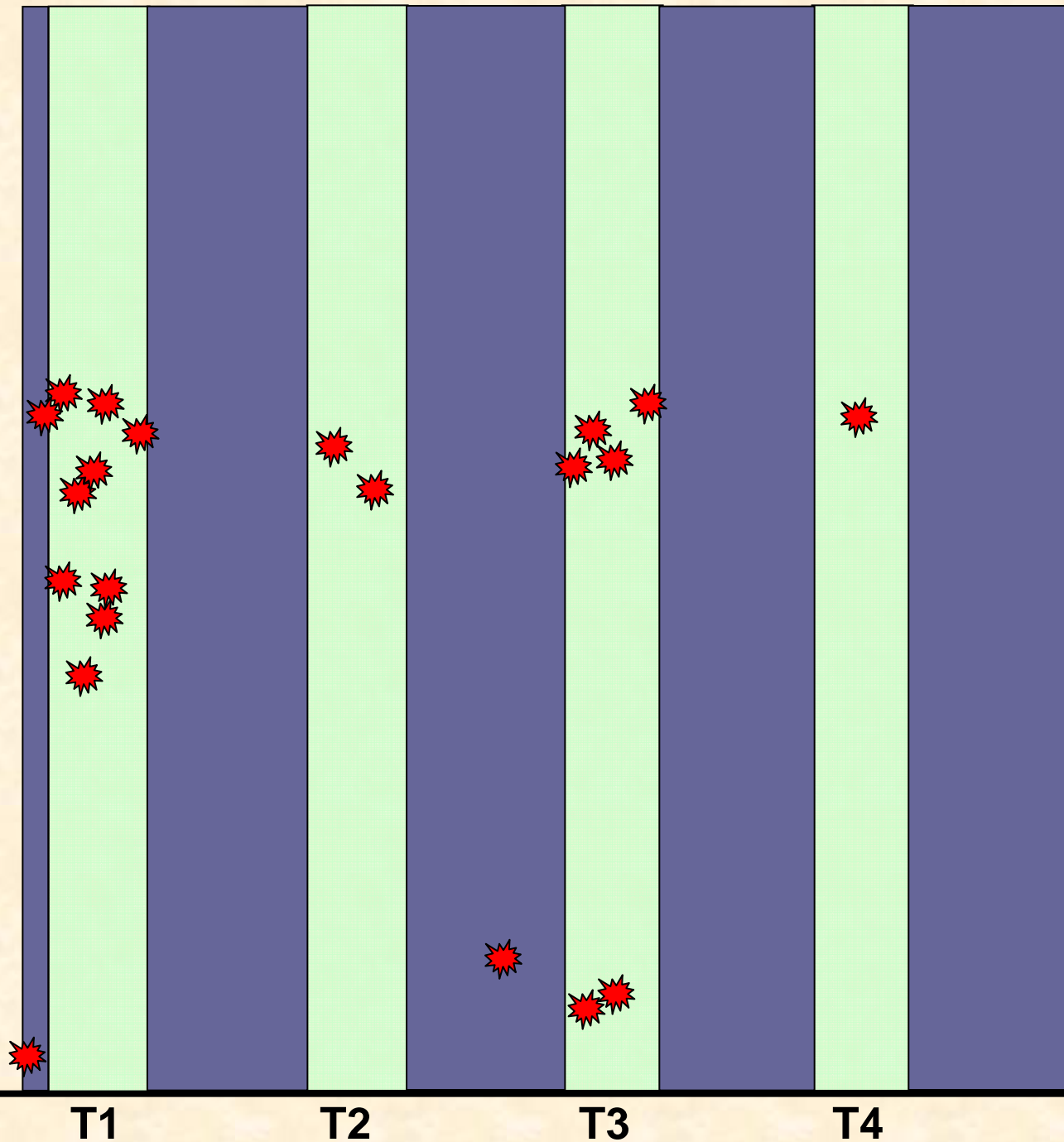
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2.2U0
15 Min

3: VLF
3.6U0
120 Min

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60 Min

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2.2U0
120 Min

6: 60 Hz
3.6U0
0.25 Min



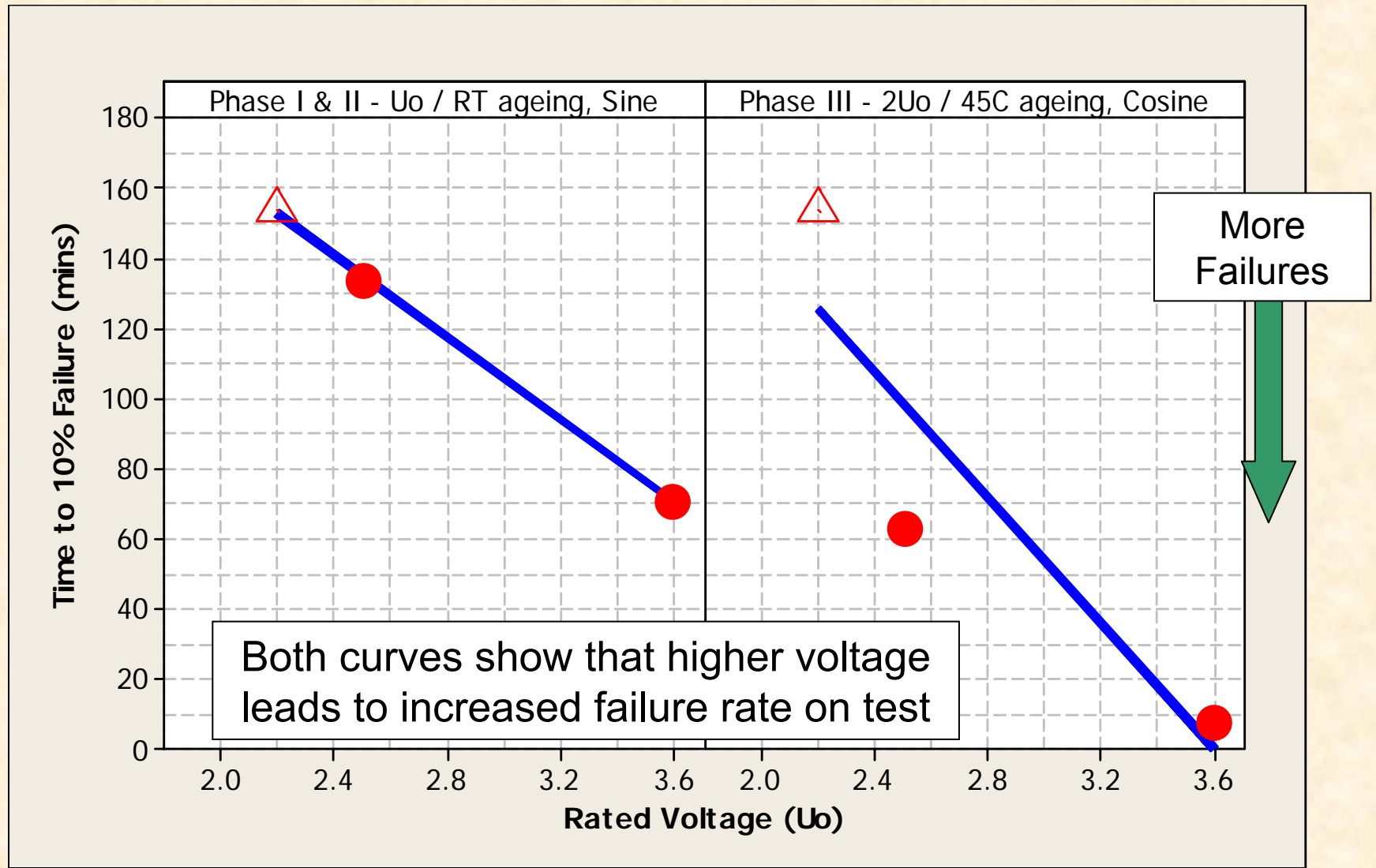
T1

T2

T3

T4

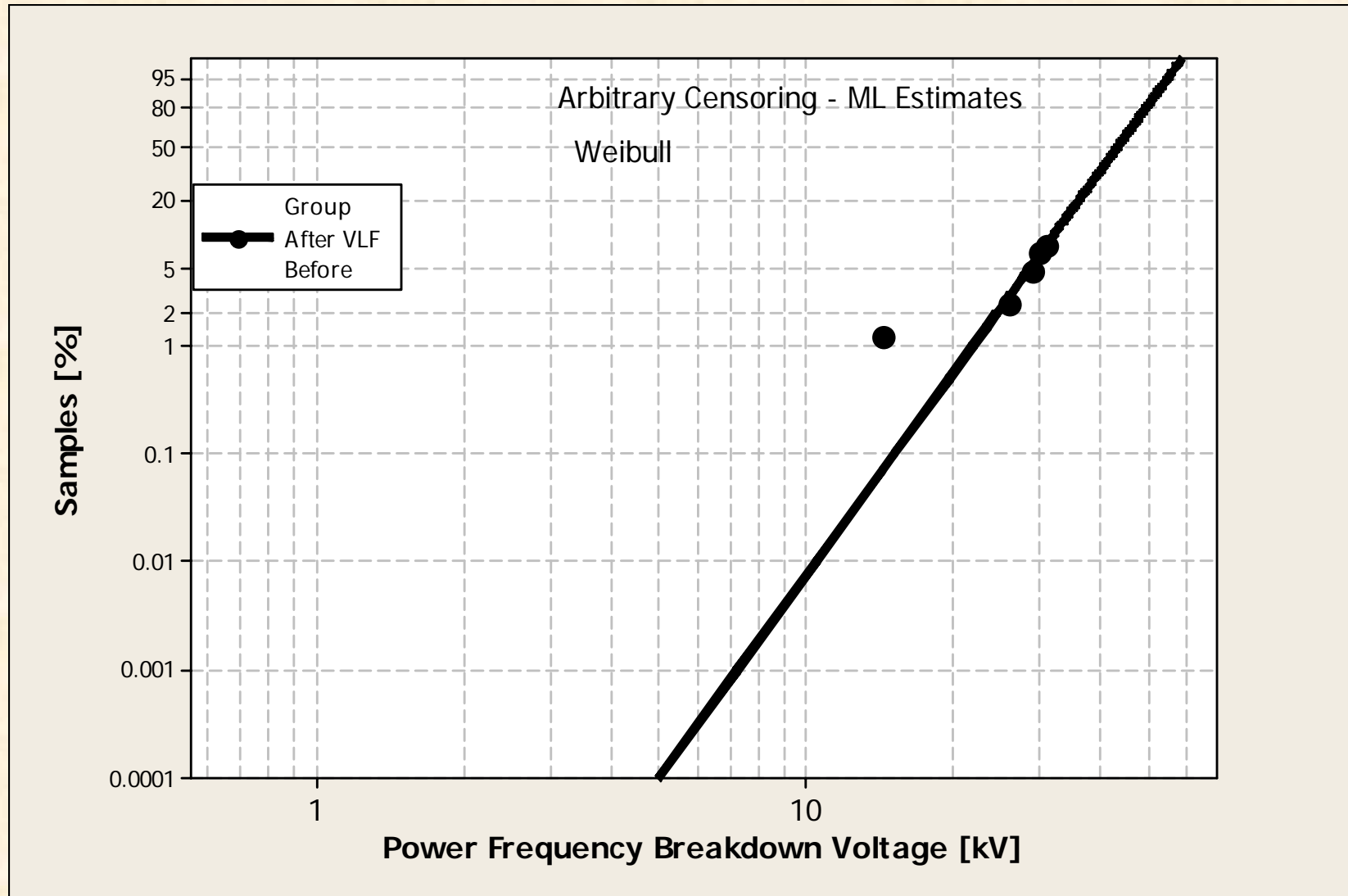
Voltage Effect on Times to Failure



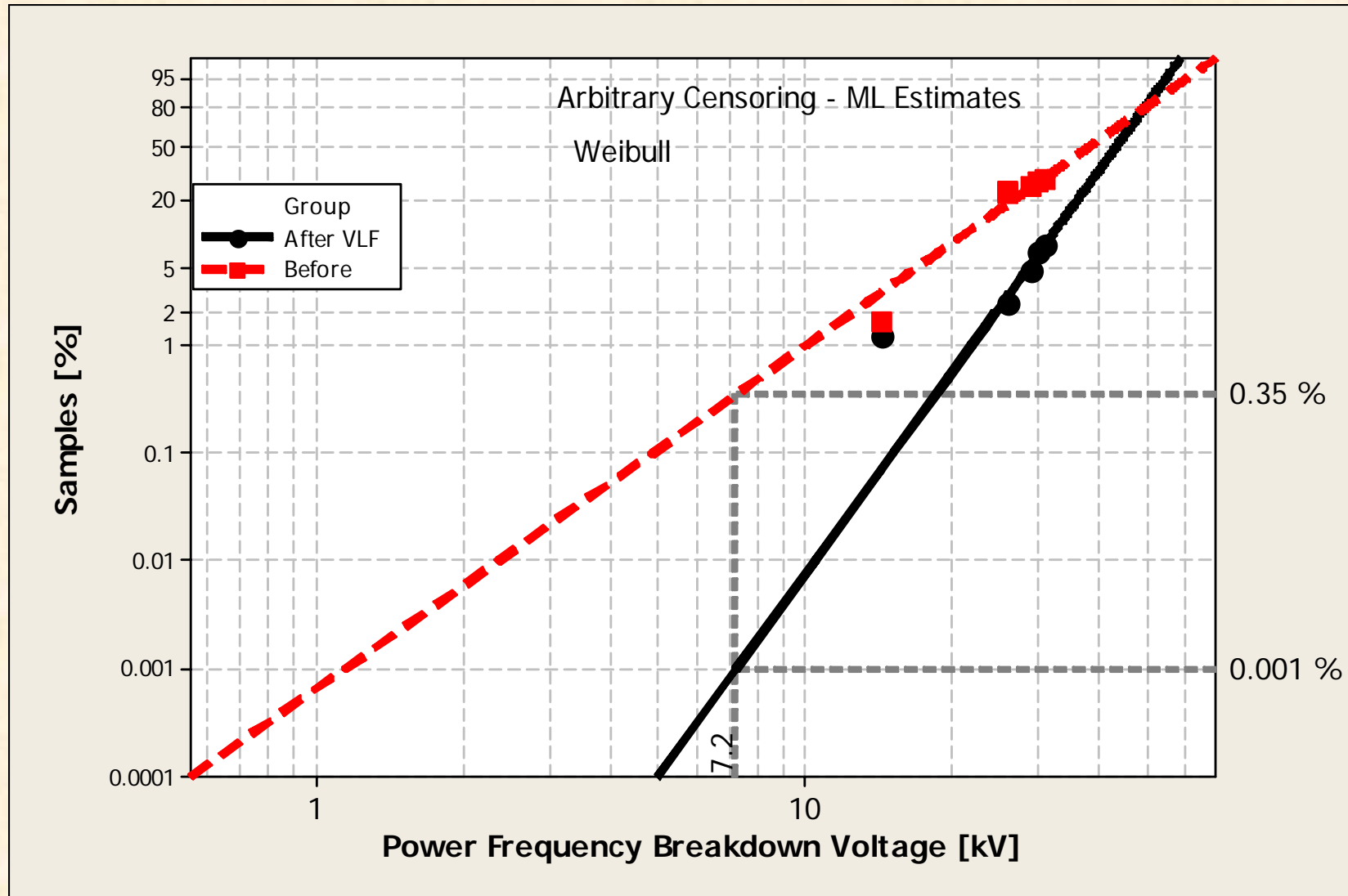
What can we say about the cables

- After the tests in situ 60Hz breakdown test was conducted
- Because we know when failures occurred we can make some reasonable estimates of the range of 60Hz stresses for these
- Thus
 - Can measure – strength after tests
 - Can infer – strength before

Breakdown Performance



Breakdown Performance



VLF Test Program Summary

- Phase A (U_0 aging, 20°C Sinusoidal) and Phase B ($2U_0$ aging, 45°C Cosine-Rectangular) are complete.
- No VLF exposed samples have failed under 60 Hz aging @ U_0 & $2U_0$.
- VLF failure occurrence did not increase with sequential application
- VLF failures on test:
 - Less than 15 mins: 12 % (2 failures)
 - 15 – 60 mins: 71 % (12 failures)
- Estimates of the breakdown performance with and without VLF show that the VLF tested samples improved.

What does this tell us?

- IEEE400.2 voltages are quite some way from the “cliff edge”
- Great care needs to be used if voltages higher than IEEE400.2 are used
- Test times of 15 mins or less leave many weak spots in place
- 30 mins seems a practical compromise
- Little benefit from going to 60 mins
- Repeated VLF exposure does not cause failure under subsequent AC

