NEETRAC
National Electric Energy Testing, Research, and Applications Center

IEEE PES Power & Energy Society®

Survival Performance of New and Aged Temporary Protective Grounds

J.C. Hernandez-Mejia, Anil Poda, Caryn Riley
NEETRAC

Notice

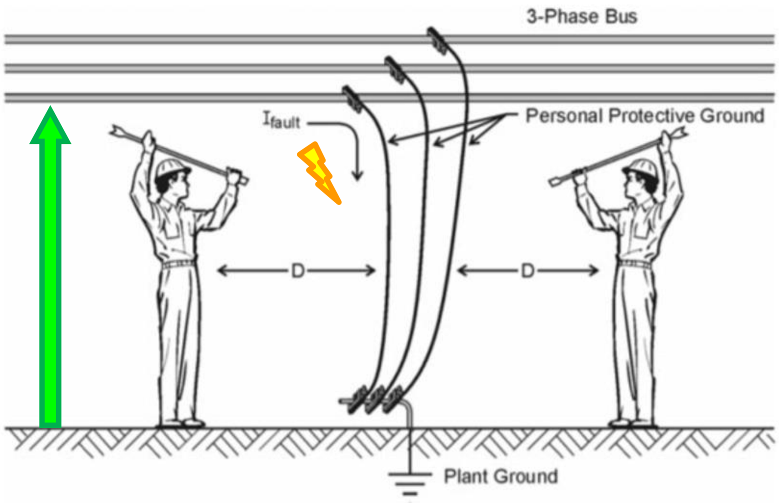
The information contained herein is, to our knowledge, accurate and reliable at the date of publication.

Neither GTRC nor The Georgia Institute of Technology nor NEETRAC shall be responsible for any injury to or death of persons or damage to or destruction of property or for any other loss, damage or injury of any kind whatsoever resulting from the use of the project results and/or data.

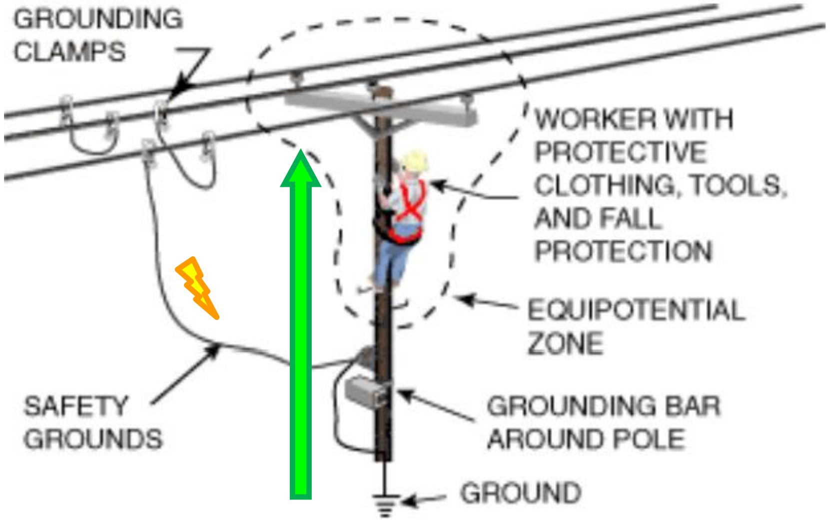
GTRC, GIT and NEETRAC disclaim any and all warranties, both express and implied, with respect to analysis or research or results contained in this report.

It is the user's responsibility to conduct the necessary assessments in order to satisfy themselves as to the suitability of the products or recommendations for the user's particular purpose. No statement herein shall be construed as an endorsement of any product, process or provider.

What does a TPG do?



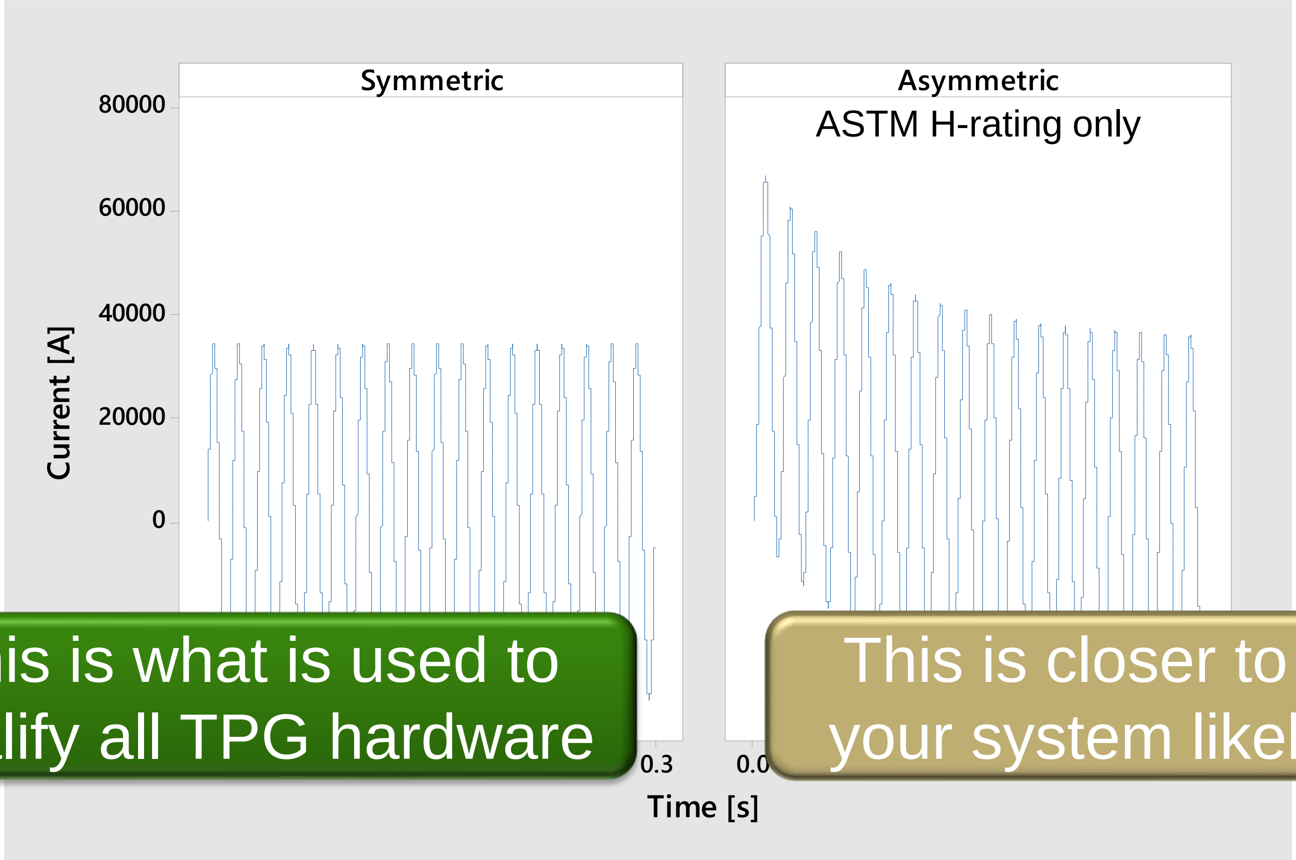
https://testguy.net/content/269-Applying-and-Removing-Protective-Grounds



https://www.osha.gov/etools/electric-power/hazardous-energy-control/equipotential-zone

Provide an equipotential zone is a work zone in which the worker is protected from electric shock from differences in electric potential between objects in the work area

Symmetric & Asymmetric Fault Tests



This is what is used to qualify all TPG hardware

This is closer to what your system likely has

Historical TPG Tests

- Review conducted of all TPG fault testing performed by NEETRAC and supportive members
  - 14 projects in total
  - Covers projects 1996 – 2021
  - ≈470 separate fault tests
  - Many different hardware and configurations tested
  - Tests performed according to ASTM F855
  - 80% of tests utilized asymmetric fault currents

ASTM F855 Symmetric & Asymmetric Fault Tests

TABLE 1 Protective Ground Cable, Ferrule, Clamp and Assembly Ratings for Symmetrical Current

Grade	Grounding Clamp Torque Strength, min				Short Circuit Properties[A]							Continuous Current Rating, A RMS, 60 Hz
	Yield[B]		Ultimate		Withstand Rating, Symmetrical kA RMS, 60 Hz			Ultimate Rating Capacity[CD], Symmetrical kA RMS, 60 Hz				
	lbf·in.	n·m	lbf·in.	n·m	15 cycles (250 ms)	30 cycles (500 ms)	Copper Cable Size	15 cycles (250 ms)	30 cycles (500 ms)	60 cycles (1 s)	Maximum Copper Test Cable Size	
1	280	32	330	37	14	10	#2	18	13	9	2/0	200
2	280	32	330	37	21	15	1/0	29	21	14	4/0	250
3	280	32	330	37	27	20	2/0	37	26	18	4/0	300
4	330	37	400	45	34	25	3/0	47	33	23	250 kcmil	350
5	330	37	400	45	43	30	4/0	59	42	29	250 kcmil	400
6	330	37	400	45	54	39	250 kcmil or 2 2/0	70	49	35	350 kcmil	450
7	330	37	400	45	74	54	350 kcmil or 2 4/0	98	69	48	550 kcmil	550

[A] Withstand and ultimate short circuit properties are based on performance with surges not exceeding 20 % asymmetry factor (see 9.1 and 12.3.4.2).
[B] Yield shall mean no permanent deformation such that the clamp cannot be reused throughout its entire range of application.
[C] Ultimate rating represents a symmetrical current which the assembly or individual components shall carry for the specified time.
[D] Ultimate values are based upon application of Onderdonk's equation to 98 % of nominal circular mil area allowed by Specifications B172 and B173.

NOTE 1—TPG testing is done on complete assemblies. Assembly ratings assume the grade of lowest graded component (see 43.1.6).

Table 1
X/R = 1

TABLE 2 Ultimate Assembly Rating for High X/R Ratio Applications

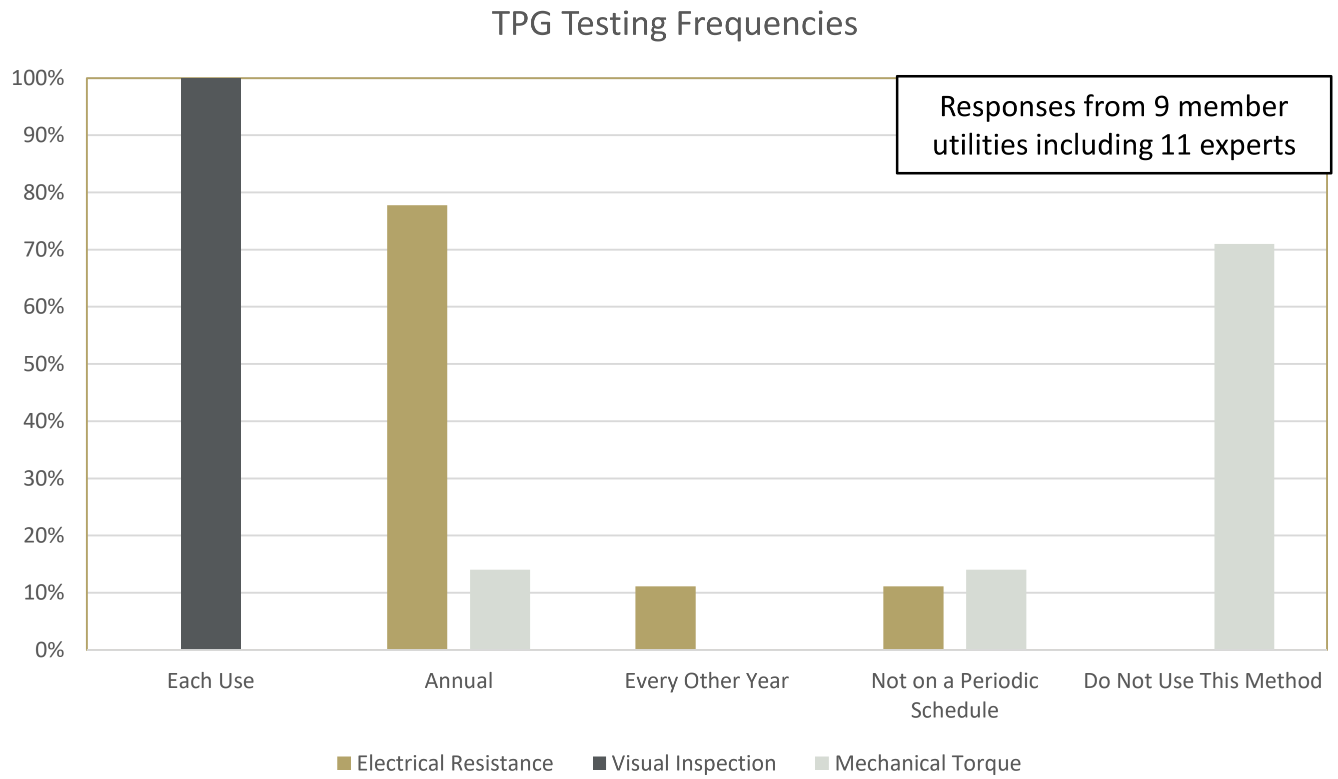
Grade Size	Rating Rated Current (kA)	High Asymmetrical Test Requirements X/R = 30 Cycle Current Peak Values (kA) Rating X 2.69															Test Duration (cycles)	I^2t (Mega amps²-s)
		1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th		
1H	15	41	37	34	32	30	28	27	26	25	25	24	24	23	23	23	15	74
2H	25	68	62	57	53	50	47	45	43	42	41	40	39	38	38	38	15	208
3H	31	84	76	70	65	61	58	56	53	52	50	49	48	47	47	46	15	312
4H	39	105	96	88	82	77	73	70	67	65	63	62	61	60	59	58	15	501
5H	47	127	116	106	99	93	88	84	81	78	76	74	73	72	71	70	15	728
6H	55	148	135	124	116	109	103	98	94	91	89	87	85	84	83	82	15	997
7H	68	183	167	154	143	134	127	121	117	113	110	107	105	104	102	101	15	1523

NOTE 1—The above current values are based on electromechanical test values.
NOTE 2—Assemblies that have been subjected to these shall not be re-used.
NOTE 3—For use with currents exceeding 20 % asymmetry factor.
NOTE 4—See X4.7.2 for additional information.
NOTE 5—Alternate testing circuits are available for laboratories that cannot achieve the above requirements. See Appendix X4 for details.

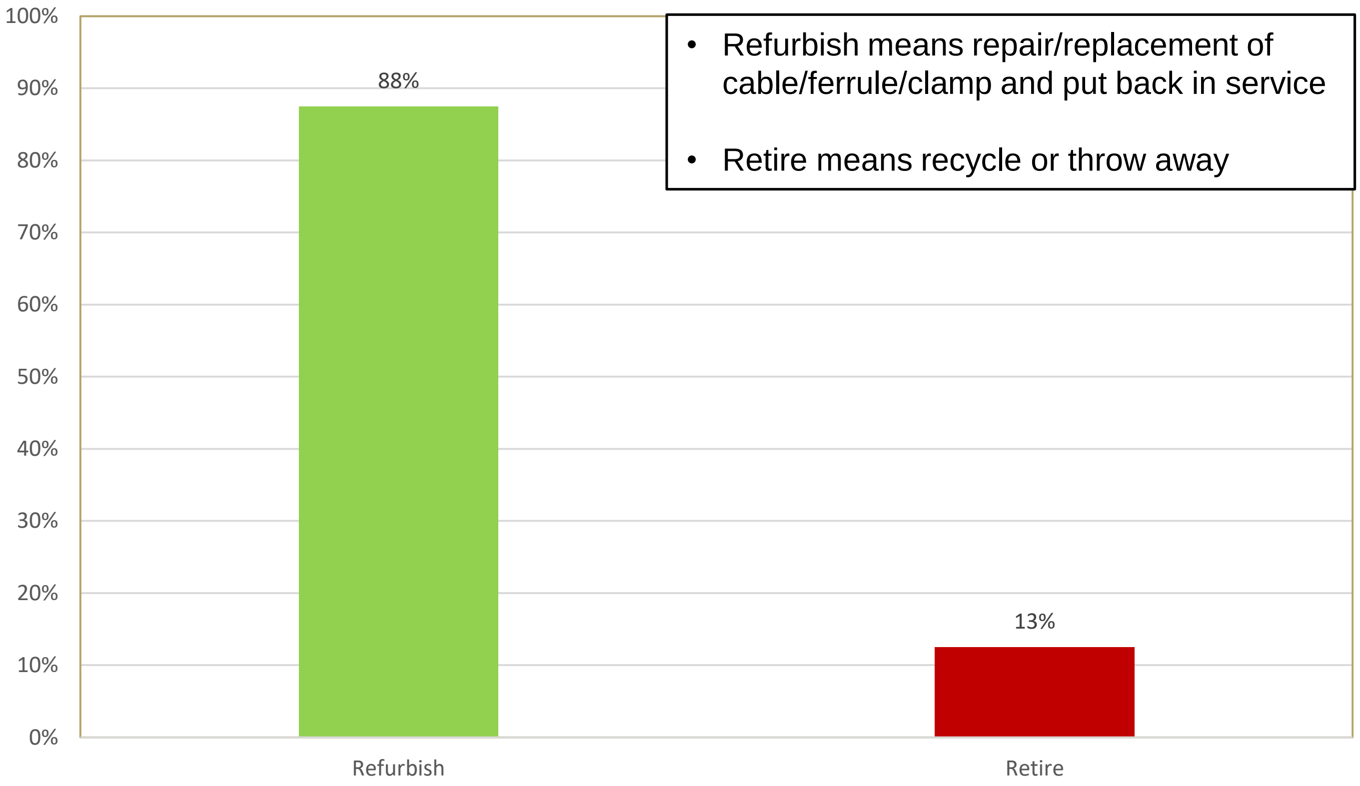
Extracted from ASTM F855-2015: Standard Specifications for Temporary Protective Grounds to be Used on De-Energized Electric Power Lines and Equipment

Table 2
X/R = 30

TPG Maintenance Practices

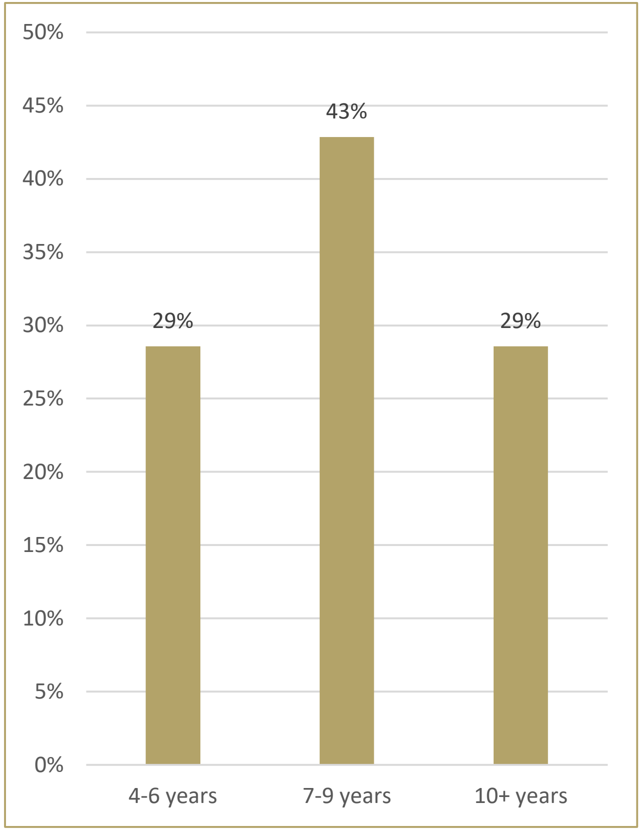


What happens to TPG's that Fail Testing?

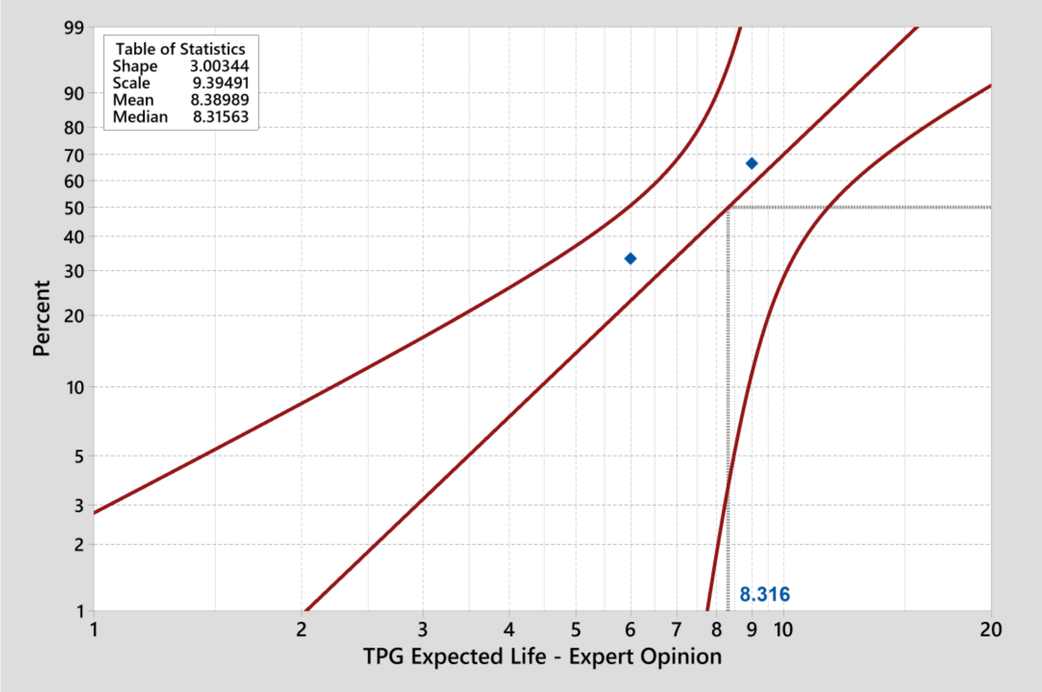


- Refurbish means repair/replacement of cable/ferrule/clamp and put back in service
- Retire means recycle or throw away

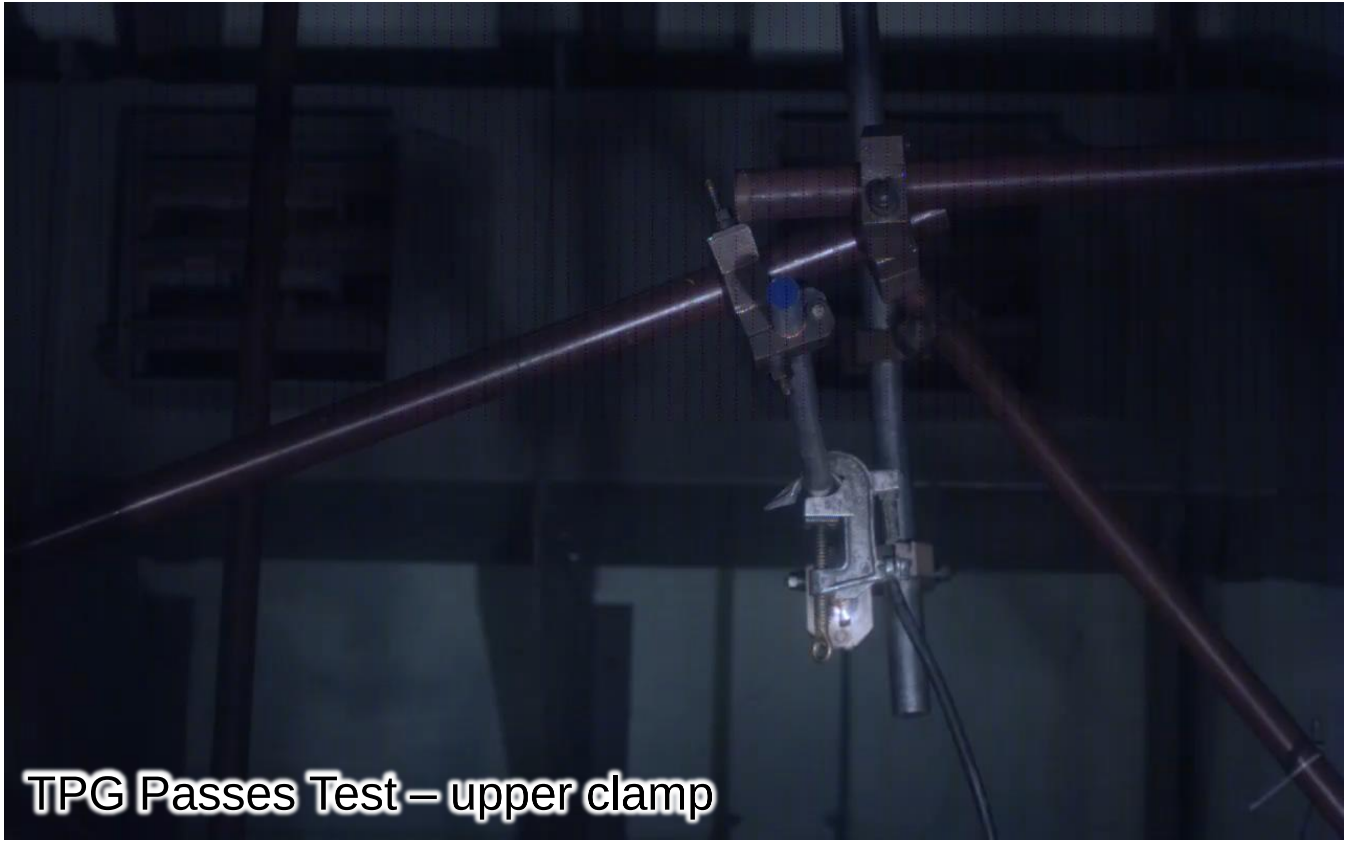
TPG Lifetime Expectation



Weibull Compounded Expert Opinion – TPG Life Estimate

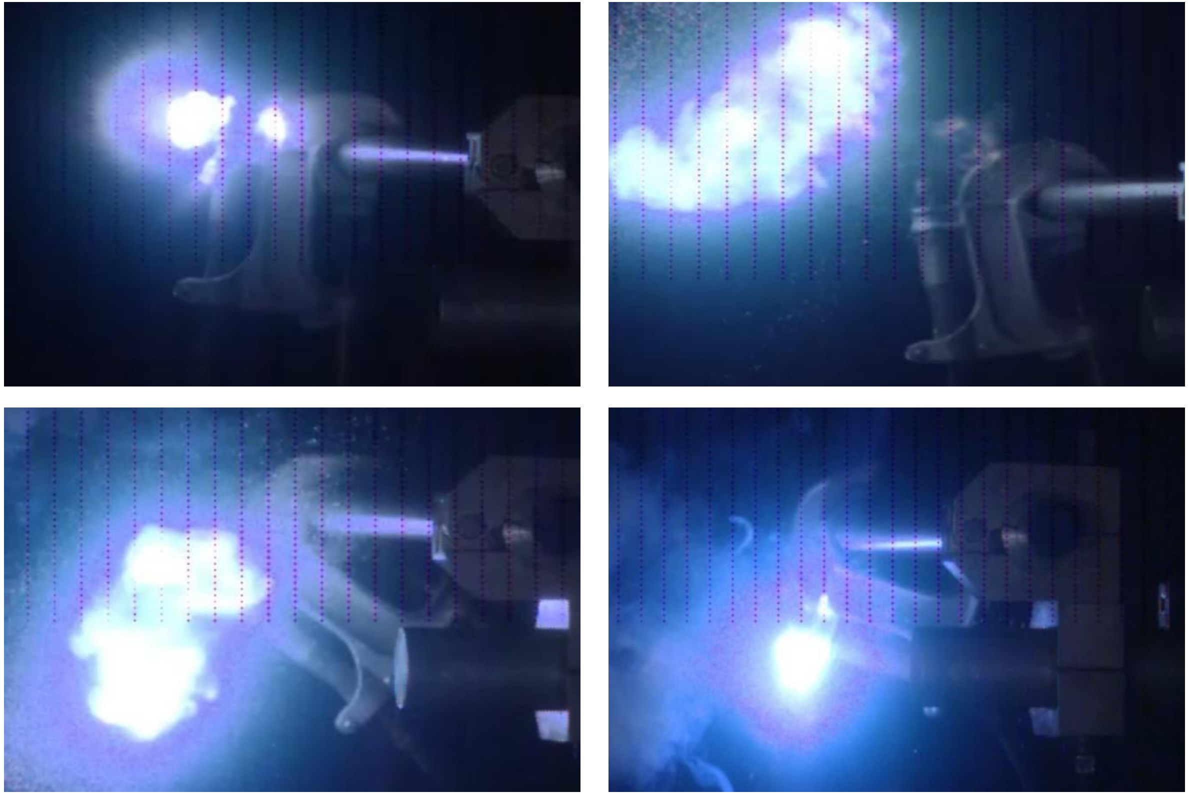


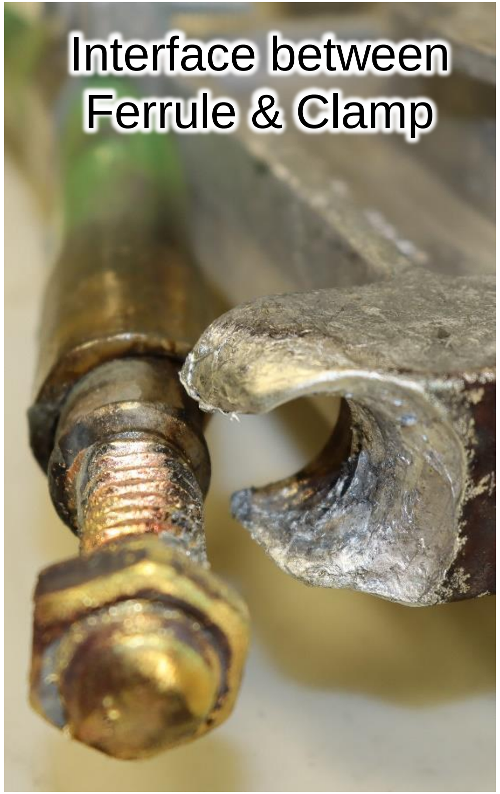
Example – High Speed Camera



Example – High Speed Camera

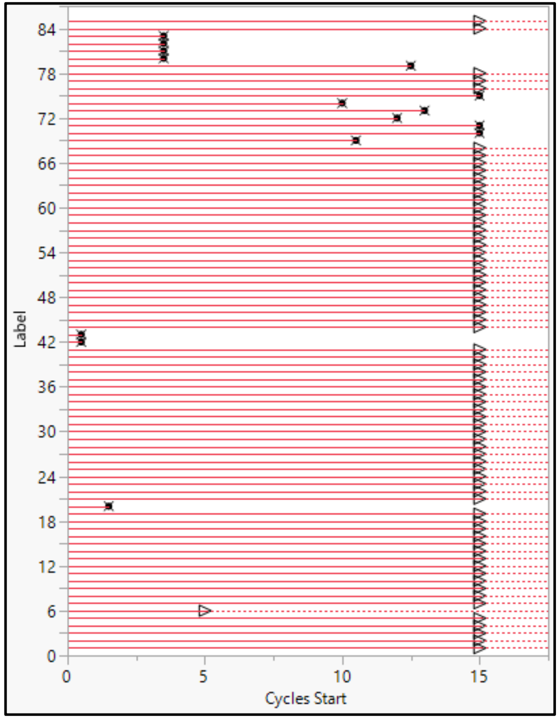
Aged TPGs – Most Common Failure Mode





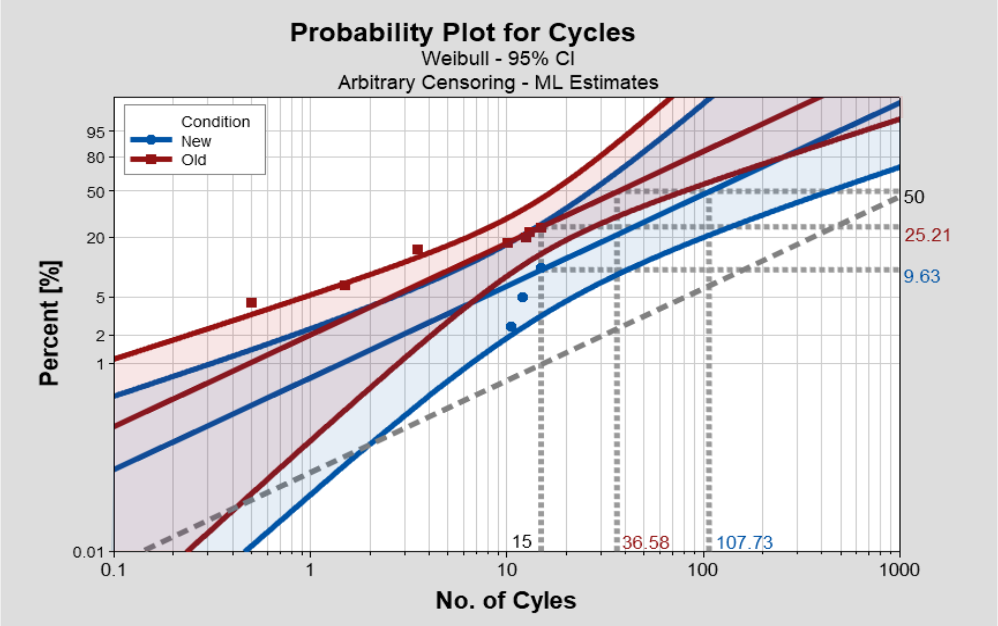
Performance Assessment - Overall

Event Plot

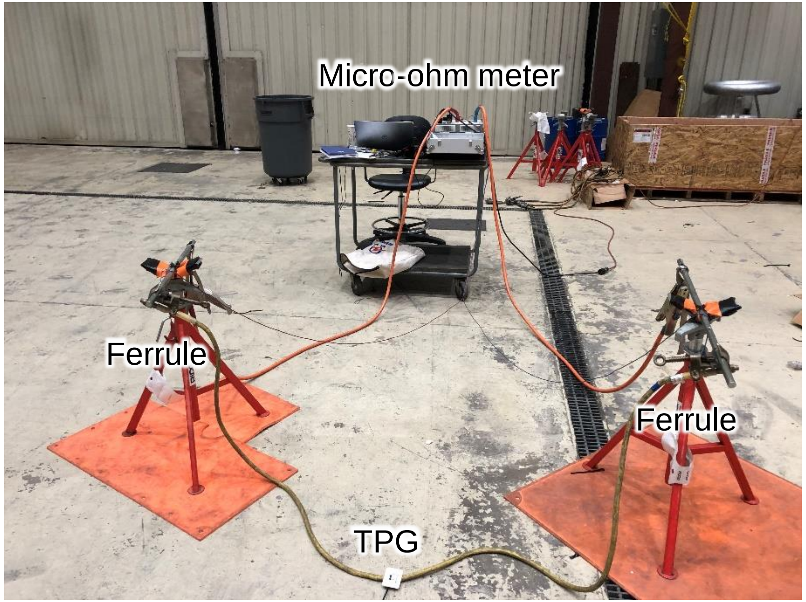


Best Case Scenario – Survival Samples consider as suspensions

Analysis considering only actual failures is being conducted



Pre-diagnostics – dc Resistance



F2249 – $20^{\varepsilon 1}$

TABLE X2.3 R_{max} Limits – DC Resistance (mΩ) (Cable + Terminations)

Cable Length (ft)	#2 Cable			1/0 Cable			2/0 Cable			4/0 Cable		
	5°C (41°F)	20°C (68°F)	35°C (95°F)	5°C (41°F)	20°C (68°F)	35°C (95°F)	5°C (41°F)	20°C (68°F)	35°C (95°F)	5°C (41°F)	20°C (68°F)	35°C (95°F)
1	0.48402	0.49430	0.50458	0.42276	0.42920	0.43564	0.40240	0.40757	0.41274	0.37178	0.37502	0.37826
2	0.64804	0.66860	0.68916	0.52553	0.53840	0.55127	0.48481	0.49514	0.50547	0.42355	0.43004	0.43653
3	0.81206	0.84290	0.87374	0.62829	0.64760	0.66691	0.56721	0.58271	0.59821	0.47533	0.48506	0.49479
4	0.97608	1.01720	1.05832	0.73105	0.75680	0.78255	0.64962	0.67028	0.69094	0.52710	0.54008	0.55306
5	1.14010	1.19150	1.24290	0.83382	0.86600	0.89818	0.73202	0.75785	0.78368	0.57888	0.59510	0.61132
6	1.30412	1.36580	1.42748	0.93658	0.97520	1.01382	0.81442	0.84542	0.87642	0.63065	0.65012	0.66959
7	1.46814	1.54010	1.61206	1.03934	1.08440	1.12946	0.89683	0.93299	0.96915	0.68243	0.70514	0.72785
8	1.63216	1.71440	1.79664	1.14211	1.19360	1.24509	0.97923	1.02056	1.06189	0.73420	0.76016	0.78612
9	1.79618	1.88870	1.98122	1.24487	1.30280	1.36073	1.06164	1.10813	1.15462	0.78598	0.81518	0.84438
10	1.96021	2.06300	2.16580	1.34764	1.41200	1.47637	1.14404	1.19570	1.24736	0.83776	0.87020	0.90265

$$Rm = 1.05\,RL + 2Y \text{ m}\Omega$$

To be correlated with High Power Test Results

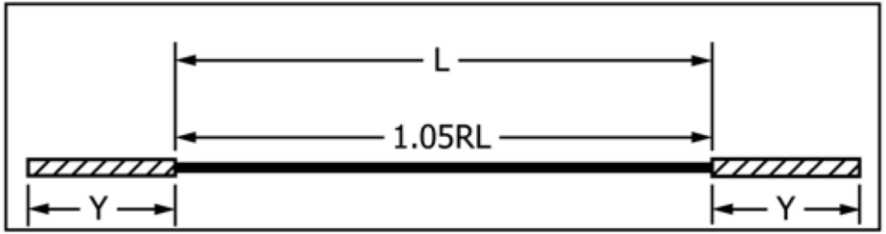


FIG. 1 Resistance and Impedance of Copper Grounding Jumper Assemblies

Correlation Between Performance and Diagnosis

New

Prediction \ Performance	Pass	Fail
Pass	35	3
Fail	1	1

Aged

Prediction \ Performance	Pass	Fail
Pass	17	5
Fail	17	6

All

Prediction \ Performance	Pass	Fail
Pass	52	8
Fail	18	7

Case	T_{corr}	False + Err [%]	False - Err [%]
New	0.75	2.5	7.5
Aged	0.07	38.0	11.0
Both	0.35	21.2	9.4

Main Project Takeaways - Benchmarking

- All TPGs are visually inspected before each use – general indications only
- Approx. 80% of utilities perform an annual dc resistance test to diagnose their TPGs. Only ~15% also use the mechanical torque test annually
- According to expert opinion, the expected life of a TPG (B50) is approx. 8 years, 10% (B10) of TPGs are retired/refurbished in 2 years while 80% (B80) are retired/refurbish in 12 years
- Approx. 90% of TPGs that fail the dc resistance or torque tests are refurbished for reuse

Main Project Takeaways - Tests

- There are substantial differences between the energy (I^2t) of the symmetrical and asymmetrical (ASTM H-rating) fault current tests for the same RMS target value
- Bronze flat clamps (regardless of TPG's age condition) failed at higher failure events than the other clamp types
- Longer TPGs showed to have lower failure rates – this may be related to the additional inertia they pose to damp violent ferrule movements
- In median terms, New TPGs showed lower probability of failure (~ 1.5 times smaller) when compared with Aged TPGs

Main Project Takeaways - Tests

- The dc resistance test as currently deployed may not be a good predictor for diagnosing Aged TPGs. It was better correlated with New TPG performance but exhibited considerable False+ and False- errors
- The weakest part of an aged TPG assembly seemed to be the galvanic interface between the clamp and the ferrule followed by interface between the ferrule and the cable

Open Issues and Potential Future Work

- There are still open issues that remain and may be addressed by future work, such as:
  - What are the forces or strength capabilities of the grounding assemblies during fault current conduction?
  - Are there any applicable diagnostics tools with better prediction performance?
  - What is the impact of installation torque? In the field? Is it a factor?
  - What about dc applications?
  - Understanding of contact resistances (ferrules to cable & ferrule to clamp) as assessment criteria – Why is *Y* (below) 16 mΩ?

$$Rm = 1.05\,RL + 2Y \text{ m}\Omega$$

The resistance of Y in the Rm (Eq 2) has been determined by conservative analysis of the data to be 0.16 mΩ. This value is below the "fusing range" of cables that passed the fault tests. The value of $Y = 0.16$ mΩ or $2Y = 0.32$ mΩ for all cable sizes.

Thank you for your attention

Questions?