Shorter Duration Accelerated Cable Tests for High-Performance TR-XLPE Insulations

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Cable Aging with Reduced-Wall TR-XLPE

- Aging cables of Reduced-wall TR-XLPE
  - drivers – aging acceleration for high performance material evaluations
  - stress enhancement
- ACLT
  - Lifetime
  - Generalized water treeing assessment
- AWTT
  - 120-day aging, breakdown stress and breakdown voltage
- “Modified” TR-XLPE
  - An attempt to further improve TR-XLPE performance
- Conclusions

Drivers for Reduced Wall Aging

- Reduce the aging times for accelerated aging
  - Accelerated cable life test using today's clean, conventional semicons and TR-XLPE can lead to test duration > 1 year… too long.
  - Reduced times needed for timely development of more robust insulation materials
- Enhanced stress for cable water-treeing test
  - includes effect of semicons vs. "material" WTGR test (ASTM D-6097)

Reduced-wall TR-XLPE Cables for ACLT

- Cable Manufacturing (2001)
  - 1/0 stranded Al
  - 15 mil clean, conventional conductor shield
  - 40 mil strippable insulation shield
  - Tooling sized to make 150 mil insulation and allow draw-down to 110 mil
  - Reduced-wall cables made on 1+2 triple, dry CV line
  - copper mesh applied as neutral

Stress Enhancement in Reduced-wall "4,4" ACLT

Reduced-wall cables with #1/0 conductor: 34.6kV Test Voltage

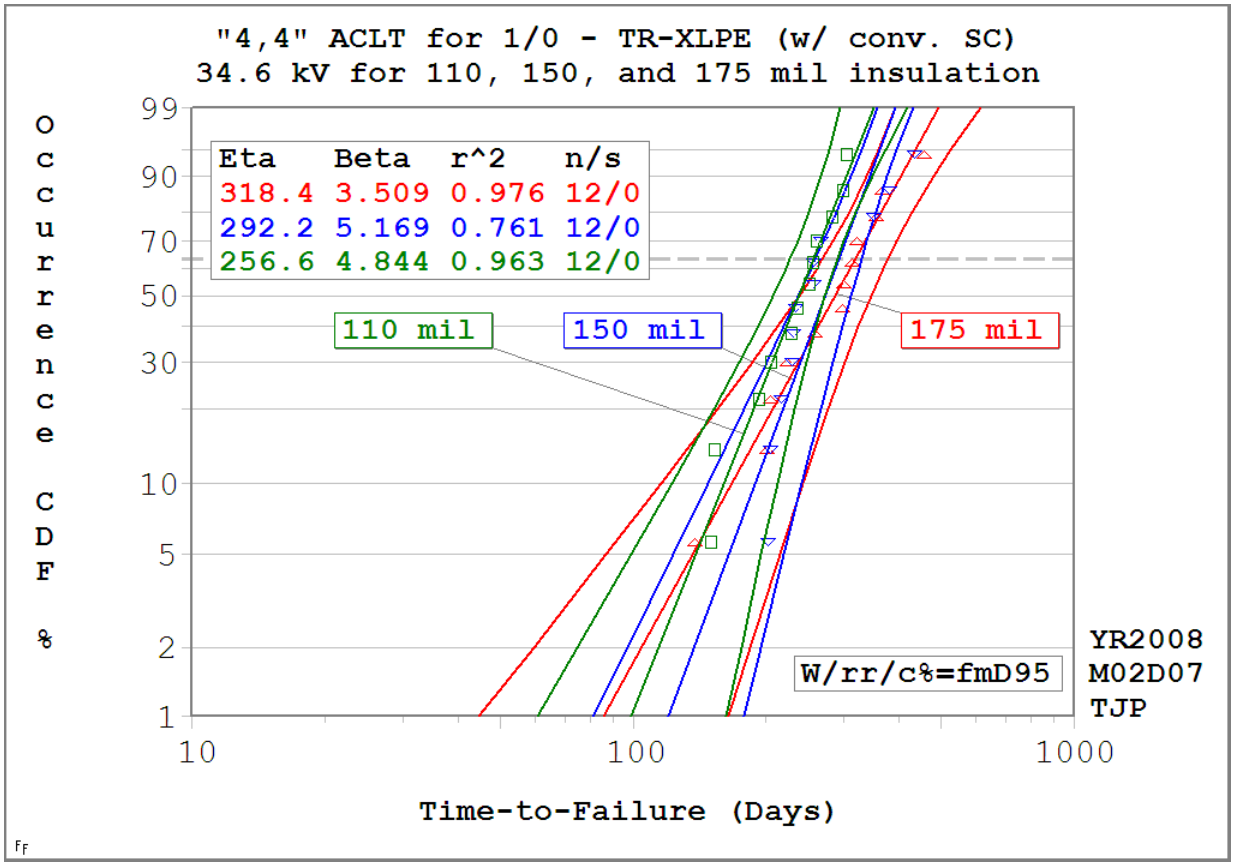
Insulation thickness (mil)	Eavg kV/mm [V/mil]	Emax kV/mm [V/mil]	Stress Enhancement (Emax)
110	12.4 [315]	15.5 [394]	1.44
150	9.1 [231]	12.1 [309]	1.12
175	7.8 [198]	10.8 [275]	1.00

ACLT program (beginning in 2002)

- Test voltage of 34.6kV for all designs (4xVg for 15kV cable)
- 90C conductor temperature in air, water tank temperature uncontrolled
  - typical 175-mil… 70-75C mid sample in water, 46-55C water temp.
  - for 110-mil… 67-72C mid sample in water, 47-53C water temp.
- 12 specimen populations in dedicated aging tanks by insulation thickness.

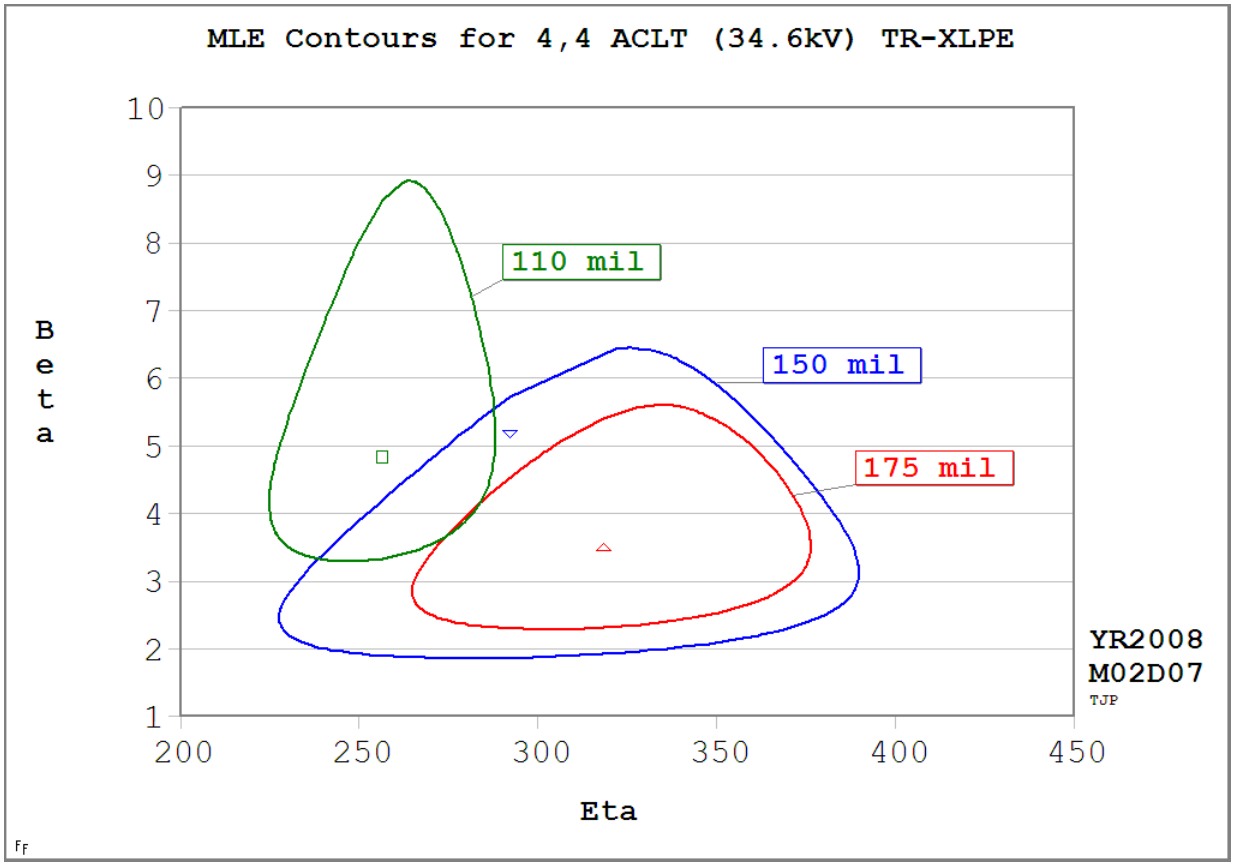
The following ACLT data will include a 1/0-175mil TR-XLPE cable with the same semicons, made on a different true-triple, dry CV line

“4,4” ACLT (34.6kV test voltage)

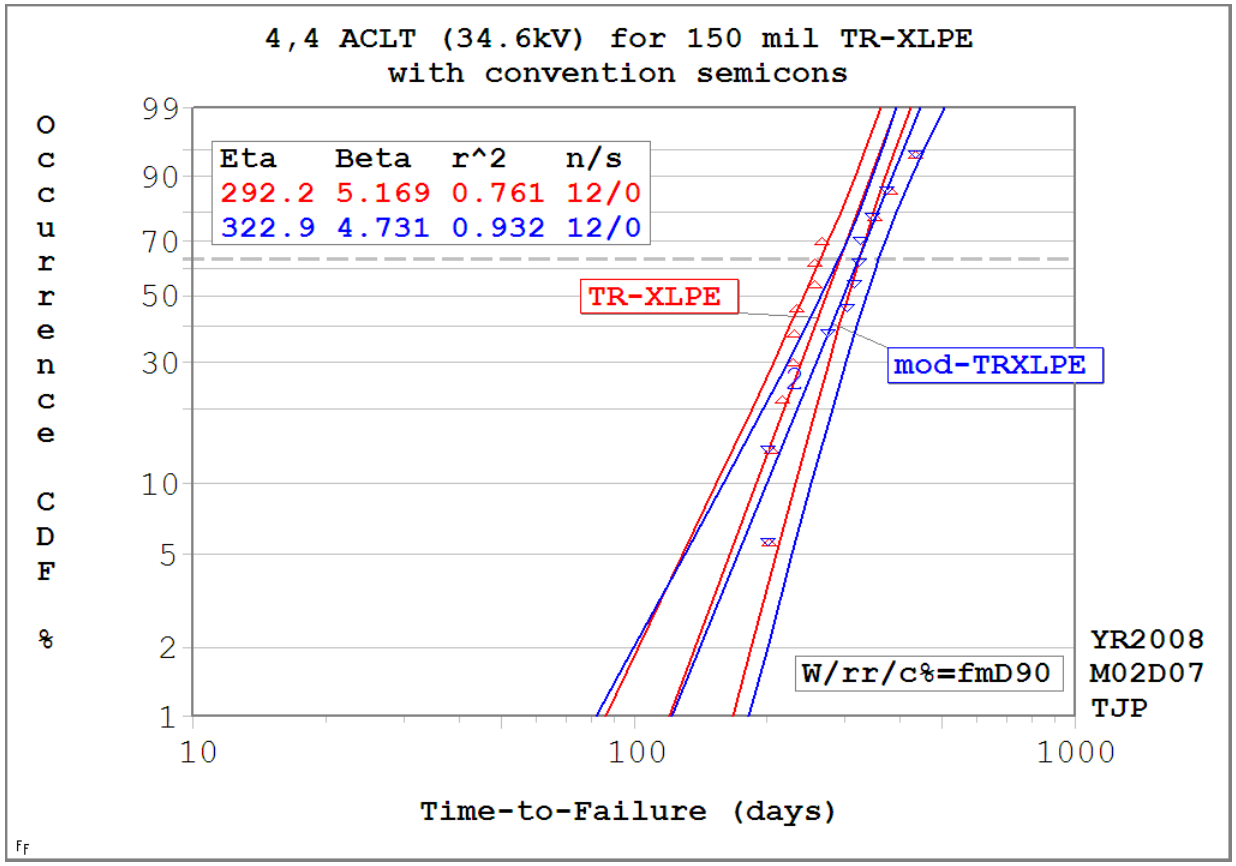


- Significant overlap in lifetimes with suggestion that reduced wall at same test voltage leads to slight reduction in accelerated life.

Effect of TR-XLPE insulation thickness on “4,4” ACLT (34.6kV) lifetime

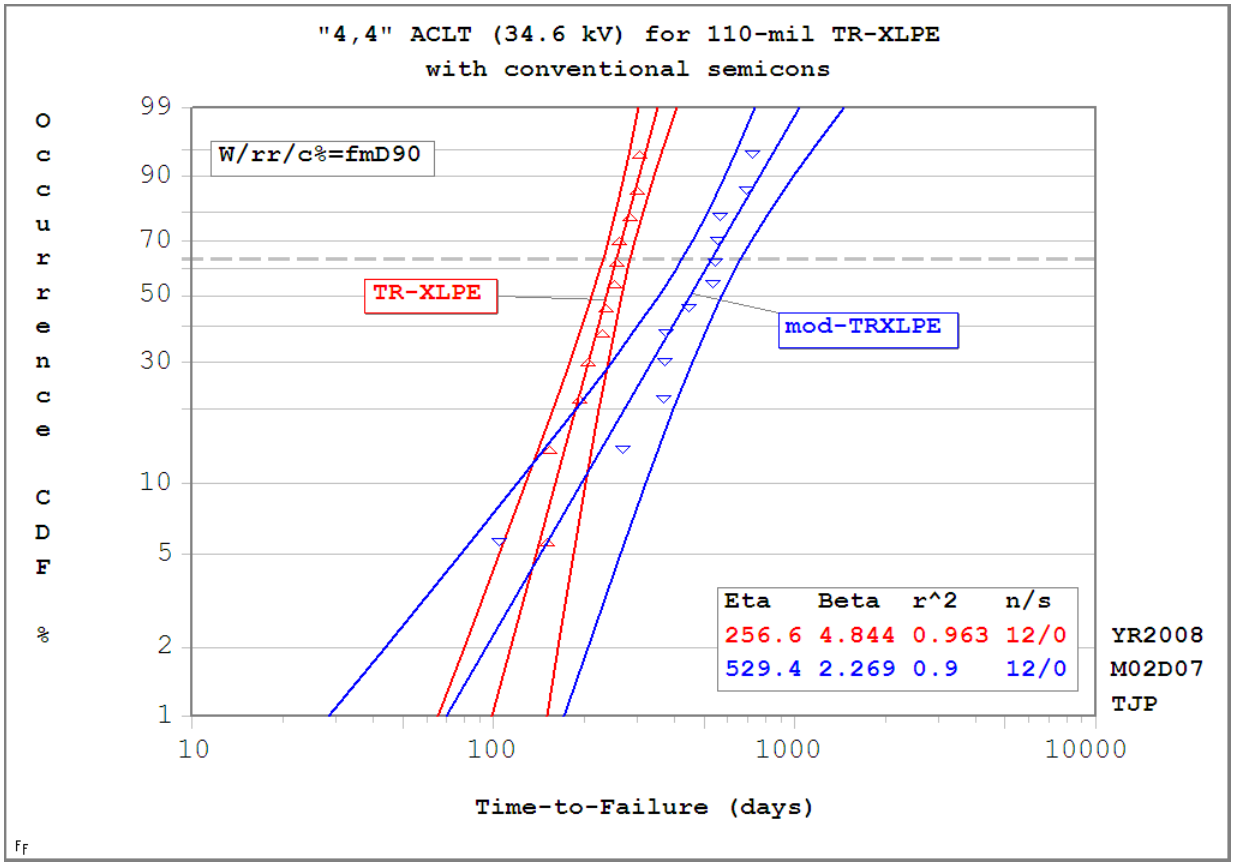


“4,4” ACLT (34.6 kV) for 150 mil TRXLPE



- “Modified” TRXLPE provides no apparent increase in ACLT lifetime for 150-mil insulated cables

“4,4” ACLT (34.6 kV) for 110 mil TRXLPE



- “Modified” TRXLPE provides significant increase in ACLT lifetime for 110-mil insulated cables.

Differentiation of 110-mil mod-TRXLPE

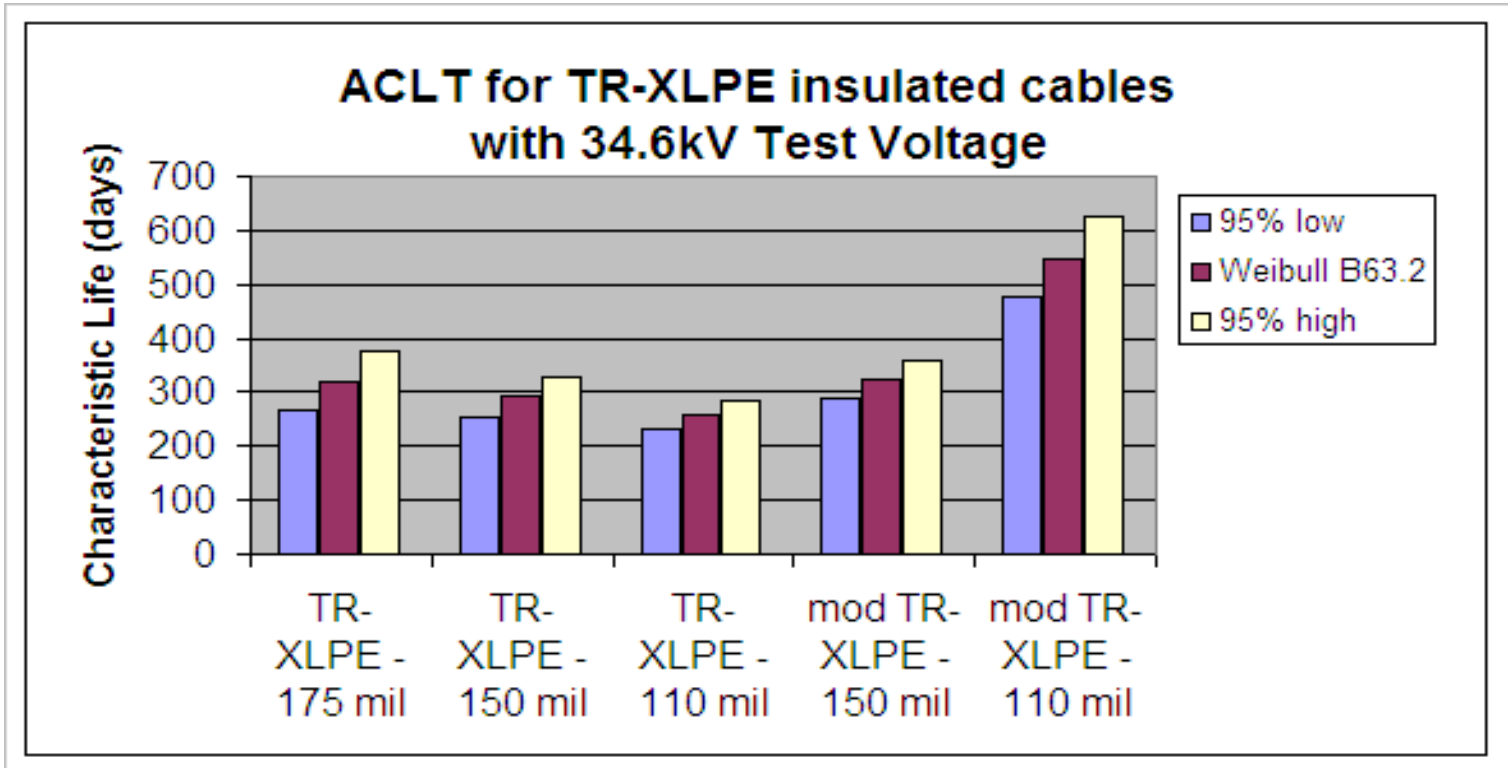
Treeing Comparison from failed ACLT samples

Insulation	Insulation Thickness (mil)	ACLT Aging Time (days)	Density BTT < 5mil	Density CSAT < 5mil	Density ISAT < 5mil
TR-XLPE	150	267	"Low"	"Low"	"None"
mod TR-XLPE	150	230	"Low"	"None"	"None"
mod TR-XLPE	150	316	"Low"	"None"	"None"
TR-XLPE	110	257	"Low"	"Low"	"Low"
TR-XLPE	110	262	"Med"	"Low"	"Low"
mod TR-XLPE	110	267	"Low"	"None"	"None"

For similar aging times in ACLT, the modified TRXLPE yields

- similar BTT density
- slightly reduced vented tree density

ACLT for Reduced-wall TRXLPE Cable



- Reduced wall TR-XLPE yields trend towards reduced accelerated life
  - statistically similar, based upon Weibull confidence interval overlap
- "Modification" of TR-XLPE yields no significant difference in accelerated life at 150 mil.
- "Modified" TR-XLPE yields substantial increase in life under high-stress
  - (believe this is due to added resistance to tree initiation and propagation)

Stress Enhancement in Reduced-Wall AWTT

Reduced-wall cables with #1/0 conductor: 26.0 kV Test Voltage			
Insulation thickness (mil)	Eavg kV/mm [V/mil]	Emax kV/mm [V/mil]	Stress Enhancement (based on Emax)
105	9.8 [248]	12.1 [308]	1.49
150	6.8 [173]	9.1 [232]	1.12
175	5.6 [149]	8.1 [206]	1.00

- Note that E_{max} (105-mil) in AWTT = E_{max} (150-mil) in ACLT
  - very little difference in accelerated lifetime between standard and 150 mil wall
- AWTT evaluations limited to 105 mil and 175 mil cables

Reduced-wall TR-XLPE Cables for AWTT

- Cable Manufacturing (2006)
  - 1/0 stranded Al
  - 15 mil conductor shield (acetylene black)
  - 40 mil strippable insulation shield
  - Tooling sized to make 175 mil insulation and allow draw-down to 105 mil
  - Cables made on same 1+2 triple, dry CV line on same day.
  - copper mesh applied as neutral

AWTT results – consider breakdown stress
cables aged at 26.0 kV (3xVg for 15kV cable)

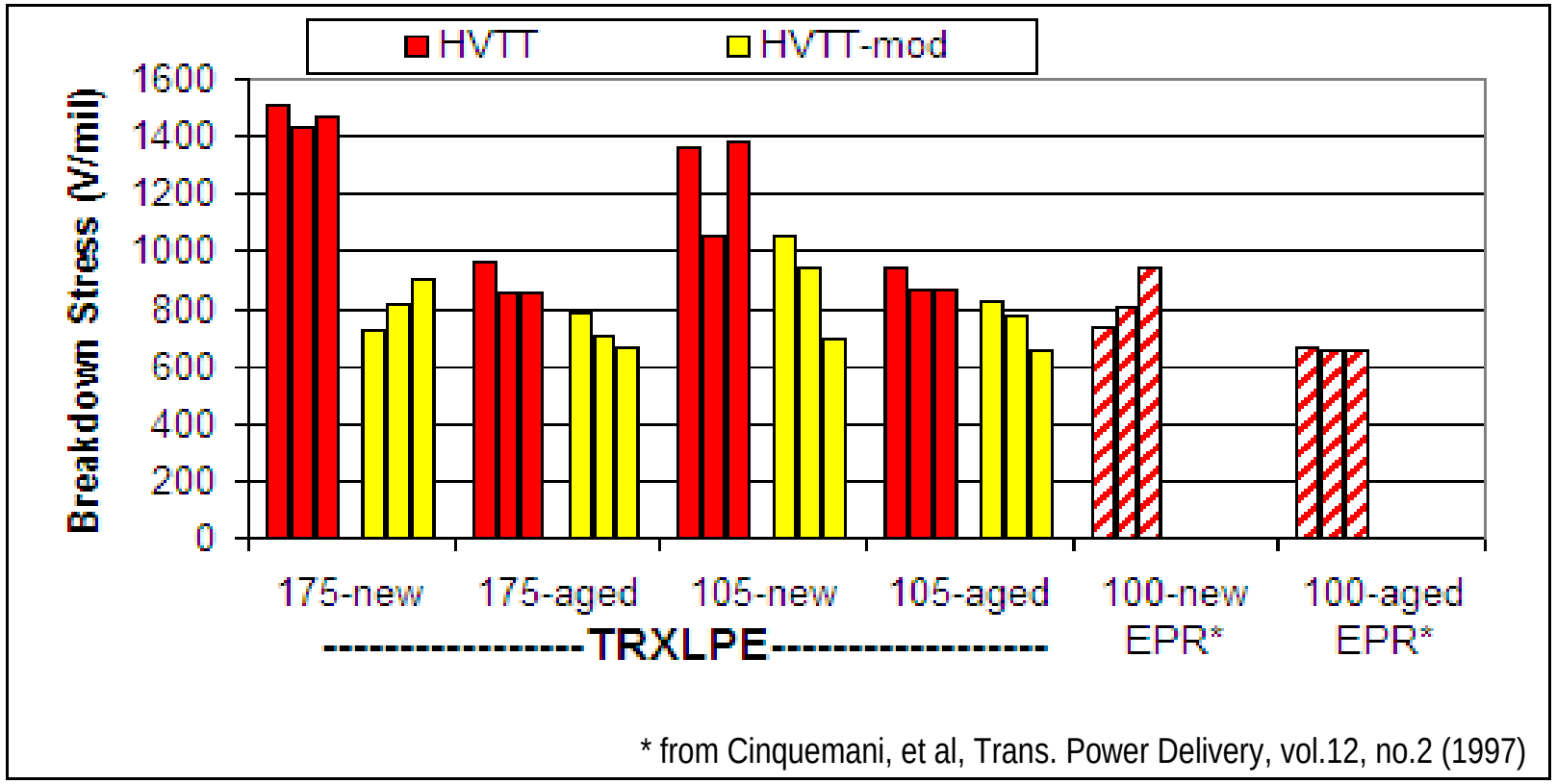
		Impulse Breakdown Stress (V/mil)		HVTT Breakdown Stress (V/mil)	
		Unaged	Aged-120d	Unaged	Aged-120d
TRXLPE	105 mil	3619	2714	1363	940
		3393		1050	860
		2714		1377	860
	175 mil	3750	1360	1475	960
		4102	2317	1427	855
		3614	2087	1511	850
modified TRXLPE	105 mil	3393	2714	1050	820
		3635	2714	944	780
		3393	2490	693	660
	175 mil	3263	2413	728	788
		3534	2750	814	707
		2952	2410	904	662

"Unaged" is after 14d cyclic aging.

Reduced-wall yields a similar breakdown stress as standard wall.

"Modification" appears to have a slight negative impact on HVTT.

Comparison of HVTT Breakdown Stress (120d AWTT)



- Breakdown stress is similar for standard and reduced-wall cables.

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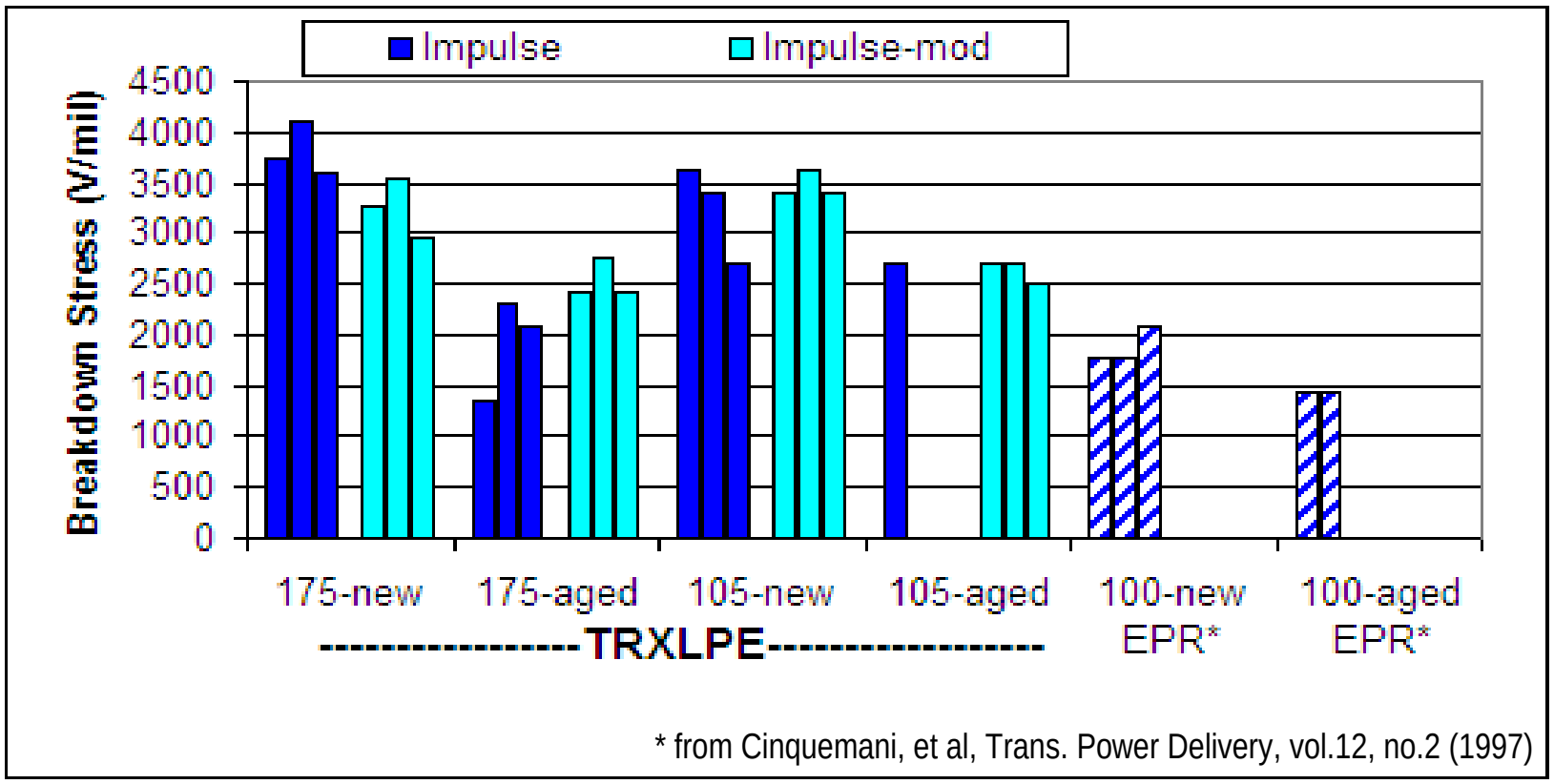
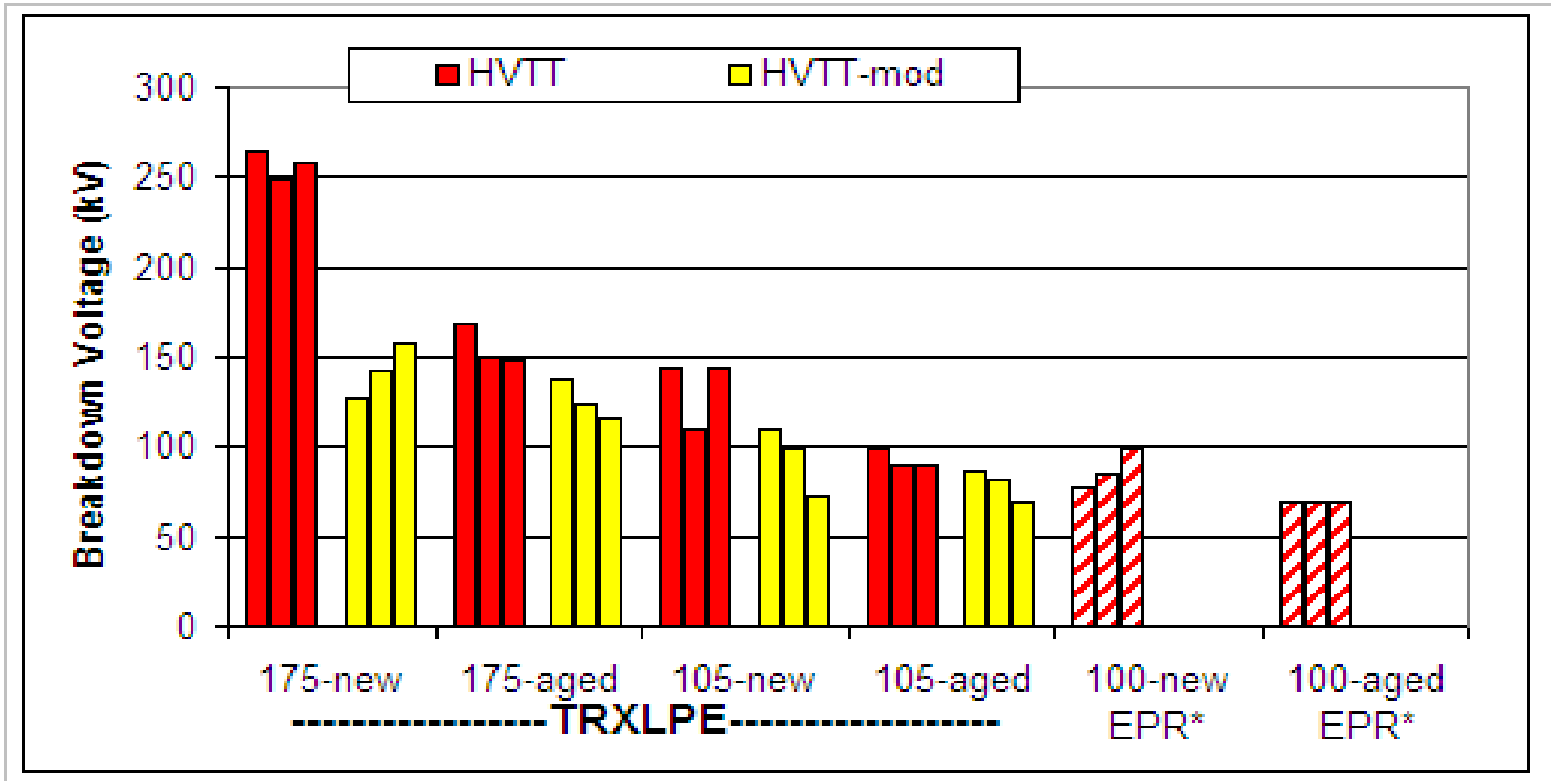


- Impulse breakdown stress is similar for standard and reduced-wall cables.

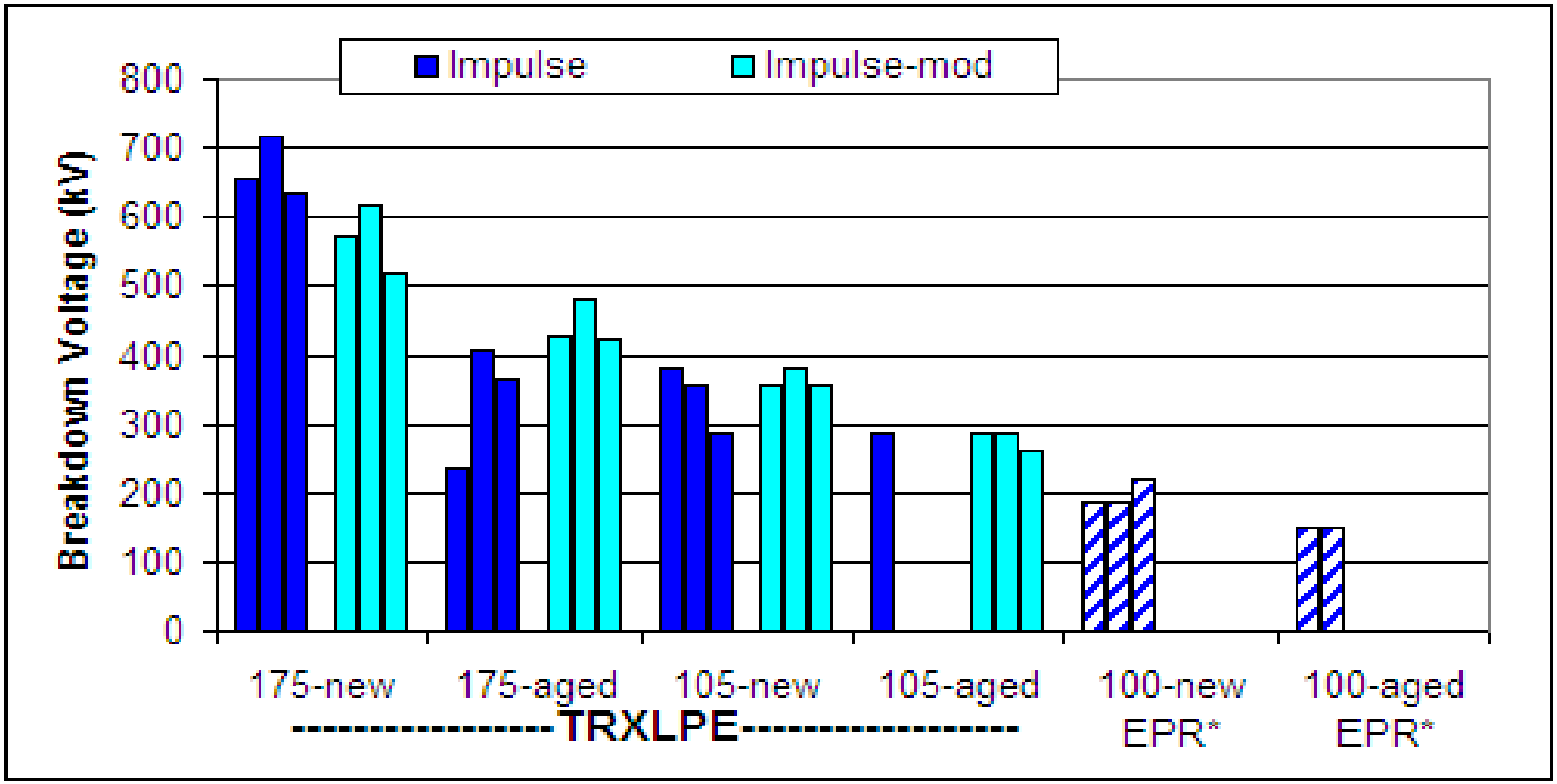
Comparison of HVTT Breakdown Voltage (120d AWTT)



* from Cinquemani, et al, Trans. Power Delivery, vol.12, no.2 (1997)

- Reduced-wall yields lower breakdown voltage.

Comparison of Impulse Breakdown Voltage (120d AWTT)



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- Reduced wall yields lower impulse breakdown voltage.

Conclusions

- Attempts to utilize reduced-wall cables as a means to significantly reduce accelerated aging times for high-performance TR-XLPE materials were not successful.
  - "4,4" ACLT protocol at 44% increased stress level (110 mil versus 175 mil) yields only moderate acceleration in time to failure for standard TR-XLPE.
  - Breakdown stress after aging (120-days, AWTT) does not readily distinguish between a 105 mil construction versus standard 175 mil.
  - Significant aging in less than 120-days requires greater than 12kV/mm (300 V/mil)
- TR-XLPE provides better retained breakdown stress (and voltage) as compared to EPR in accelerated aging of reduced-wall cables.
- Suggests TR-XLPE is an excellent candidate where reduced-wall cable designs are required (e.g. PILC replacement)
- A "modified" TR-XLPE material was found to provide significantly *extended* ACLT under high-stress conditions, while yielding only marginally reduced breakdown strength.