The Hidden Efficiencies in Distribution Transformers

Eric Hsieh, NEMA
John Caskey, NEMA
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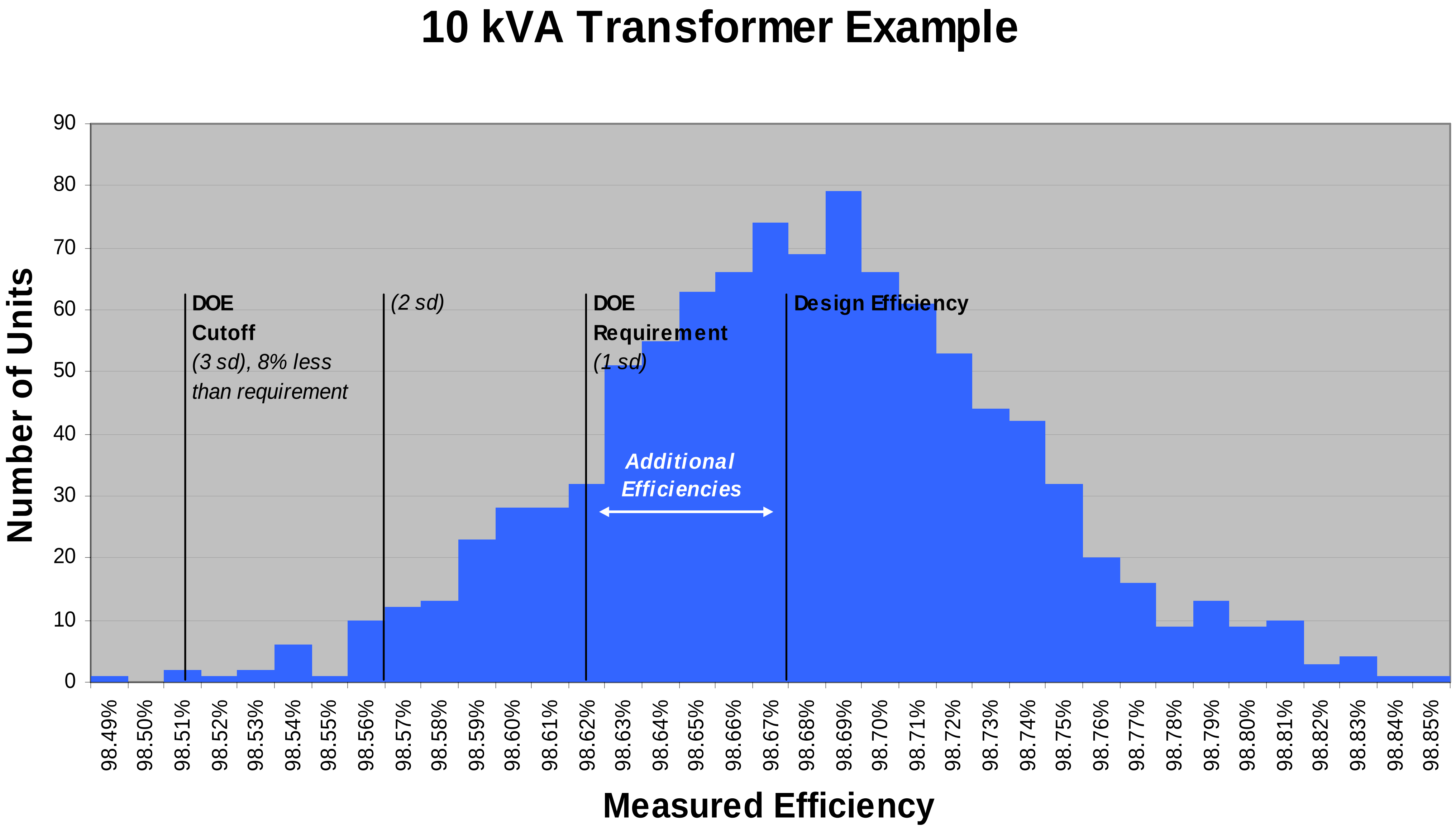
Executive Summary

- DOE Final Rule 10 CFR 431 requires medium voltage dry-type and liquid-immersed distribution transformers to meet certain energy efficiency levels by January 1, 2010.
- In order to meet this rule, equipment manufacturers will produce transformers that on average will be significantly more energy efficient than calculated by DOE.
- This increased energy efficiency (and associated CO2 reduction) occurs because:
  1. In order to avoid excessive testing failures and rework (per 71 FR 24985), manufacturers will design to higher energy efficiency levels than required by DOE.
  2. For multiple connection (dual voltage) distribution transformers, the transformer must meet the rule on the voltage connection with the highest losses which means that the other connection is more energy efficient than the DOE rule.

2006 Test Procedure Provisions

- 8% Single Unit Tolerance
  - "[T]he sampling plan tolerance is based on a single-unit sample tolerance (confidence limit) of eight percent..." 71 FR 24974
  - If any single unit tests more than 8% below the efficiency standard, the batch is noncompliant
- Multiple Connection
  - "The final rule requires the manufacturer to determine the basic model's efficiency either at the voltage at which the highest losses occur or at each voltage at which the transformer is rated to operate." 71 FR 24985
  - All connections must meet efficiency standard, even if the less efficient connection is rarely used
- These provisions require designs with higher average efficiencies than required by the 2007 DOE final rule

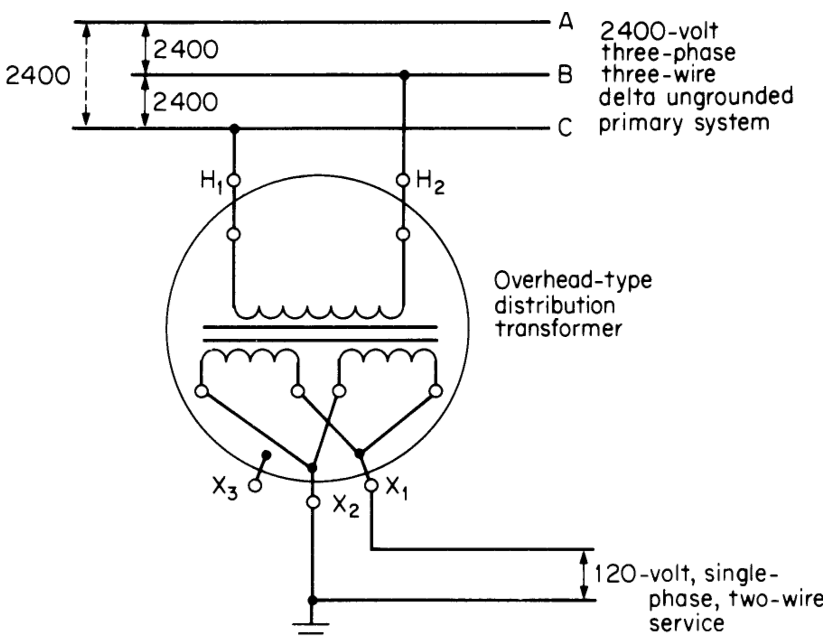
Single Unit Cutoff Requires Higher Design Efficiencies

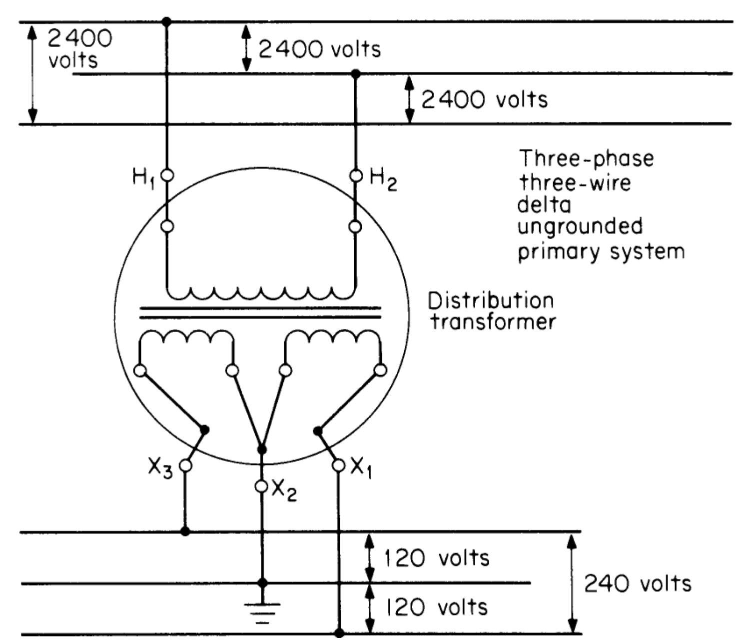


Single Unit Cutoff Considerations

- Standard deviation for losses
  - Assume normal distribution of loss variations
  - Determined through empirical data
  - Range from 2.7% to 6%; NEMA recommended 4%
  - DOE selected 4% (71 FR 24989)
- If design efficiency = DOE standard
  - 2.2% of units measure 8% below DOE standard
  - These units must be repaired
  - Entire batch must be retested; unacceptable manufacturer cost
- If design efficiency = DOE standard + 4% (1 standard dev.)
  - 0.1% of units measure 8% below DOE standard
  - Significantly lower risk of repair and re-test cost

120V/240V Connections



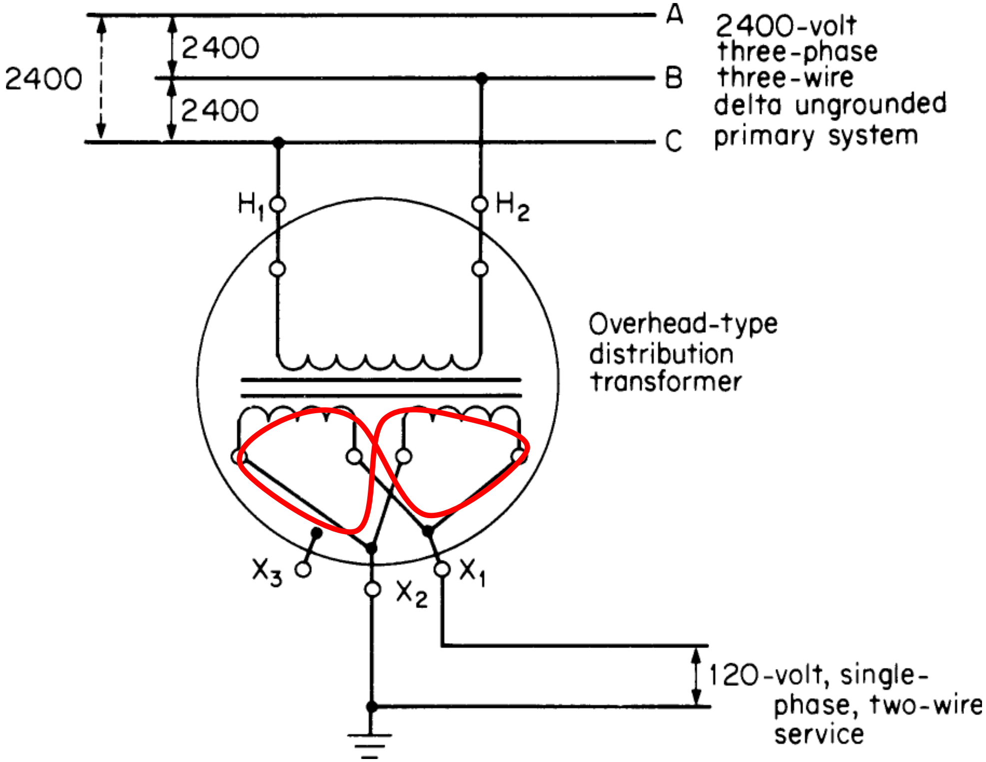


- Parallel connection
- More capacity for a single 120V connection
- Used rarely (less than 2% of installations)

- Series connection
- Provides both 120V and 240V service
- Most common configuration

Illustration Source: Shoemaker and Mack, “Lineman and Cableman’s Handbook,” 2006, pg. 15.9

Parallel Connection Losses



- Parallel connection creates complete loop through both secondary coils
- Any irregularity in bushings, coils, etc. results in circulating current
- Circulating current reduces capacity and efficiency
- Empirical: ~0.1% reduction versus series connection
- Meet efficiency standard on parallel → series *more efficient* than required
- Applies to Design Lines 1 and 2

Illustration Source: Shoemaker and Mack, “Lineman and Cableman’s Handbook,” 2006, pg. 15.9

Example Calculation

- Design Line 1: Liquid-immersed, single phase, rectangular tank
- Representative unit: 50 kVA, 14.4 kV primary, 120/240V secondary
- DOE efficiency standard: 99.08%
- Allowable losses @ 50% load
  - 50 kVA / 2* (1-.9908) = 230 W
- 4% Lower Design Target
  - 230 W * .96 = 220.8 W
- Initial Design: 99.12%
- Adder for series/parallel losses: 99.12% + 0.1%
- Target Design Efficiency: 99.22%

Efficiency Gains – 1 phase Liquid Immersed

	kVA	TSL1	TSL2	DOE Final	TSL3	TSL4	Design Eff.	DOE Final	TSL5	Design Eff.	TSL6
Graph Example	10	98.40	98.40		98.44	98.48		98.62	98.69	**98.78**	99.32
	15	98.60	98.56		98.59	98.63		98.76	98.82	**98.91**	99.39
	25	98.70	98.73		98.76	98.79		98.91	98.96	**99.05**	99.46
	37.5	98.80	98.85		98.88	98.91		99.01	99.06	**99.15**	99.51
Example Calc.	**50**	**98.90**	**98.90**		**98.90**	**99.04**		**99.08**	**99.19**	**99.22**	**99.59**
	75	99.00	99.04		99.06	99.08		99.17	99.21	**99.30**	99.59
	100	99.00	99.10		99.12	99.14		99.23	99.26	**99.36**	99.62
	167	99.10	99.21		99.23	99.25		99.27	99.35	**99.40**	99.66
	250	99.20	99.26	99.31	99.36	99.45	**99.44**		99.69		99.70
	333	99.20	99.31	99.36	99.40	99.49	**99.49**		99.71		99.72
	500	99.30	99.38	99.42	99.46	99.54	**99.54**		99.74		99.75
	667	99.40	99.42	99.46	99.50	99.57	**99.58**		99.76		99.77
	833	99.40	99.45	99.49	99.52	99.60	**99.61**		99.77		99.78

Efficiency Gains – 3 phase Liquid Immersed

kVA	kVA / Phase	TSL1	TSL2	DOE Final	Design Eff.	TSL3	DOE Final	TSL4	Design Eff.	TSL5	TSL6
15	5	98.10	98.36	98.36	**98.53**	98.68		98.68		99.25	99.31
30	10	98.40	98.62	98.62	**98.78**	98.89		98.89		99.37	99.42
45	15	98.60	98.76	98.76	**98.91**	99.00		99.00		99.43	99.47
75	25	98.70	98.91	98.91	**99.05**	99.12		99.12		99.50	99.54
112.5	38	98.80	99.01	99.01	**99.15**	99.20		99.20		99.55	99.58
150	50	98.90	99.08	99.08	**99.22**	99.26		99.26		99.58	99.61
225	75	99.00	99.17	99.17	**99.30**	99.33		99.33		99.62	99.65
300	100	99.00	99.23	99.23	**99.36**	99.38		99.38		99.65	99.67
500	167	99.10	99.32	99.25	**99.38**	99.45		99.45		99.69	99.71
750	250	99.20	99.24			99.31	99.32	99.37	**99.45**	99.66	99.66
1000	333	99.20	99.29			99.36	99.36	99.41	**99.49**	99.68	99.68
1500	500	99.30	99.36			99.42	99.42	99.47	**99.54**	99.71	99.71
2000	667	99.40	99.40			99.46	99.46	99.51	**99.58**	99.73	99.73
2500	833	99.40	99.44			99.49	99.49	99.53	**99.61**	99.74	99.74

Conclusion

- Liquid-filled transformers will be designed much closer to TSL 5 and 6, higher than the TSLC selected by DOE
- Similar design efficiencies necessary for medium-voltage dry-type
- Country will save considerably more energy and reduce CO_2 emissions more than DOE has calculated