Task Force to investigate Distribution Transformer Loading – DOE updates

Philip J Hopkinson, PE , David Brender, Senior Member

Presentation Items

1. DOE has established 15 issues and / or questions
2. September 18 questions published with answers requested by October 18.
3. HVOLT Inc. responded directly to DOE and copied stakeholder groups
4. Data Gathering proposals from Dan Mulkey and from Steve Rosenstock
5. Future Direction
6. Discussion

Building Technologies Office

DOE Issues a Request for Information Pertaining to Test Procedures for Distribution Transformers

The U.S. Department of Energy (DOE) has issued a pre-publication *Federal Register* notice initiating a data collection process through a Request for Information to consider whether to amend DOE's test procedure for distribution transformers.

- DOE requests and will accept comments, data, and information in response to the distribution transformers test procedure RFI until 30 days after the notice publishes in the Federal Register. DOE will send a follow-up e-mail when the notice publishes to announce the closing date of the comment period.
- Interested persons are encouraged to submit comments using the Federal eRulemaking Portal at http://www.regulations.gov. Alternatively, interested persons may submit comments, identified by docket number EERE-2017-BT-TP-0055, by Email (DistributionTransformers2017TP0055@ee.doe.gov), postal mail, or hand delivery/courier.
- DOE has gathered data and identified several issues associated with the test procedure on which DOE is interested in receiving comment. These issues mainly concern the degree to which the per-unit load testing measurement accurately represents in-service distribution transformer performance, and provides test results that reflect energy efficiency, energy use, and estimated operating costs during a representative average use cycle of an in-service transformer.
- DOE welcomes written comments from the public on any subject within the scope of this document (including topics not raised in this request for information).
- Find product information for Distribution Transformers including current standards and test procedures; statutory authority; waivers, exceptions and contact information. The docket for this rulemaking is EERE-2017-BT-TP-0055.

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6450-01-P

DEPARTMENT OF ENERGY

10 CFR Part 429 and 431

[EERE-2017-BT-TP-0055]

Energy Conservation Program: Test Procedure for Distribution Transformers

AGENCY: Office of Energy Efficiency and Renewable Energy, Department of Energy.

ACTION: Request for information (RFI).

SUMMARY: The U.S. Department of Energy ("DOE") is initiating a data collection process through this RFI to consider whether to amend DOE's test procedure for distribution transformers. To inform interested parties and to facilitate this process, DOE has gathered data, identifying several issues associated with the currently applicable test procedure on which DOE is interested in receiving comment. The issues outlined in this

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Issue 1. DOE seeks comment, data, and information regarding initial (first year of service) PUL data for distribution transformers.

Issue 1 per HVOLT Inc: PUL data from loading studies to date shows considerable diversity, varying from light loading in rural settings to > 70% of nameplate in some urban settings as well as for Commercial and Industrial loads.

PUL means Per Unit Load

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Issue 2. DOE requests input on the initial RMS PUL values presented in section I.B of this RFI. More broadly, DOE requests input on the distribution of PUL values experienced by the population of

Issue 2 per HVOLT Inc.: Feedback from PG&E on this subject has related the following load summaries:

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Type	Rate	Peak	Annual LF	Peak Day LF	Peak Month LF
Residential	E7	7/23/06	38.6%	71.7%	46.7%
Residential	E1	7/23/06	39.3%	74.5%	51.3%
Commercial	A1	7/24/06	39.8%	62.1%	47.0%
Commercial	A10	7/24/06	47.3%	68.6%	55.0%
Commercial	E19S	7/24/06	59.2%	78.2%	65.4%
Commercial	A6	7/25/06	59.7%	85.8%	74.5%
Industrial	E20S	8/9/06	61.9%	78.7%	68.7%
Commercial	E19V	7/25/06	62.8%	83.5%	71.3%
Commercial	E19P	7/25/06	67.2%	84.6%	72.9%
Industrial	E20P	7/25/06	70.7%	89.0%	77.7%
Industrial	E20T	7/21/06	79.1%	94.9%	84.4%

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Rate Class Definitions

E1 Residential
E7 Residential Time of Use (TOU)
E19P, E19S, E19V - Medium General Demand-Metered TOU Service
E20P, E20S, E20T - Service To Customers With Maximum Demands Of 1000 Kilowatts Or More
A1 Small General Service
A10 Medium General Demand-Metered Service
A6 Small General Time-Of-Use Service

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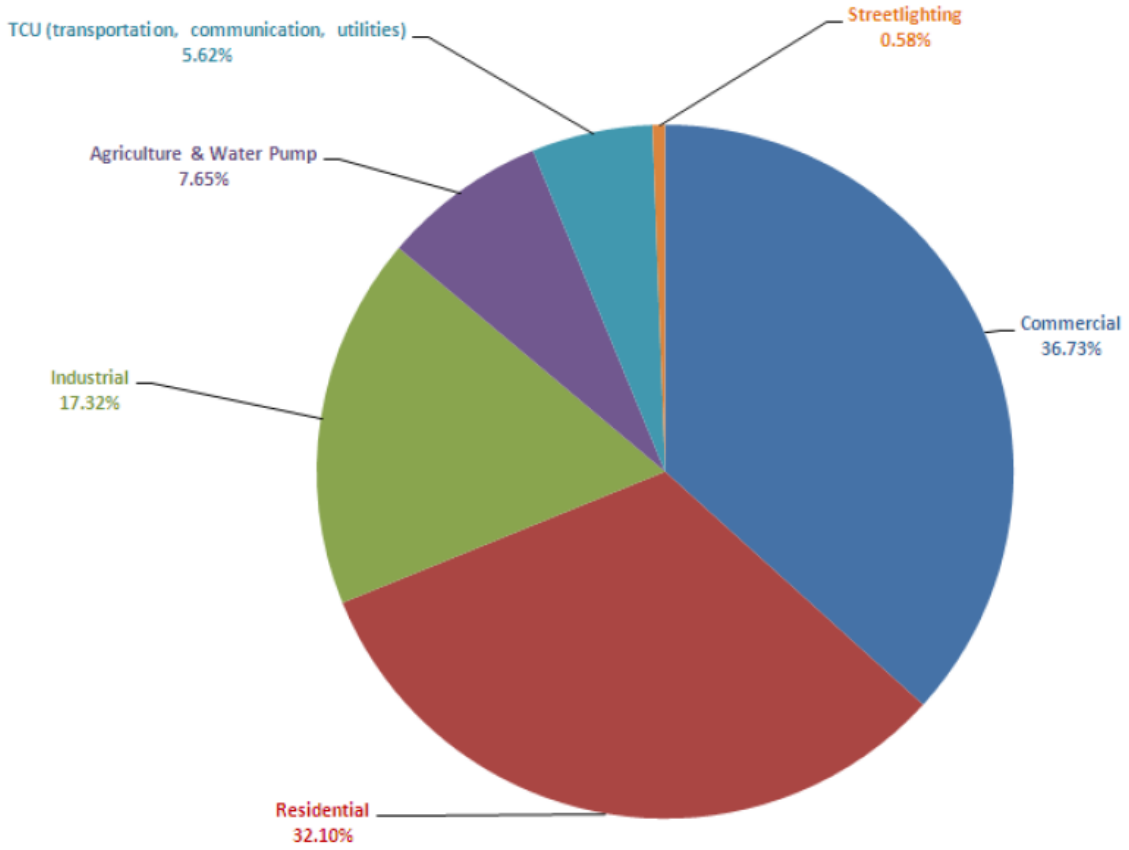
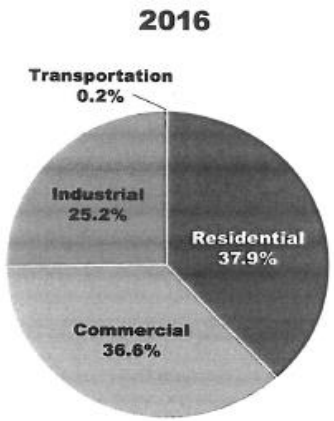
Figure D-1: Sector Shares of Total Electricity Consumption (2012)



Source: California Energy Commission staff

California energy consumption compared to total US where in 2016:

Use	California	Total US
1. Residential	32.1%	37.9%
2. Commercial	36.7%	36.6%
3. Industrial	17.3%	25.2%
4. Transportation	5.6%	0.2%
5. All Other	8.3%	0.0%



Proposal to establish Task Force to investigate Distribution Transformer Loading

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Data Gathering Per Dan Mulkey

1. **Single-phase overhead serves residential, small to medium commercial, agricultural, and industrial.**

2. **Three-phase overhead are mostly small to medium agricultural but also used to supply small to medium commercial and industrial**

3. **Single-phase submersible is mostly residential with some small commercial**

4. **Three-phase submersible is mostly small to medium commercial with some multi-family residential**

5. **Single-phase pad-mount is mostly residential with some small commercial**

6. **Three-phase pad-mount is mostly commercial and industrial with some agricultural and some multi-family residential**

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Issue 3. transformers of a given category (e.g., specific kVA, phases, application,

etc.). Specifically, commenters should specify whether the distributional data they provide represents the first year of service, or the full lifetime.

The PG&E data represents a total summary and not a first year only.

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Issue 4. DOE seeks comment, data and information regarding the load growth

estimate over the life of distribution transformers currently being installed. Specifically, DOE seeks comment, data and information on whether loads will increase over time, and if so, what the annual load growth would be for liquid-immersed, LVDT, and MVDT transformers, respectively.

No hard data on this subject. Utilities focused on Peak Demand as non-peak loading has little effect on distribution design needs.

Load growth normally results from new loads being added to existing circuits. LVDT's may be relatively constant. However, MVDT's are likely to see new loading associated with electrification of motor vehicles in residential applications and new processes in Commercial and Industrial applications.

Offsets in loading by efficiency improvements and distributed resources.

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Issue 5. **DOE seeks comment, data and information regarding the extent to which efficiency is taken into account in transformer purchasing decisions.**

Feedback from all members of the taskforce of > 100 members is that all purchases of distribution transformers are only for DOE-compliant transformers. Beyond that, purchase decisions are mostly on price and delivery and other compliance with users specifications.

TOC owning cost purchases beyond the DOE requirements have almost totally disappeared.

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Issue 6. DOE seeks comments, data, and information regarding the

appropriateness of the current test procedure requirements with respect to temperature

correction. Specifically, DOE requests comment on whether testing at specified ambient

conditions or correcting to the same internal temperature is more representative of distribution transformer in-service performance.

HVOLT Inc. believes that temperature of tested transformers is accurately measured and recorded such that this should not be a concern.

Task Force to investigate Distribution Transformer Loading – DOE updates

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Issue 7. DOE seeks comments, data, and information regarding how temperature

varies with PUL, and how significantly it affects transformer performance over a PUL range. Specifically, under the current internal temperature correction methodology, DOE requests comment on how it could specify the reference temperature for testing at PULs other than the current test PUL.

Temperature rise generally rises with load current to the 1.6 power at steady state conditions.

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Issue 8. DOE seeks comments, data, and information on the continued use of a

single test PUL requirement. Further, if a single test PUL requirement is maintained, DOE seeks comment on whether the existing single test PUL requirements should be maintained or whether alternate single test PUL requirements may better match the typical or RMS value in service. In addition, DOE seeks comment on the testing burden using an alternate single test PUL as compared to the current test procedure.

1. **The 2016 rules for efficiency (50% of load for medium voltage and 35% load for LV) are good**

2. **Loading levels and diversity were explored in the work leading up to the 2016 rules but there was inadequate data to make any changes to the measurement points.**

3. **Loading is better understood today and load diversity is significant, dependent on transformer application.**

Task Force to investigate Distribution Transformer Loading – DOE updates

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Issue 8 Cont'd. DOE seeks comments, data, and information on the continued use of a

single test PUL requirement. Further, if a single test PUL requirement is maintained, DOE seeks comment on whether the existing single test PUL requirements should be maintained or whether alternate single test PUL requirements may better match the typical or RMS value in service. In addition, DOE seeks comment on the testing burden using an alternate single test PUL as compared to the current test procedure.

3.a. Many Transformers purchased in bulk and placed in stock and applied as needed.

3.b. Same transformer may be in a light or heavy loaded application.

3.c. Same transformer may be applied in residential, commercial or industrial applications.

4. Ideally, transformers should be designed to be energy efficient at light loads and at heavy loads.

Task Force to investigate Distribution Transformer Loading – DOE updates

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5. Existing metric measures efficiency at one load level, either 50% or 35% of rated load.

6. New low loss core materials have complicated the efficiency picture:

a. **All transformers are at their maximum efficiency at the load where core loss equals load loss.**

b. **Transformers, using conventional grain oriented core steel, normally are at their peak efficiency at the measurement points of 50% load or 35% load, and are slightly less efficient at either side of the measurement load.**

4. Ideally, transformers should be designed to be energy efficient at light loads and at heavy loads.

Task Force to investigate Distribution Transformer Loading – DOE updates

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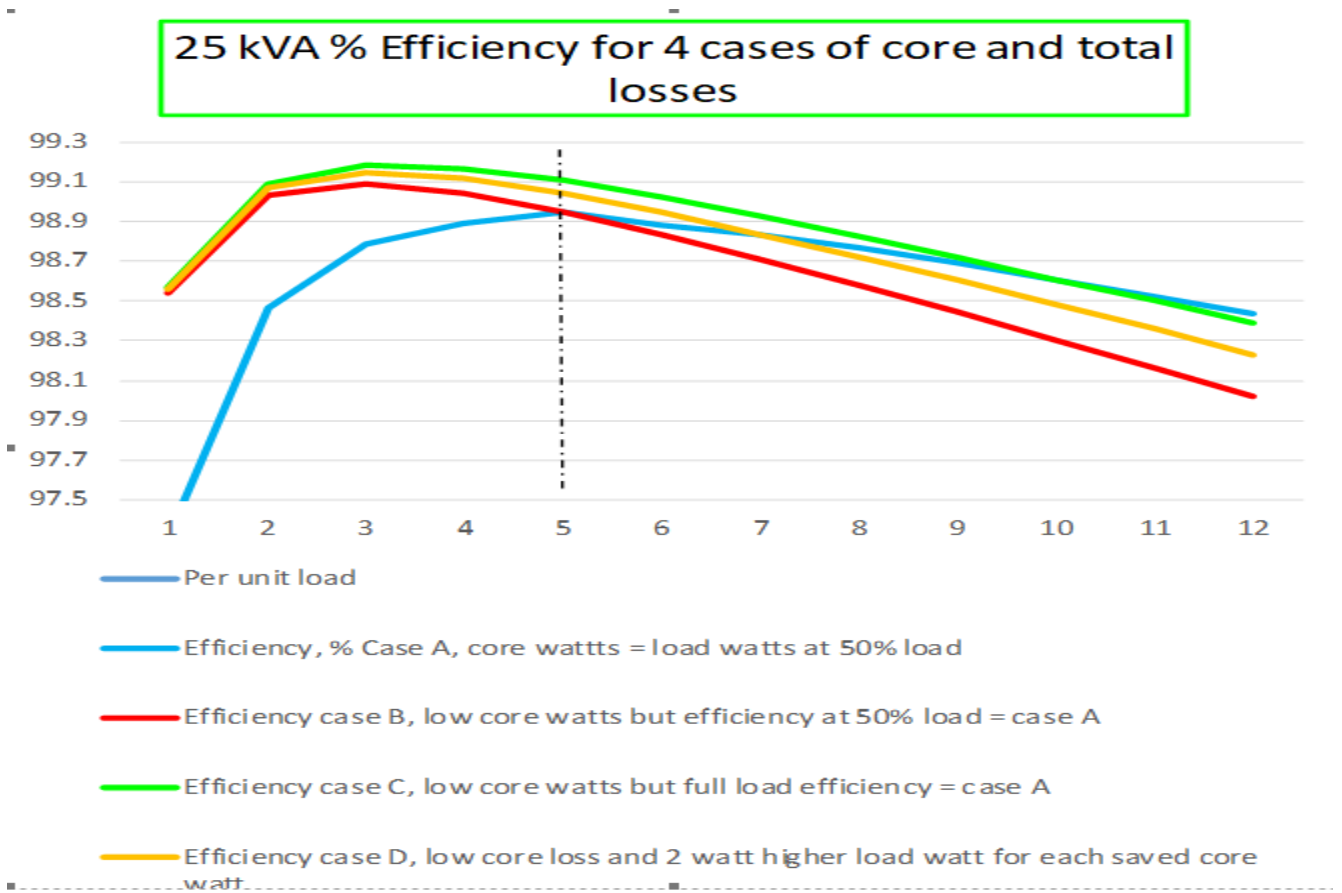

4. Ideally, transformers should be designed to be energy efficient at light loads and at heavy loads.

Task Force to investigate Distribution Transformer Loading – DOE updates

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25kVA Designs studied for losses, efficiencies and costs

1. Material costs from 2016 DOE rule-making used to valuate designs
2. M3, M4, and SA1 Amorphous core materials compared
3. Copper and Aluminum conductors compared
4. All designs forced to meet DOE efficiency at 50% load
5. Losses and efficiency examined at peak load efficiency ant at full load
6. Hypothetical 400 watt limit introduced as max allowed losses to see impact
7. 400 watt limit was standard for 25 kVA pole types in 1966 for electric utilities

4. Ideally, transformers should be designed to be energy efficient at light loads and at heavy loads.

Task Force to investigate Distribution Transformer Loading – DOE updates

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Design Summary of 25 kVA Options — Philip J Hopkinson, PE — 10/3/2017

Design	Materials							Weights				Losses				Efficiencies				Material Costs			
Spreadsheet Number	Core Steel	Inner LV	HV	Outer LV	Volt/turn	B core, KG	Tank D	Core lbs	LV lbs	HV Lbs	total lbs	NL watts	LL watts	FL Watts	50%Load	PL	%Load peak efficiency	total watts @ 25% load	efficiency at 25%load	Core Cost	LV	HV	Total
10	M3	AL	CU	AL	6.00	15.8	18	153	28.1	37.7	369	71	273	348	98.05	98.84	54	83	98.54	$ 186.33	$ 32.83	$ 95.84	$ 433.97
11	M4	AL	CU	AL	6.00	14.0	18	182	25.8	41.9	409	75	288	330	98.05	98.70	57	88	98.49	$ 205.15	$ 36.00	$ 106.15	$ 498.97
12	M3	AL	CU	AL	5.00	15.8	18	137	28.3	44.1	357	63	308	369	98.05	98.84	48	77	98.64	$ 168.81	$ 40.54	$ 111.94	$ 422.97
13	M3	CU	CU	CU	6.00	16.4	15	144	48.7	38.0	357	73	262	335	98.05	98.88	56	85	98.51	$ 186.83	$ 43.11	$ 91.38	$ 508.78
14	M3	AL	AL	AL	5.45	15.5	17	165	28.4	38.0	330	73	288	339	98.05	98.88	55	85	98.51	$ 181.84	$ 60.23	$ 85.07	$ 481.00
15	M3	AL	CU	AL	6.00	15.5	15	163	22.5	37.1	360	72	288	338	98.05	98.87	55	84	98.52	$ 183.58	$ 40.89	$ 94.18	$ 437.62
16	M3	AL	AL	AL	4.80	14.7	15	161	21.8	25.0	305	62	314	318	98.05	98.92	47	76	98.66	$ 167.32	$ 52.46	$ 82.38	$ 438.45
17	M3	CU	CU	CU	5.00	17.1	15	118	36.2	48.4	350	68	283	359	98.05	98.88	50	79	98.60	$ 157.24	$ 167.45	$ 117.57	$ 530.08
18	SA1	AL	CU	AL	5.22	13.5	17	185	37.8	34.2	335	22	487	509	98.05	99.00	22	44	98.22	$ 386.70	$ 51.09	$ 111.88	$ 533.13
19	SA1	AL	CU	AL	5.00	13.5	17	181	36.1	35.1	333	22	481	502	98.05	97.99	22	43	98.23	$ 381.04	$ 42.42	$ 114.23	$ 522.69
22	SA1	AL	CU	AL	5.00	13.5	17	169	28.3	48.3	419	23	365	388	98.20	98.95	27	38	98.32	$ 263.19	$ 65.10	$ 158.15	$ 586.18
23	SA1	AL	CU	AL	5.00	13.5	16	169	26.7	44.0	389	22	378	400	98.15	98.93	26	39	98.30	$ 263.12	$ 54.91	$ 144.11	$ 564.15
24	M3	AL	CU	AL	5.00	13.5	16	156	21.4	39.8	375	49	371	420	98.05	98.85	38	57	98.50	$ 181.45	$ 52.07	$ 100.53	$ 444.08
25	M3	AL	CU	AL	5.00	13.5	16	156	21.8	46.1	374	49	351	400	98.10	98.83	38	57	98.50	$ 181.50	$ 52.84	$ 116.02	$ 450.36

Notes :

1. All designs meet the 2016 DOE efficiency requirement of 98.25% at 50% load
2. SA1 Amorphous core designs 18, 19, and 22 assume that amorphous ribbon is purchased in the US and fabricated into finished cores in the respective transformer manufacturers.
3. All designs optimized to material prices page 21 that were used in 2016 rule making.
4. Columns T and U examine the total losses and efficiency at the efficiency where amorphous core designs are at peak efficiency at ~ 22% load.
5. Amorphous core design 22 restricts current densities to the same level as was done in M3 Core Steel designs such that total full load losses are similar to that of the silicon steel designs for improved efficiency at high loading.
6. Least first cost options examined seem to be with M3 core material, copper HV, and aluminum sheet LV.
7. Sheet 23 examines a reasonable upper limit on total losses of ~23 * 97% DOE losses that would be easily met by all of the DOE designs and assures the user that low core loss designs would still be efficient at all loads.
8. Sheet 24 examines M3 core material at 13.5 KG, the same as Amorphous core with total losses not constrained but meeting the DOE requirement at 50% load.
9. Sheet 25 examines M3 core material at 13.5 KG but with total losses constrained to 400 watts. Note that efficiency at 50% load now exceeds the DOE requirement.

Conclusions

1. Arbitrary limits of flux density normally lead to suboptimal performance and cost.
2. Highest overall efficiency occurs when peaked at RMS-equivalent load.
3. Transformers applied in diverse loading loads should be as efficient as possible over all of their expected loads
4. Light load applications may be candidates for smaller kVA transformers

4. Ideally, transformers should be designed to be energy efficient at light loads and at heavy loads.

Task Force to investigate Distribution Transformer Loading – DOE updates

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25kVA Designs studied for losses, efficiencies and costs

1. Design 15 with M3, copper HV and AL strip LV typical for CGO Steel

2. Design 19 with SA1 amorphous core, copper HV and Al strip LV typical of amorphous.

3. Both meet required efficiency of 98.95 % at 50% load

4. When total losses limited to 400 watts, both designs efficient at high loads

4. Ideally, transformers should be designed to be energy efficient at light loads and at heavy loads.

Task Force to investigate Distribution Transformer Loading – DOE updates

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Issue 9. **DOE seeks comments, data, and information regarding testing a single transformer at multiple PULs. Specifically, DOE seeks comment on the degree to which a multiple-PUL weighted-average efficiency would more accurately reflect distribution transformer operation in service, as compared to the current test procedure. In addition, DOE seeks comment on any additional testing burden that might be associated with testing at multiple PULs.**

HVOLT Inc. does not believe that multiple PUL's are necessary but does believe that a limit should be placed on total losses of distribution transformers. The limit would be at approximately 2.9* allowable losses at the 50% measurement point for medium voltage transformers and at approximately 5 * allowable losses for Low Voltage Dry type transformers.

4. Ideally, transformers should be designed to be energy efficient at light loads and at heavy loads.

Task Force to investigate Distribution Transformer Loading – DOE updates

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Issue 10. DOE seeks comments, data, and information regarding the number of

PULs (and the corresponding test PUL values) that parties believe may be appropriate for a multiple PUL test procedure. In addition, DOE seeks comments, data, and information

HVOLT Inc. believes that this is an overly burdensome requirement on the manufacturers. The existing test requirements require no load and full load watts to be measured. Pass-fail criteria today are calculated from the measured losses. The HVOLT Inc. proposal to also limit total losses to a tolerant level does not require more testing but is simply a calculated result from existing losses data.

4. Ideally, transformers should be designed to be energy efficient at light loads and at heavy loads.

regarding what weightings or additional requirements may be necessary under a multiple PUL test procedure.

HVOLT Inc. is not a manufacturer and defers this issue to the manufacturers for comment. Most large manufacturers track model performance very carefully and use deviations from expected values to either tighten designs or to add more tolerance.

4. Ideally, transformers should be designed to be energy efficient at light loads and at heavy loads.

Task Force to investigate Distribution Transformer Loading – DOE updates

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Issue 11. DOE seeks comments, data, and information on whether there are any other options or alternative metrics not presented in this RFI that should be considered for measuring and rating the efficiency of distribution transformers.

HVOLT Inc. continues to recommend that total losses be added as a metric to the existing test requirements.

With the recommended relationships from Isssue 9, the result should be transformers that are efficient at all loads.

Under this criteria, low core loss is certainly encouraged but conductor losses are also limited to assure that high efficiency occurs at all loads.

4. Ideally, transformers should be designed to be energy efficient at light loads and at heavy loads.

Task Force to investigate Distribution Transformer Loading – DOE updates

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Issue 12. DOE seeks comment regarding the sampling requirements for

distribution transformers. Specifically, DOE seeks information on how manufacturers have been applying the sampling provisions. DOE also seeks comments from

manufacturers on whether there are instances in which there are questions as to how to apply the sampling requirements or select the appropriate sample size.

HVOLT Inc. does not have issues with this requirement.

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Issue 13. DOE seeks comment regarding the represented values of efficiency

relative to calculated values, specifically, whether manufacturers typically represent the minimum efficiency standard, the maximum represented efficiency (RE) allowable, or a different value; how manufacturers determine what value to represent; and why.

HVOLT Inc. does not have comment here.

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Issue 14. **DOE's requirements related to AEDMs are at 10 CFR 429.70. This section specifies under which circumstances an AEDM may be developed, validated, and applied to product performance ratings for certain covered products and equipment.**
AEDM application to distribution transformers is permitted pursuant to 10 CFR 429.47(a)(2) and may serve a manufacturer who finds it burdensome to physically test units of each basic model sold. However, DOE notes that currently, manufacturers frequently test every basic model instead of calculating efficiency using the AEDM provisions.

HVOLT Inc. believes that all manufacturers test each transformer produced for losses and normally have sufficient margin in the designs to limit fallout.

Task Force to investigate Distribution Transformer Loading – DOE updates

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Issue 15. DOE seeks information regarding the usefulness of the AEDM provisions, and whether and why manufacturers select the option to use AEDMs.

HVOLT Inc. believes that the AEDM provisions are useful in describing tolerance and objectives. Large volumes of production have an easier means of achieving

Proposal to establish Task Force to investigate Distribution Transformer Loading

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Loading Task Force Activities

Current Interested Participants:

a. **EEI via Steve Rosenstock**
b. **Several large Utilities:**
    - i. **PG&E**
    - ii. **So. Cal. Ed.**
    - Iii. **PECO**
    - iV **AEP**
    - V **DUKE**
c. **Some Wind and Solar Customers**

Mechanics:

a. **Establish compatible EXCEL Data file for data reporting**
b. **Use real time data acquisition for key locations**
c. **Use neutral clearing house (EEI) for gathering data and maintaining neutrality.**
d. **Annual load cycles gathered by rate class and logged over full 8760 hourly period/yr.**

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From Steve Rosenstock, EEI spokesman on 10/2/17:

1. **Table 1 of the PG&E report makes a nice template for a "first cut" of information gathering and identified as Tier 1.**

2. **Tier 2 could be more detailed data on sub-categories of residential / commercial / industrial as shown on your slides**

3. **Tier 3 is the most detailed data of sub categories based on geographic location or other key operational variables (such as trending data, if available).**

Proposal to establish Task Force to investigate Distribution Transformer Loading

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PG& E Perspective Conclusions:

1. Load cycles by hourly data logging should be accurate.

2. Load cycles by rate class capture daily, monthly, and annual load ranges

3. Load factors can be calculated by day, month and year vs. Load Cycles

4. RMS-equivalent easily obtained from hourly data but Load Factor OK.

5. Transformer nameplate kVA is less than peak capability based on modelling

Proposal to establish Task Force to investigate Distribution Transformer Loading

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Dan Mulkey

Utility				PG&E	PG&E	PG&E	PG&E	PG&E	PG&E
Transformer Type				1P-OH	1P-SUB	3P-SUB	3P-PM	3P-OH	3P-PM
Nameplate kVA				10	25	750	500	150	1500
# of Residential Customers				2	3				
# of Commercial Customers								5	
# of Industrial Customers						1	1		1
# of Agricultural Customers									
# of Other Customers								1	
	Date	day	hour	Time (hrs)	Transformer 126534	Transformer 126535	Transformer 126536	Transformer 126537	Transformer 126538	Transformer 126539
2	12/31/06 5:00 PM	365	17	8753	1.18	1.99	287.44	241.91	66.53	820.49
3	12/31/06 6:00 PM	365	18	8754	1.22	2.05	287.56	237.07	65.49	817.08
4	12/31/06 7:00 PM	365	19	8755	1.16	1.92	283.59	228.53	62.80	808.54
5	12/31/06 8:00 PM	365	20	8756	1.08	1.93	281.14	222.33	62.03	806.12
6	12/31/06 9:00 PM	365	21	8757	0.99	1.90	276.16	217.49	60.13	795.69
7	12/31/06 10:00 PM	365	22	8758	0.91	1.65	271.59	213.65	57.74	783.36
8	12/31/06 11:00 PM	365	23	8759	0.85	1.37	267.71	211.66	56.07	775.47
9										
10	Max				2.00	3.38	555.70	556.38	116.11	1666.77
11	Min				0.41	0.67	253.39	199.85	51.48	712.86
12	Av				0.79	1.31	373.55	329.46	72.89	1177.99

Proposal to establish Task Force to investigate Distribution Transformer Loading

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Data Gathering Per Dan Mulkey

1. **Single-phase overhead– most used size is the smallest size purchase – currently the 15 kVA**

2. Three-phase overhead – most used size is 150 kVA (next to largest available size) presumably agricultural load

3. Single-phase submersible – most used size is 100 kVA (most are used in residential subdivisions where customers are aggregated up to the design voltage drop or flicker limit)

4. Three-phase submersible – most used size is 150 kVA (smallest available size) presumably commercial load

5. Single-phase pad-mount – most used size is 100 kVA (most are used in residential subdivisions where customers are aggregated up to the design voltage drop or flicker limit)

6. Three-phase pad-mount – most used size is 150 kVA (default type commercial and industrial)

On a percent by transformer unit – the small single-phase transformer serving residential will absolutely overwhelm everything else. Change that to % of kVA or % of energy or % of cost, I suspect that the commercial/industrial served by a three-phase pad-mount will slightly exceed the residential served by single-phase transformer.

Proposal to establish Task Force to investigate Distribution Transformer Loading

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Discussion:

1. Is the PG&E approach typical of others?
2. Are load cycles gathered by other utilities?
3. Is loading data relatable by rate class?
4. Are load cycle peaks the basis of sizing transformers?
5. Is there a common format for collecting data?
6. Can other data be shared publicly?
7. Would it be preferable to use EEI for Utility data?

Proposal to establish Task Force to investigate Distribution Transformer Loading

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Future Assignments

1. Charts to members of Task Force and all on web site.
2. Request answers to chart 15 by December 1.
3. RMS-equivalent loading by Nameplate is the goal.
4. Other formats will be collected as submitted.
5. EEI ready to assist as needed.
6. Ultimate desire is to collect data for Liquid, Dry, and LV Dry.

Next Meeting Pittsburgh