Distribution Transformer Loading

DOMINION ENERGY – 2018
Transformer Installations with 2018 Data by State

<table>
<thead>
<tr>
<th>STATE</th>
<th>Number of Transformer Installations</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC</td>
<td>8</td>
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<tr>
<td>NC</td>
<td>2,493</td>
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<tr>
<td>VA</td>
<td>57,851</td>
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<td>(blank)</td>
<td>372</td>
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</tbody>
</table>
Major Locations
Installation Types

Number of Transformer Installations

<table>
<thead>
<tr>
<th>Type</th>
<th>1P-OH</th>
<th>1P-PM</th>
<th>3P-OH</th>
<th>3P-PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-Phase Overhead</td>
<td>26,176</td>
<td></td>
<td>3,090</td>
<td></td>
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<tr>
<td>Single-Phase Pad-Mount</td>
<td></td>
<td>25,088</td>
<td></td>
<td>6,370</td>
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<tr>
<td>Three-Phase Overhead</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Three-Phase Pad-Mount</td>
<td></td>
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</tr>
</tbody>
</table>
Single-Phase Overhead

Number of Transformer Banks

Nameplate kVA Size

- 5
- 7.5
- 10
- 15
- 20
- 25
- 30
- 35
- 40
- 42.5
- 47.5
- 50
- 52.5
- 55
- 60
- 62.5
- 65
- 75
- 85
- 87.5
- 90
- 100
- 110
- 115
- 125
- 137.5
- 150
- 167
- 175
- 192
- 200
- 217
- 225
- 242
- 250
- 267
- 333
- 344
- 350

- 627
- 2,870
- 8,678
- 938
- 10,625
- 331
- 1,129
Three-Phase Overhead

Number of Transformer Banks

Nameplate kVA Size

1,139
794
169
566
156
Three-Phase Pad-Mount
Customers per Transformer
Maximum Number of Customers per Transformer

- 1P-OH: 97
- 1P-PM: 100
- 3P-OH: 141
- 3P-PM: 700
Max Number by Customer Type per Transformer
Single-Phase Overhead

Mode: 1 customer/transformer
Single-Phase Pad-Mount

Mode: 4 customers/transformer
Three-Phase Overhead

Number of customers per transformer

Mode: 1 customer/transformer
Three-Phase Pad-Mount

Number of Transformer Banks

Number of customers per transformer

Mode: 1 customer/transformer
Customers per Single-Phase Overhead Transformer by kVA Size

- **50 kVA**
  - Mode: 2 cust/trf

- **75 kVA**
  - Mode: 1 or 2 cust/trf

- **100 kVA**
  - Mode: 2 cust/trf
Customers per Single-Phase Pad-Mount Transformer by kVA Size

- **50 kVA**
  - Mode: 4 cust/trf

- **75 kVA**
  - Mode: 8 cust/trf

- **100 kVA**
  - Mode: 6 or 8 cust/trf
Customers per Three-Phase Overhead Transformer by kVA Size

- 45 kVA
- 150 kVA
- 300 kVA

Mode: 1 cust/traf
Customers per Three-Phase Pad-Mount Transformer by kVA Size

Mode: 1 cust/trf

Mode: 1 cust/trf

Mode: 1 cust/trf
Annual Load Factor:
Average Annual Load / Peak Annual Load
Annual Load Factor
All Customer Types

Number of Transformers

Average Annual Load / Peak Annual Load

RMS / Peak

Mode: 0.288

Range at ≈ ½ of the mode:
0.171 to 0.361

Average / Peak

Mode: 0.258

Range at ≈ ½ of the mode:
0.135 to 0.327
Annual Load Factor – Residential Only

Rounded to 3 digits

RMS / Peak

Average / Peak

Mode: 0.236

Mode: 0.237
Annual Load Factor – Residential Only

Rounded to 2 Digits

Number of Transformers

Range at \(\approx \frac{1}{2}\) of the mode:

- RMS / Peak: 0.17 to 0.35
- Average / Peak: 0.13 to 0.31

Mode: 0.28

Mode: 0.26
Annual Load Factor – Commercial Only

RMS / Peak

Mode: 0.35

Range at ≈ ½ of the mode: 0.24 to 0.55

Average / Peak

Mode: 0.37

Range at ≈ ½ of the mode: 0.16 to 0.51

Number of Transformers
Annual Load Factor – Mixed Use Res/Comm

RMS / Peak
- Mode: 0.31
- Range at ≈ ½ of the mode: 0.21 to 0.38

Average / Peak
- Mode: 0.29
- Range at ≈ ½ of the mode: 0.18 to 0.34
Annual Load Factor

**RMS Average / Peak Load**
- Dominion 2018 All Transformers: 0.288
- Dominion 2018 Residential Only Transformer: 0.28
- Dominion 2018 Commercial Only Transformer: 0.35
- Dominion 2018 Mixed Use Res/Comm Transformer: 0.31
- Duke Energy Transformer LF: 0.3

**Numerical Average / Peak Load**
- Dominion 2018 All Transformers: 0.258
- Dominion 2018 Residential Only Transformer: 0.26
- Dominion 2018 Commercial Only Transformer: 0.37
- Dominion 2018 Mixed Use Res/Comm Transformer: 0.29
- Duke Energy Transformer LF: 0.2
- Toronto Hydro 2013 Residential Transformer: 0.29
- PG&E 2006 Residential **Customer**: 0.39
Annual Load Factor – Single-Phase Banks

Number of Transformers

Average Annual Load / Peak Annual Load

- **25 kVA**
  - Mode: 0.20
  - Range at ≈ ½ of the mode: 0.10 to 0.29

- **50 kVA**
  - Mode: 0.27
  - Range at ≈ ½ of the mode: 0.15 to 0.32

- **100 kVA**
  - Mode: 0.26
  - Range at ≈ ½ of the mode: 0.16 to 0.32
### Annual Load Factor – Three-Phase Banks

**75 kVA**
- Mode: 0.30
- Range at ≈ ½ of the mode: 0.20 to 0.41

**300 kVA**
- Mode: 0.30
- Range at ≈ ½ of the mode: 0.21 to 0.49

**500 kVA**
- Mode: 0.38
- Range at ≈ ½ of the mode: 0.23 to 0.54
Per Customer
Annual Load Factor – Number of Customers / Transformer Bank

Number of Transformers

1 Cust/Bank
12,232 Banks

2 Cust/Bank
8,317 Banks

3 Cust/Bank
5,661 Banks

4 Cust/Bank
5,497 Banks

Mode:

- 1 Cust/Bank: 0.15
- 2 Cust/Bank: 0.20
- 3 Cust/Bank: 0.22
- 4 Cust/Bank: 0.23

Range at ≈ ½ of the mode:

- 1 Cust/Bank: 0.09 to 0.21
- 2 Cust/Bank: 0.12 to 0.25
- 3 Cust/Bank: 0.15 to 0.27
- 4 Cust/Bank: 0.16 to 0.29
Annual Load Factor – Number of Customers / Transformer Bank

- **5 Cust/Bank**: 4682 Banks, Mode: 0.26, Range at ≈ ½ of the mode: 0.17 to 0.30
- **6 Cust/Bank**: 4055 Banks, Mode: 0.26, Range at ≈ ½ of the mode: 0.19 to 0.31
- **8 Cust/Bank**: 3066 Banks, Mode: 0.28, Range at ≈ ½ of the mode: 0.21 to 0.32
- **10 Cust/Bank**: 1887 Banks, Mode: 0.27, Range at ≈ ½ of the mode: 0.22 to 0.32

**Average Annual Load / Peak Annual Load**
The previously analyzed Toronto Hydro data did not appear to display diversity in the annual load factor – i.e. the load factor was $0.3 \pm (0.05)$ regardless of the number of customers.

However, this new Dominion data clearly shows an increase in load factor with an increase in number of customers.

Relooking at the Toronto data reveals:
1) There was an insufficient number of locations
2) An accuracy of $\pm 0.005$ is needed to display diversity (see following slide)
Annual Load Factor – Number of Customers / Transformer Bank

Dominion 1 Cust/Bank
12,232 Banks, Mixed Use
Mode: 0.15
Range at ≈ ½ of the mode: 0.09 to 0.21

Dominion 1 Cust/Bank
7194 Banks, Residential only
Mode: 0.15
Range at ≈ ½ of the mode: 0.09 to 0.20

Toronto Hydro 1 Cust/Bank
131 Banks, Residential only
Mode: 0.26
Range at ≈ ½ of the mode: 0.10 to 0.42

Average Annual Load / Peak Annual Load
Peak kW Load / Nameplate kVA
Peak kW Load / Nameplate kVA

60,725 Transformer Banks
Mix of Residential and Commercial Customers

Mode: 0.46

Range at ≈ ½ of the mode: 0.24 to 0.93

Data issues
Peak kW Load / Nameplate kVA

Residential Only
39,546 Banks

Mode: 0.51

Range at ≈ ½ of the mode:
0.27 to 0.95

Commercial Only
10,745 Banks

Mode: 0.00

0.41

Range at ≈ ½ of the mode:
0.00 to 0.66

Mixed Use
10,062 Banks

Mode: 0.53

Range at ≈ ½ of the mode:
0.24 to 0.88
Peak kW Load / Nameplate kVA

• ConEdison Overall Average **Capacity Factor** = 26% Network System Second contingency design

• Toronto Hydro – Residential Only – Mode: 0.9
• Duke Energy – Mode: 0.7
• Dominion – Overall – Mode: 0.46
• Dominion – Residential Only – Mode: 0.46
• Dominion – Commercial Only – Mode: 0.00
• Dominion – Mixed Use – Mode: 0.53
No clear correlation between customers per transformer and Peak/Nameplate ratio.
No clear correlation between customers per transformer and Peak/Nameplate ratio.
Peak-per-Unit Load:
Average kW Load / Nameplate kVA
Average kW Load / Nameplate kVA

Mode: 0.10

Range at ≈ ½ of the mode: 0.05 to 0.21
Average kW Load / Nameplate kVA

Residential Only
39,546 Banks

Commercial Only
10,745 Banks

Mixed Use
10,062 Banks

Mode: 0.10
Range at ≈ ½ of the mode: 0.05 to 0.21

Mode: 0.00
Range at ≈ ½ of the mode: 0.00 to 0.14

Mode: 0.13
Range at ≈ ½ of the mode: 0.06 to 0.23
Minimum kW Load / Peak kW Load
Minimum kW Load / Peak kW Load

Of the 60,725 transformers:
- 19 report a negative minimum load
- 43,996 report a zero minimum load
- 13 report a > 90% minimum load

Mode: 0.00
Utilization Factor:
Peak kW Load / kVA Capability
Dominion Energy uses the following multipliers of the transformer nameplate kVA to set their capability limit for normal loading:

**Single-Phase Overhead & Single-Phase Pad-Mount**
- 25 KVA – 124%
- 50 KVA – 126%
- 100 KVA – 126%
- 167 KVA – 124%
- 333 KVA – 126%
- 500 KVA – 126%

**Three-Phase Overhead & Three-Phase Pad-Mount**
- 3P-PM, 3P-SUB, 3P-OH
- 1500 KVA – 100%
- 3750 KVA – 100%
Peak kW Load / kVA Capability
46,514 Transformer Banks

Mode: 0.44

Banks with zero peak or without a capability number were excluded.

Range at ≈ ½ of the mode: 0.22 to 0.74

Data issues
Peak kW Load / kVA Capability

Residential Only
35,185 Banks

Mode: 0.37

Range at ≈ ½ of the mode:
0.22 to 0.77

Commercial Only
3429 Banks

Mode: 0.01

Mixed Use
7602 Banks

Mode: 0.45

Range at ≈ ½ of the mode:
0.23 to 0.78

Insufficient data

Number of Transformers
Peak Responsibility Factor:
Load at System Peak / Peak Load
Load at System Peak / Peak Load
58,634 Transformer Banks

Mode: 0.32

Range at ≈ ½ of the mode:
0.17 to 0.94
Load at System Peak / Peak Load

Residential Only – 38,846 Banks

Number of Transformers

Mode: 0.32

Range at ≈ ½ of the mode:
0.17 to 0.89
Load at System Peak / Peak Load
Commercial Only – 9862 Banks

Mode: 0.91

Range at ≈ ½ of the mode: 0.01 to 0.97
Load at System Peak / Peak Load

Mixed Use – 9926 Banks

Number of Transformers

Mode: 0.81

Range at ≈ ⅓ of the mode:
0.21 to 0.95
Lessons Learned

1. Add details on transformers in the transformer bank – e.g. is the 45 kVA 3Ø bank a single transformer or 3 – 15 kVA 1Ø transformers?
2. Ensure that the average load calculation sums the absolute value of the load
3. Ensure that daylight savings time change does not result in an artificial report of zero load
Appendix
Transformer Loading Terms

Load Factor: (Average load / peak load) over a specified time
Annual Load Factor: (Average yearly load / peak load for the year)
Capacity Factor: ratio of an actual electrical energy output over a given period of time to the maximum possible electrical energy output over that period. = Average Load / Capability
Utilization Factor: ratio of the maximum demand to the capacity = Max Load / Capability

IEEE C57.120 Transformer Loss Evaluation:
TLF: Transformer Loading Factor (root-mean-square of yearly load / nameplate) Energy cost varies by the load losses vary as the square of this factor.
PRF: Peak Responsibility Factor (transformer load at system peak / transformer peak load)
PUL: Peak-per-Unit Load (Average of yearly peaks over lifetime of transformer / nameplate)
Statistics Terms

**Mean**: is the "average" you're used to, where you add up all the numbers and then divide by the number of numbers.

**Median**: is the "middle" value in the list of numbers. To find the median, your numbers have to be listed in numerical order from smallest to largest, so you may have to rewrite your list before you can find the median.

**Mode**: is the value that occurs most often. If no number in the list is repeated, then there is no mode for the list.

**Standard Deviation**: is a measure that is used to quantify the amount of variation or dispersion of a set of data values. A low standard deviation indicates that the data points tend to be close to the mean (also called the expected value) of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values.

**Kurtosis**: is a measure of the "tailedness" of the probability distribution. It is a descriptor of the shape of a probability distribution.