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Impact of Electrification on Asset Life Degradation and Mitigation with DER

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Agenda

- Introduction
- Methodology
- Results
- Conclusions and future work

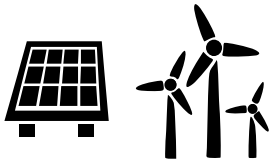
Today's Energy Landscape Is Evolving

1. **Climate change is requiring action**
   - Clean energy legislation (renewables, EE)
   - Increase in weather related outages

2. **Technology innovation is accelerating**
   - Installation base of solar is growing
   - Costs of solar/ storage are declining

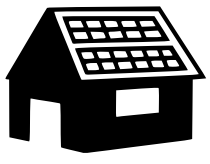
3. **Customers are increasingly digital**
   - Pervasive connectivity

Clean



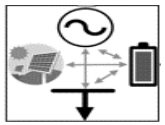
Lean

Decentralized



Communal

DERs



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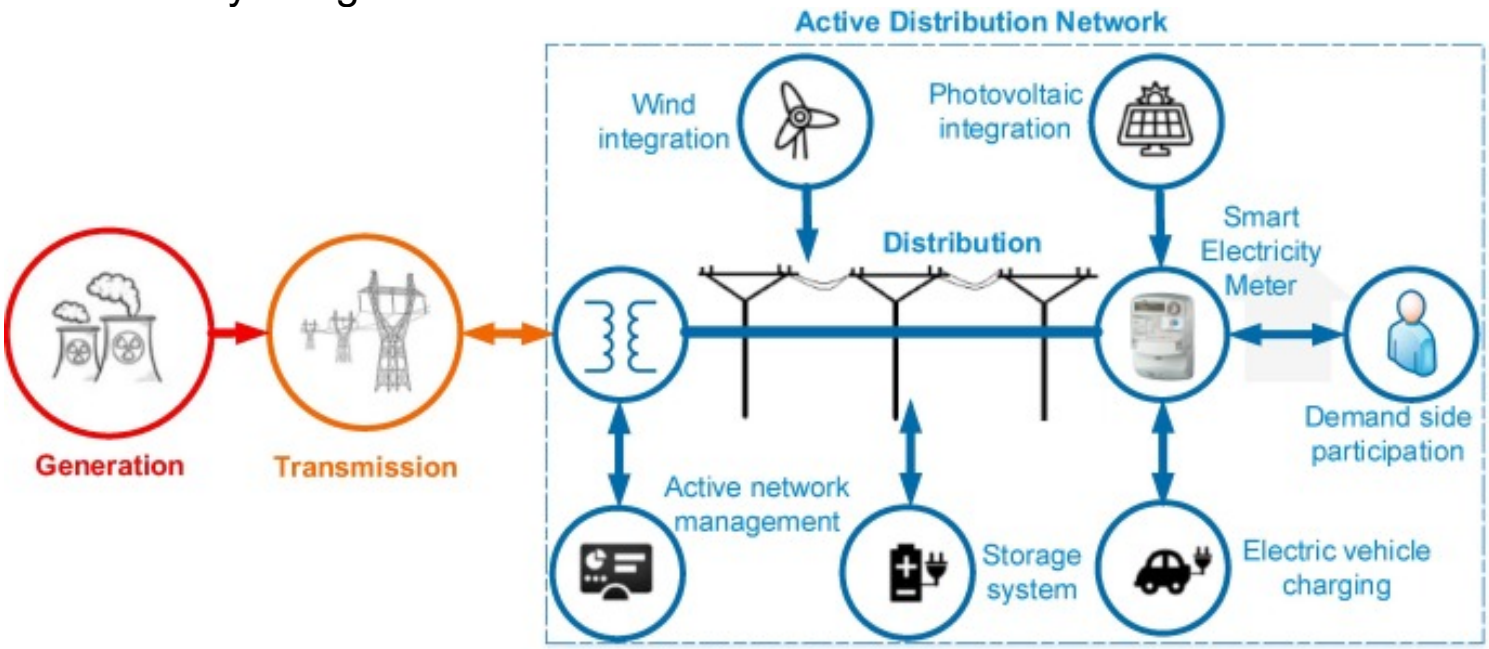
Tomorrow's distribution networks are active

- Distribution networks are currently faced with many changes
  - Resources: Distributed Energy Resources (DERs)
    - Can be dispatchable or not
    - Many are storage-like devices
      - o Complex device dynamics
      - o Valley-filling behavior



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      - Valley-filling behavior
  - Loading:
    - Electrification of loads particularly in transportation and space heating
    - Higher peak load levels as well as flatter daily and annual load shapes.
    - Valley-filling behavior results in distribution network apparatus being consistently loaded to high utilization levels.

DER can decrease peak load

DER can flatten load shapes

Asset life impacts

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- Distribution apparatus may be subject to increased operational stress compared to what it endured in the past, even if not loaded to higher net peak loads.

Asset utilization analysis aims at understanding *the impacts of these changes on asset life* and *the potential of DERs to improve asset life* under the new scenario.

Transformer loss of life

- Each clock hour of flow, reduces loss of life by more or less based on amount of flow.
- Loss of life at each hour an exponential function of the internal temperature.
- $LL(h) = L_0 \exp(k(T(h) - T_0))$
- Loss of life is cumulative, so at end of horizon total loss of life is.
- $LL^{TOT} = \sum_{h=1}^{H} LL(h) = L_0 \sum_{h=1}^{H} \exp(k(T(h) - T_0)$

h : clock hour
H: end of study horizon
L_0 : loss of life coefficient
$LL(h)$: loss of life at hour h
LL^{TOT}: cumulative loss of life at end of study horizon, *H*
T_0 : design ambient temperature, under which loss of life is negligible
$T(h)$: transformer internal temperature at hour h

Transformer internal temperature

- Equations on internal temperature dynamics:
  - The internal temperature of the transformer each hour is affected by:
    - The previous hours' internal temperature.
    - This hour's flow through the transformer
    - This hour's ambient temperature
  - $T(h) = T(h-1) + \frac{1}{M}[I^2(h)R - c\big(T(h) - T_{amb}(h)\big)]$
  - $T(h) = \frac{M}{M+c}T(h-1) + \frac{1}{M+c}I^2(h)R + \frac{c}{M+c}T_{amb}(h)$

h : clock hour
$T(h)$: transformer internal temperature at hour h
$T_{amb}(h)$: ambient temperature at hour h (in
M: coefficient used in heat dissipation component
c: coefficient used in hourly temperature difference component
$I(h)$: current magnitude at hour h
R: resistance of transformer (in per unit)

DER injection impact on transformer temperature

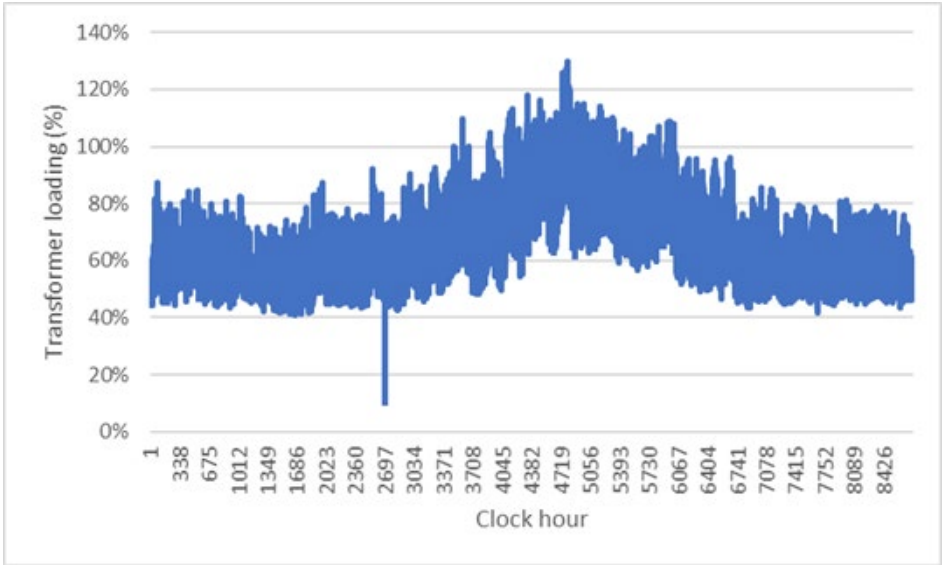
- DER injection at hour h_1 changes flow on transformer (expressed as current) at hour h.
- Sensitivity of internal temperature to current changes.

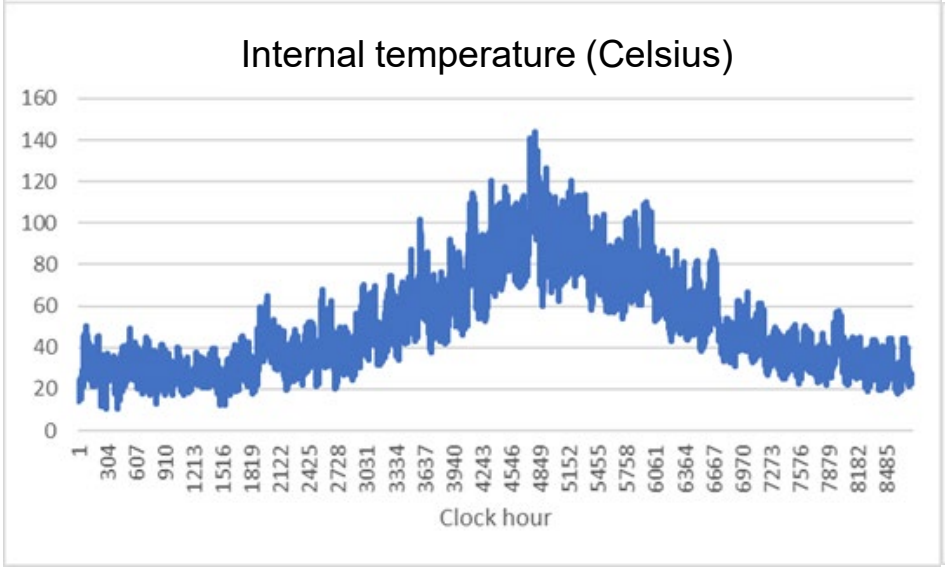
Changing the current will not affect the internal temperature of past hours

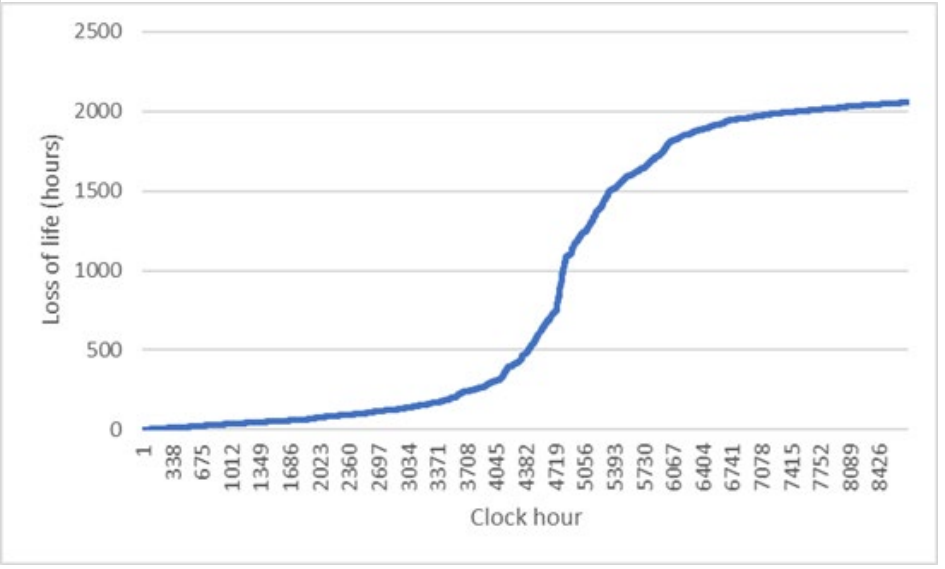
$$\frac{\partial T(h)}{\partial I(h_1)} = \frac{M}{M+c}\frac{\partial T(h-1)}{\partial I(h_1)} + \frac{2RI(h)}{M+c}\frac{\partial I(h)}{\partial I(h_1)} = \begin{cases} 0, h_1 \geq h-1 \\ \left(\frac{M}{M+c}\right)^{h-h_1}\frac{2RI(h_1)}{M+c}, h_1 < h \end{cases}$$

The effect of changing the current affects future hours with diminishing effect as time passes.

Application results: Historical loading







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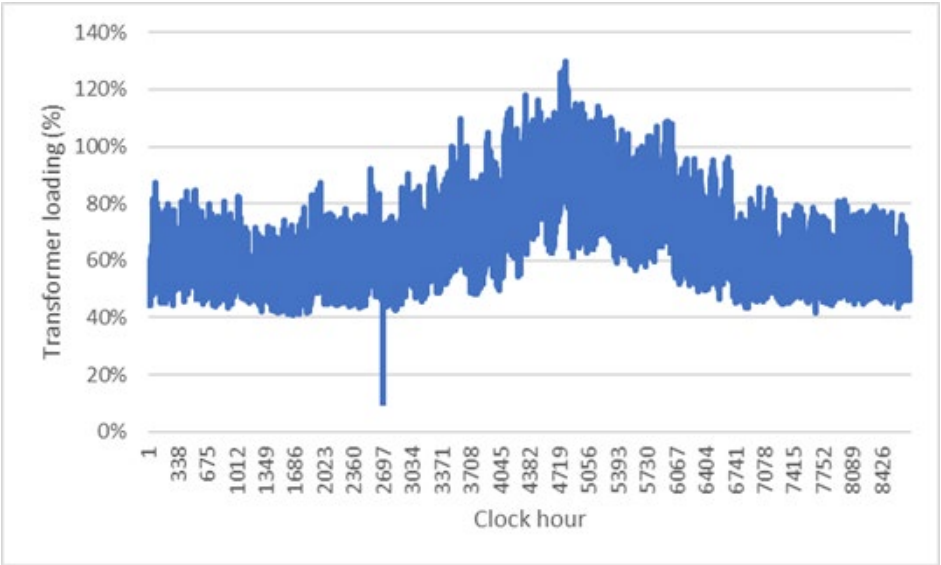
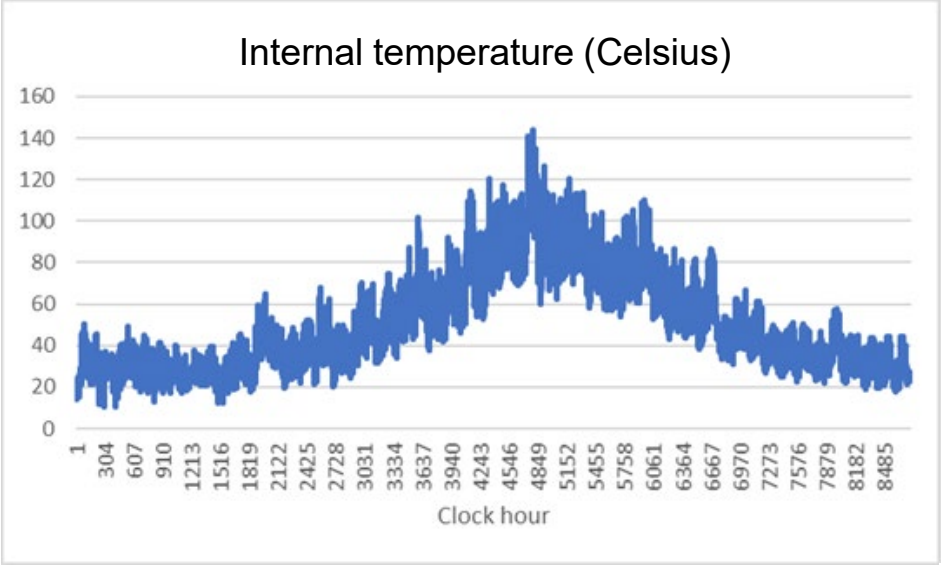
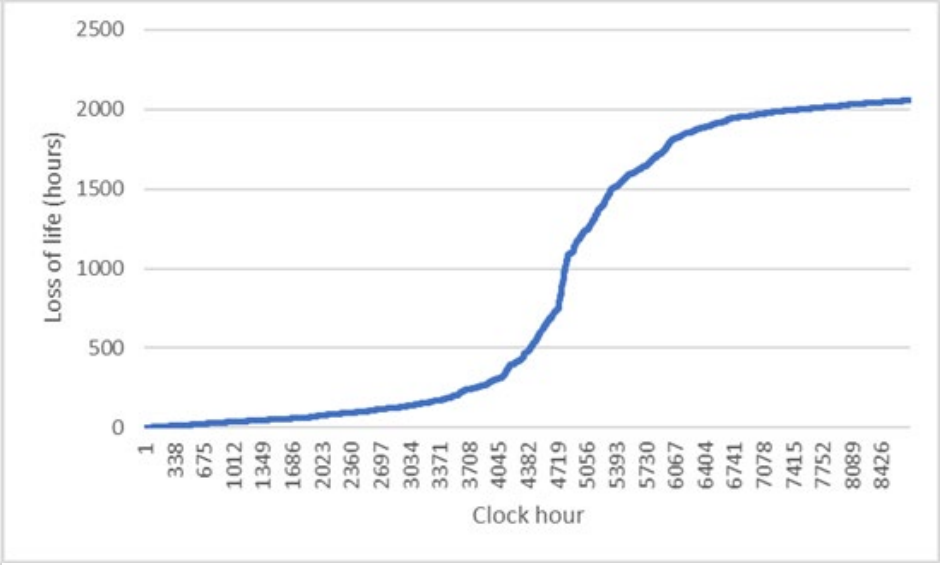
Application results: Historical loading



- Loading curve overlaid with N-1 outage
- 2057hrs of life decrease per 8760 clock hours
- Transformer lifetime is ~150,000 hours
- $\frac{150{,}000}{2{,}057}$ =73 years of life expectancy





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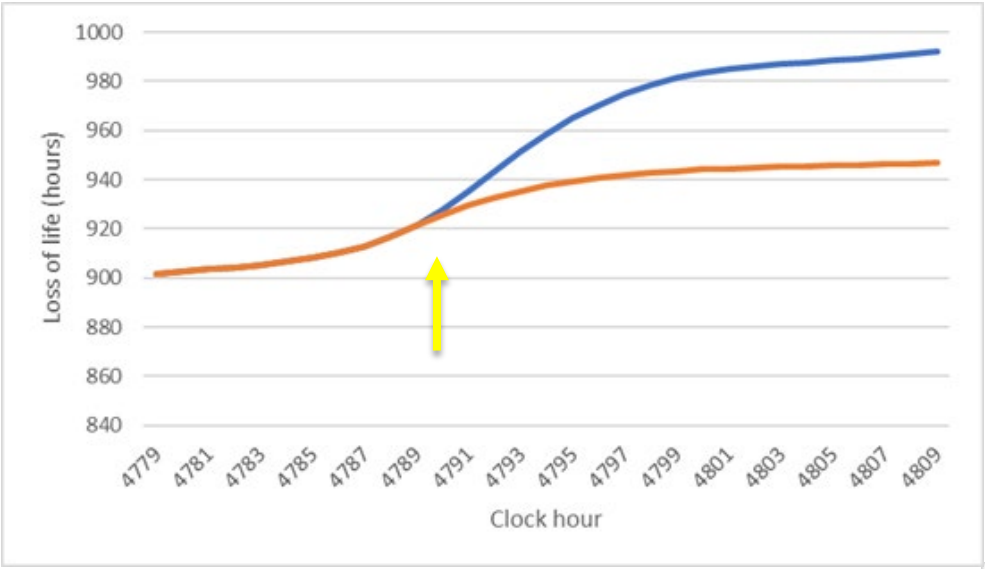
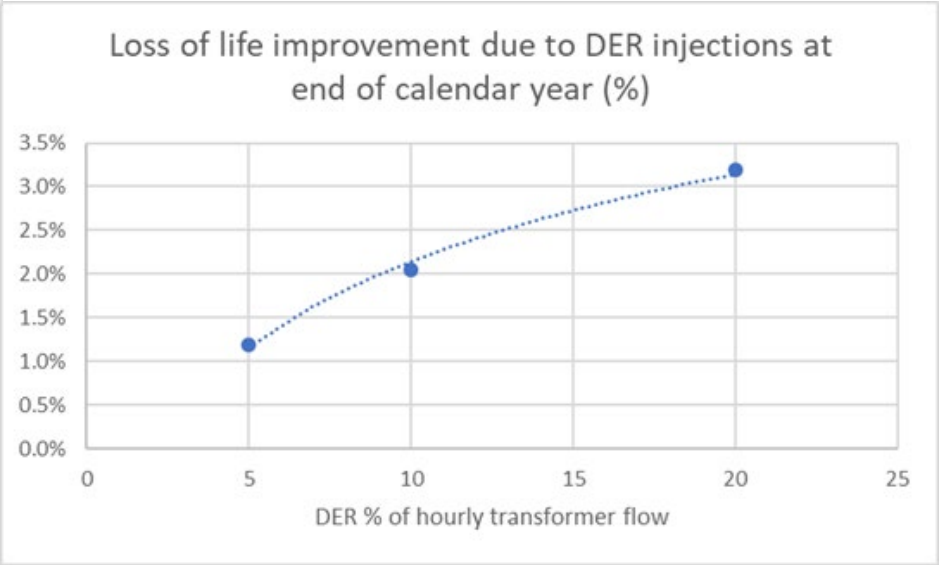


- DER injection at peak hour (h=4790)
- DER injection lasts 10 hours (h=4790 to h=4800)
- DER injection is 20% of transformer load
- DER impacts persist for more than 10 hours



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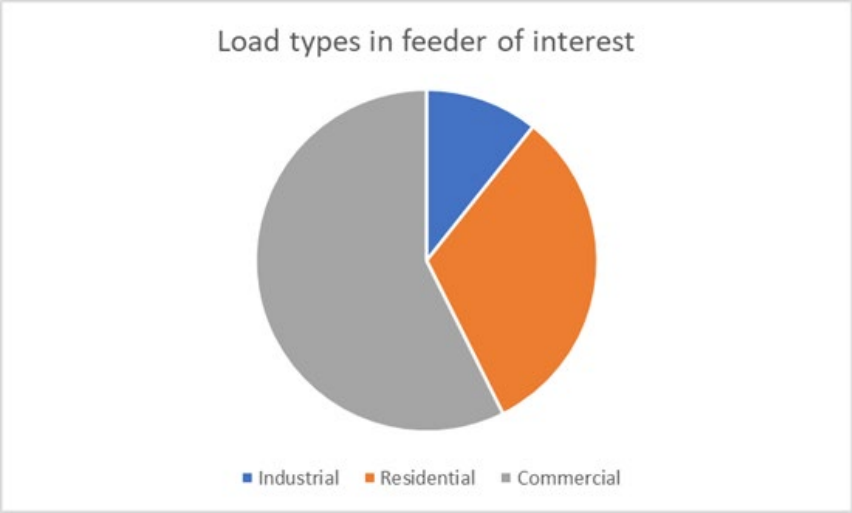
Application results: Post-electrification

- Peak increase calculated based on
  - Expected % increase of each type of load
  - % of total transformer load belonging to each type of load
    - Industrial
    - Commercial
    - Residential
    - Transportation
- Off-peak hours shifted such that difference from daily peak is halved

Industrial	0.1%
Residential	9.0%
Commercial	1.9%
Transportation	1.9%



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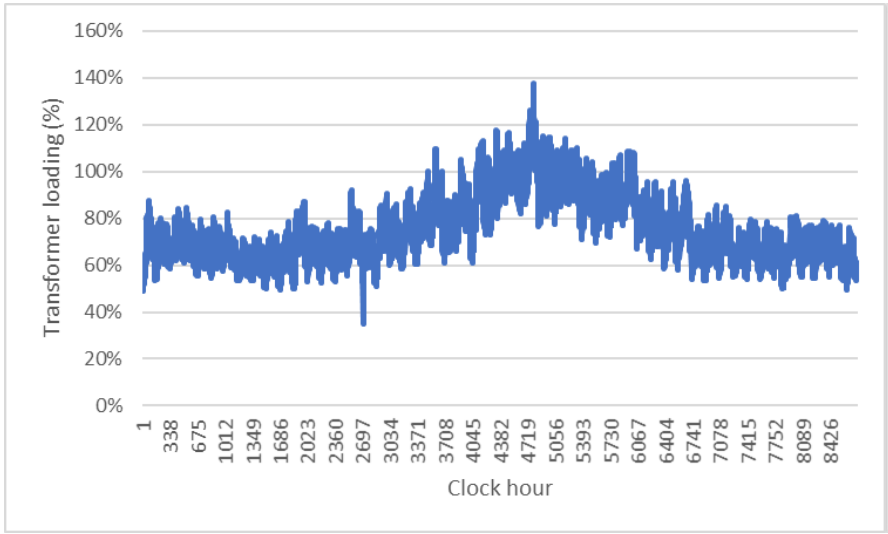

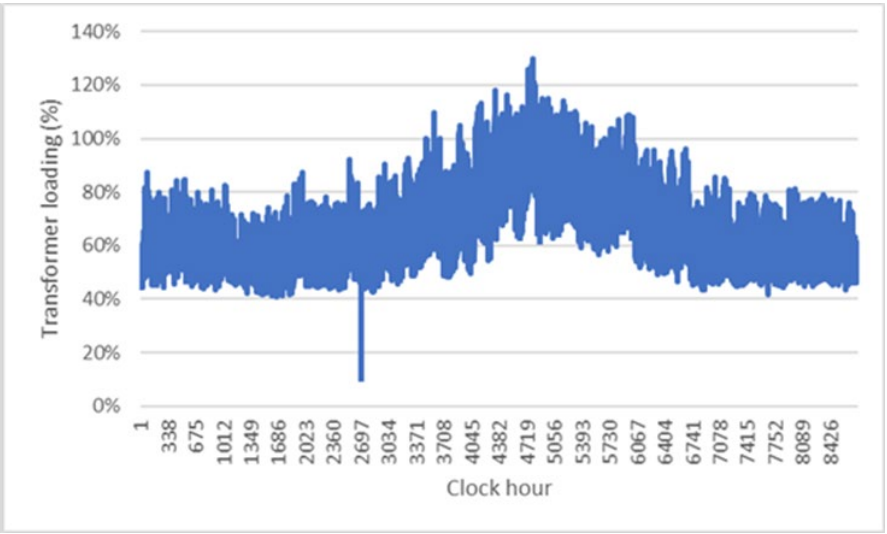

- Post-electrification
- Historical

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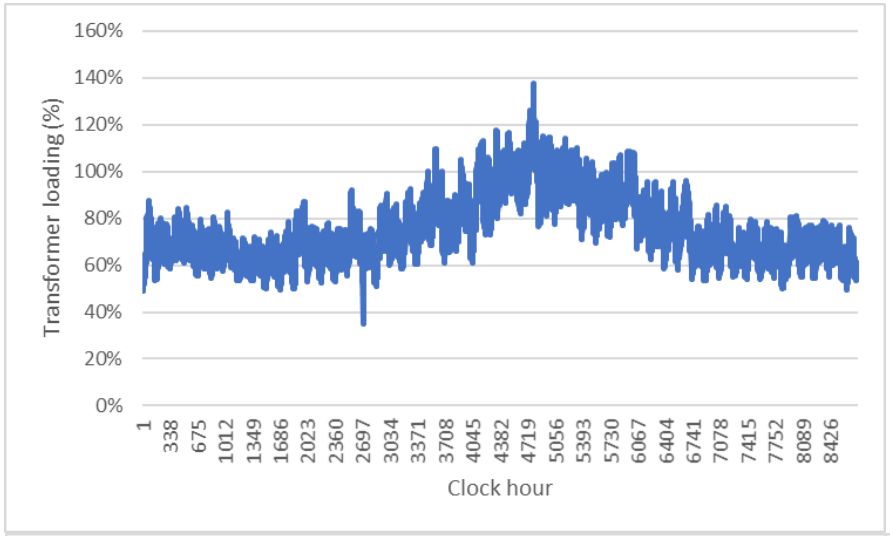

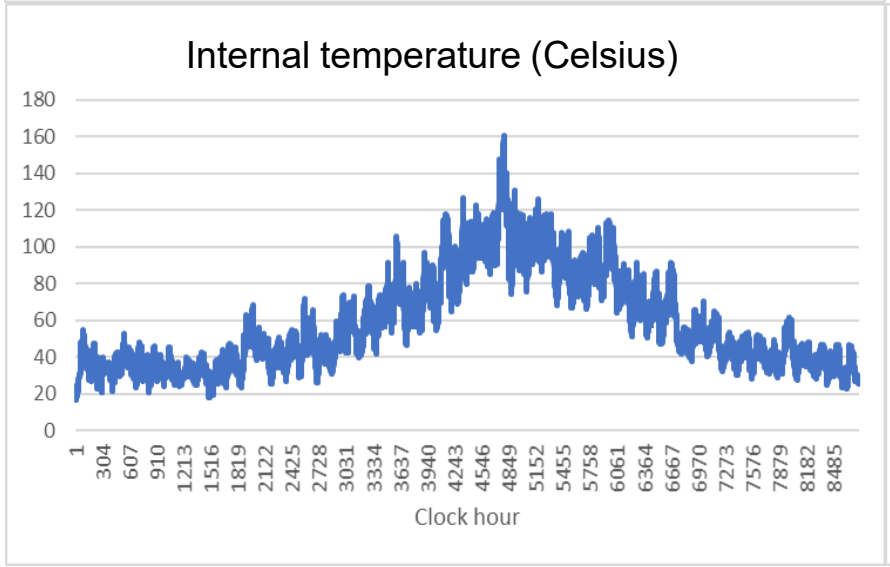

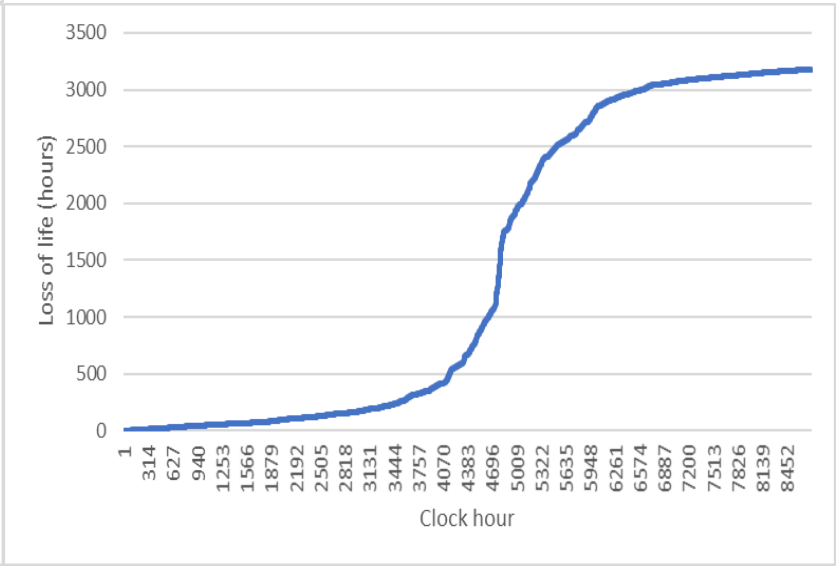

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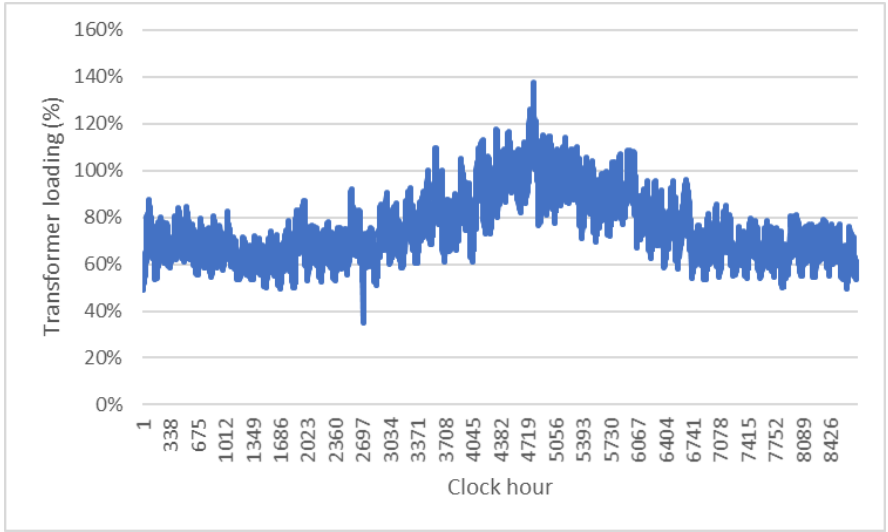
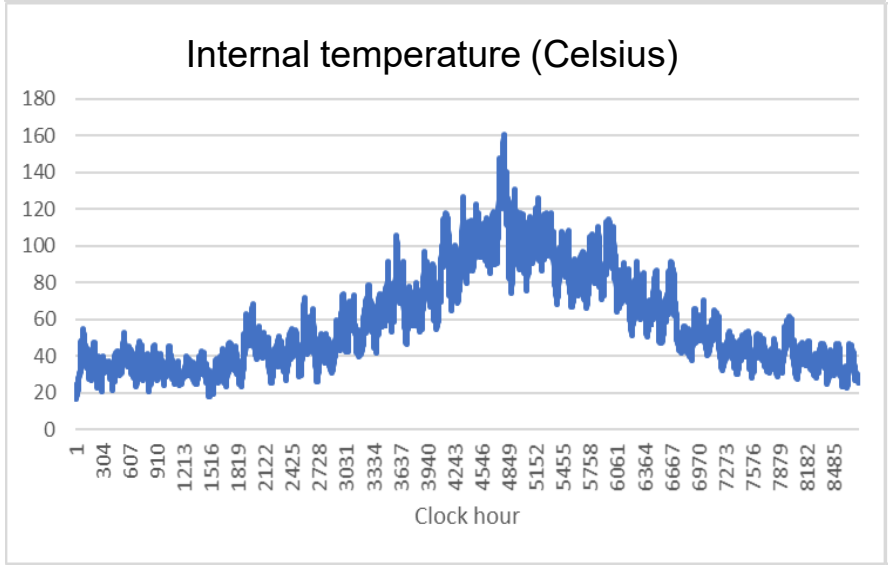
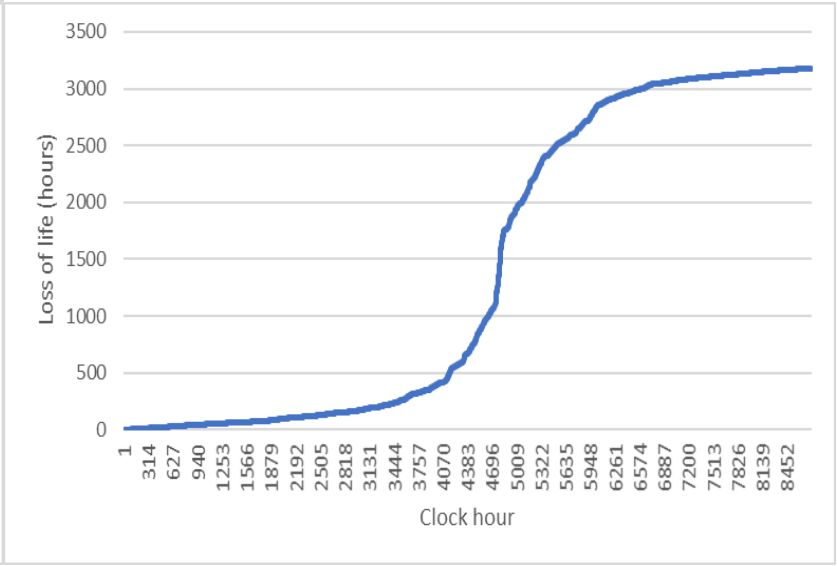


- 3178hrs of life decrease per 8760 clock hours
- Transformer lifetime is ~150,000 hours
- $\frac{150{,}000}{3{,}178}$ =47 years of life expectancy
- Life expectancy drops 35% (as compared to historical loading)





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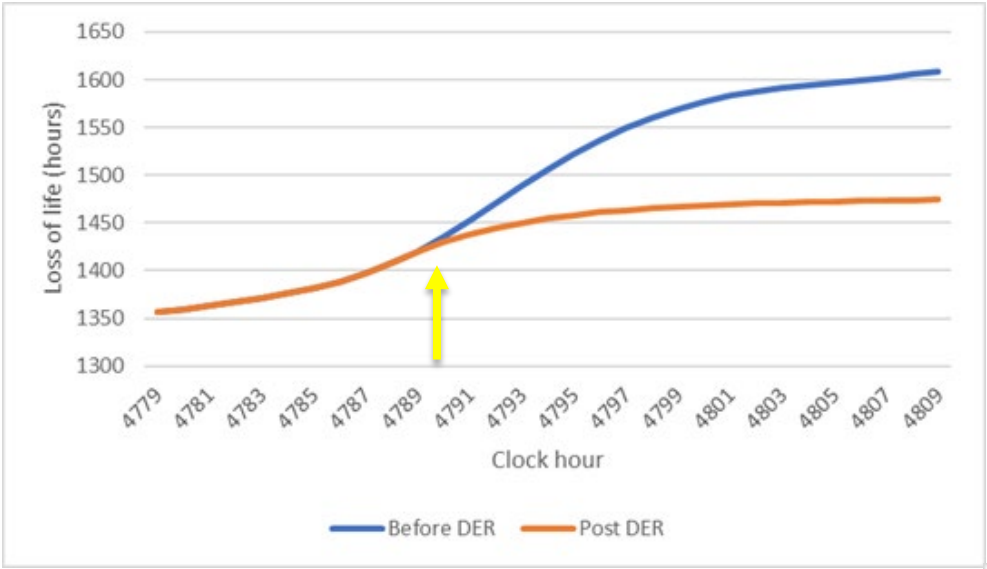

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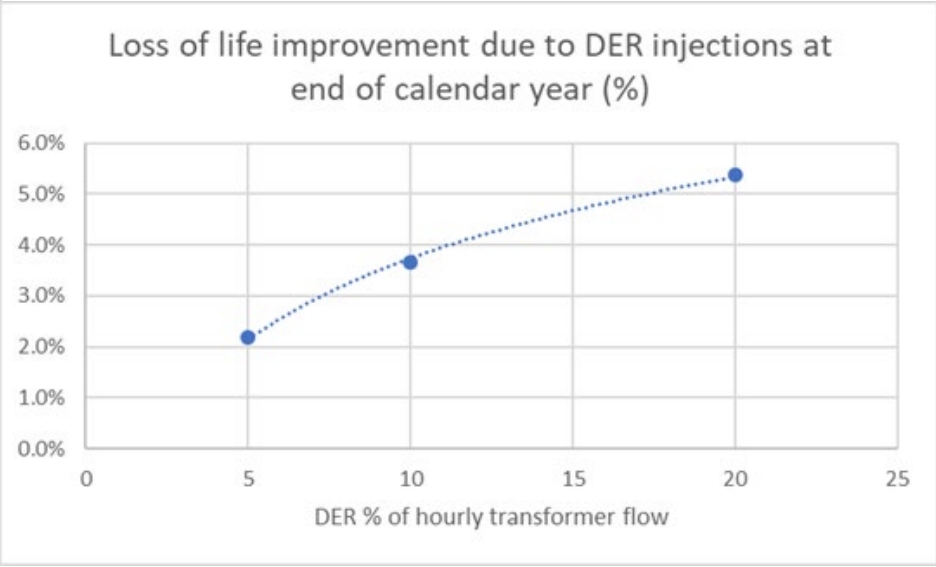

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Conclusions

- Asset life decreases more with high loading for long hours (e.g. N-1) than extreme loading for short bursts
- This means that electrification impacted curves can lead to significant asset life decrease
  - Our simulations are consistent in indicating that no cool-down can have a higher impact to loss of life than a higher daily/annual peak
- DER impact is not linear, shaving the very top of the peak is the most valuable injection and value in $/MW decreases as we provide more.
- This is true even if shaving the very peak is still leaves the transformer overloaded.

Future work

- Refine off-peak hours' rise due to electrification (flatter load profiles)
- Incorporate ambient temperature rise due to climate change/ global warming
  - High temperatures climb higher
  - Raised nighttime temperature further decrease cooling potential
- New transformer loading practices in rating, sizing and operations in the new loading environments

Thank You!

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