Analyzing Distribution Transformer Degradation with Increased Power Electronic Loads

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ABSTRACT

- The influx of **non-linear power electronic loads** into the distribution network has the potential to disrupt the existing distribution transformer operations.
- To have a good understanding of present standing challenges, a knowledge of the generation and load mix as well as the **current harmonic estimations** are essential for designing transformers and evaluating their performance.
- We investigate a mixture of essential power electronic loads for a household and their potential impacts on **transformer eddy current losses** and **derating** using **harmonic analysis**.
- Peak load conditions are chosen for each scenario to perform a transformer derating analysis. Our findings reveal that in the presence of **high-power electronic loads** (especially **3rd harmonics**), along with increasing PV generation may worsen **transformer degradation**.

MOTIVATION AND CHALLENGES

➢ **Operation of Harmonic Loading on Distribution Transformers**

Increased voltage and current harmonics lead to **premature ageing** and **degradation** of transformers. Variable frequency drives contribute to more **3rd harmonics** and if not properly compensated would lead to additional losses.

➢ **Lack of High-Fidelity Load Models**

"ZIP" based traditional load models lack the **cross-coupling effects** of voltages and currents that can represent the enhanced harmonic spectrum essential to understand the effects of harmonics on transformer losses.

THE PROPOSED FRAMEWORK

The proposed framework utilizes development of high-fidelity models for various power electronic household appliances in **PSCAD**.

❑ **Eddy Current Losses**

The eddy current losses of a distribution transformer can be categorized into the **frequency** and **non-frequency** dependent part, given by (1). The harmonic induced eddy current losses are summarized as (2).

$$Tr_{EC} = I_1^2 R_{DC} + \sum_{h=1}^{h_{max}} I_h^2 R_h \quad (1)$$

$$Tr_{EC} = P_{EC-R} \sum_{h=1}^{h_{max}} I_h^2 R_h \quad (2)$$

Tr_{EC} - Eddy current loss
R_{DC} - dc winding resistance
I_1 - Fundamental current
I_h - Current harmonics
R_h - Effective resistance comprising of non-frequency and frequency component
P_{EC-R} - winding eddy current loss factor

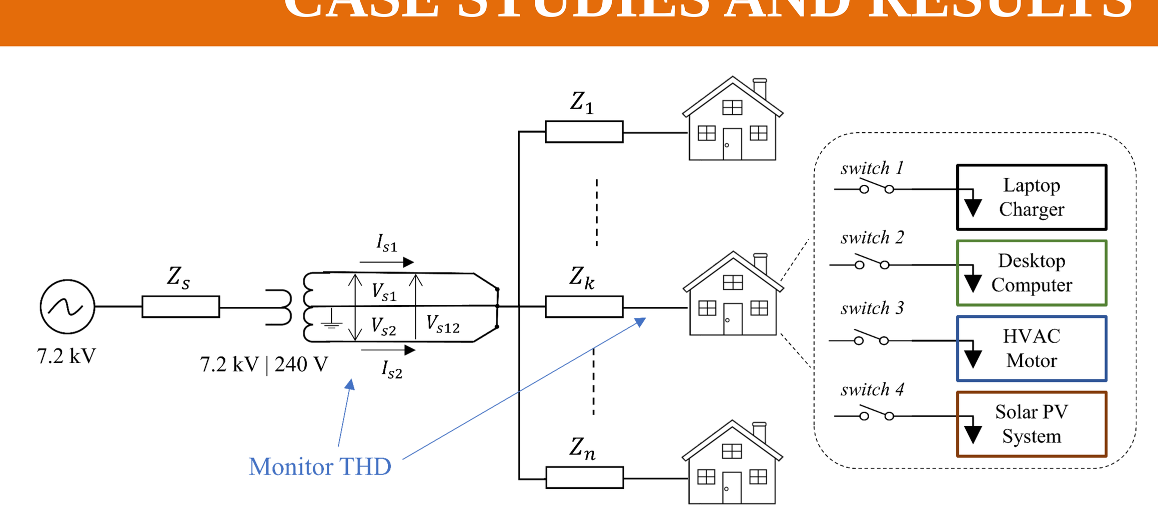
❑ **Harmonic Loss Factor**

Harmonic loss factor is defined as the ratio of the total loss due to **eddy current** due to harmonics and the **winding current losses** in the absence of harmonics, it is given as (3).

$$F_{HL} = \frac{\sum_{h=1}^{h_{max}} I_h^2 h^2}{\sum_{h=1}^{h_{max}} I_h^2} \quad (3)$$

F_{HL} - Hamonic loss factor

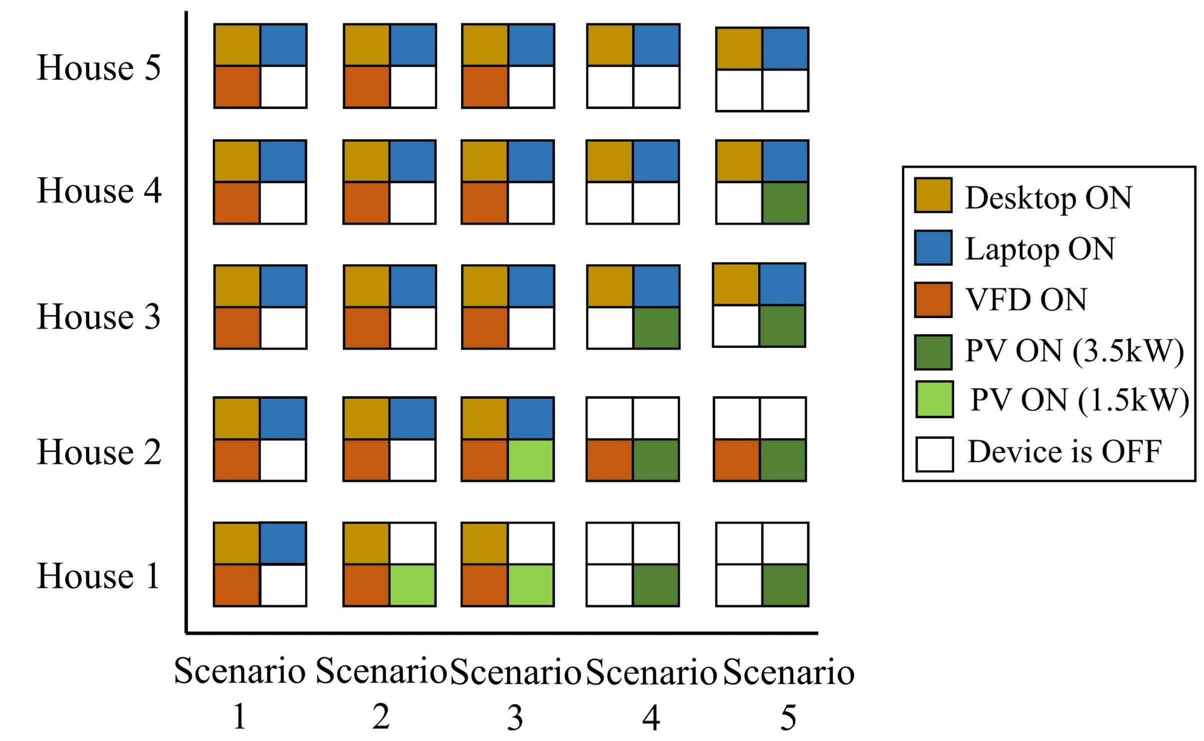
CASE STUDIES AND RESULTS



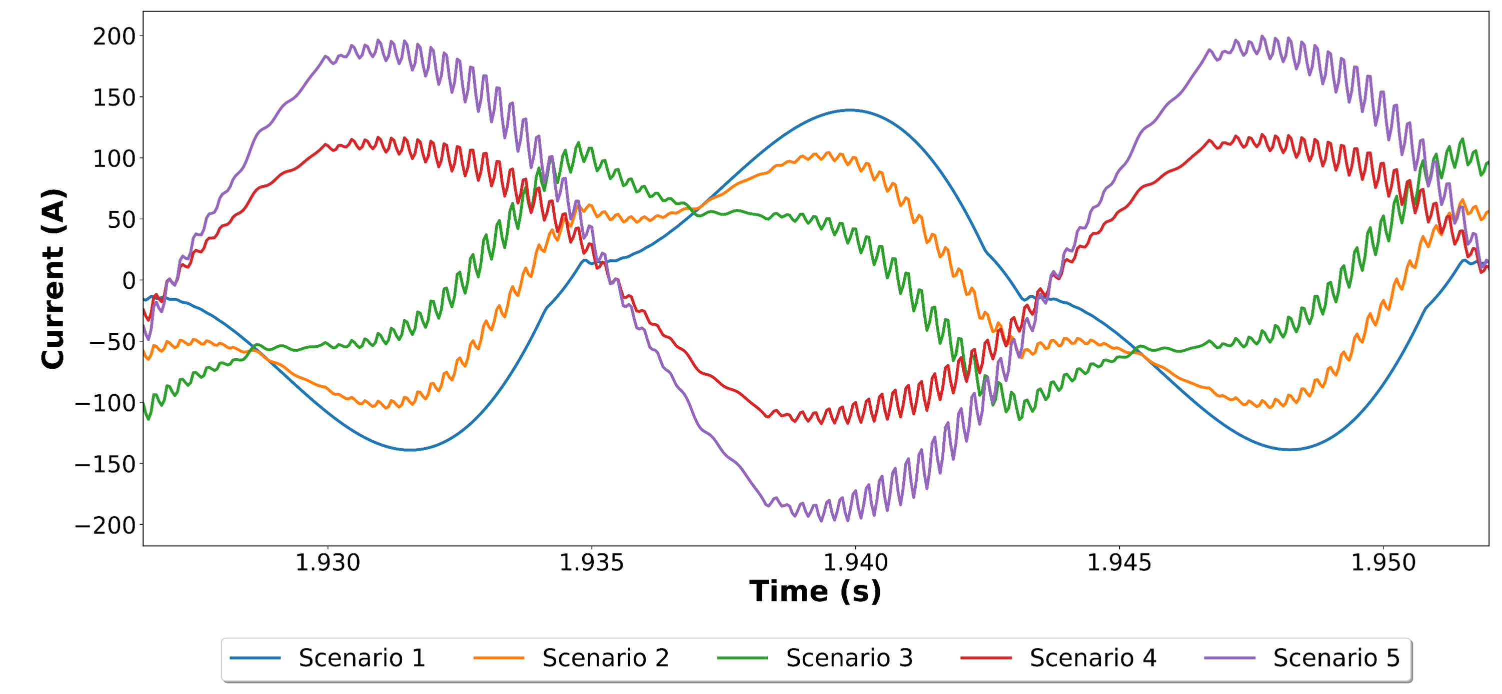
Simulation setup in PSCAD comprising of 5 houses connected to a distribution transformer.

Scenarios	PV units	Peak Load Time	Total PV generation	Total other load	Net load
1	0	evening	0 kW	9.5 kW	9.5 kW
2	1	evening	1.5 kW	9.5 kW	8 kW
3	2	evening	3 kW	9.5 kW	6.5 kW
4	3	day	10.5 kW	2.5 kW	-8 kW
5	4	day	14 kW	2.5 kW	-11.5 kW

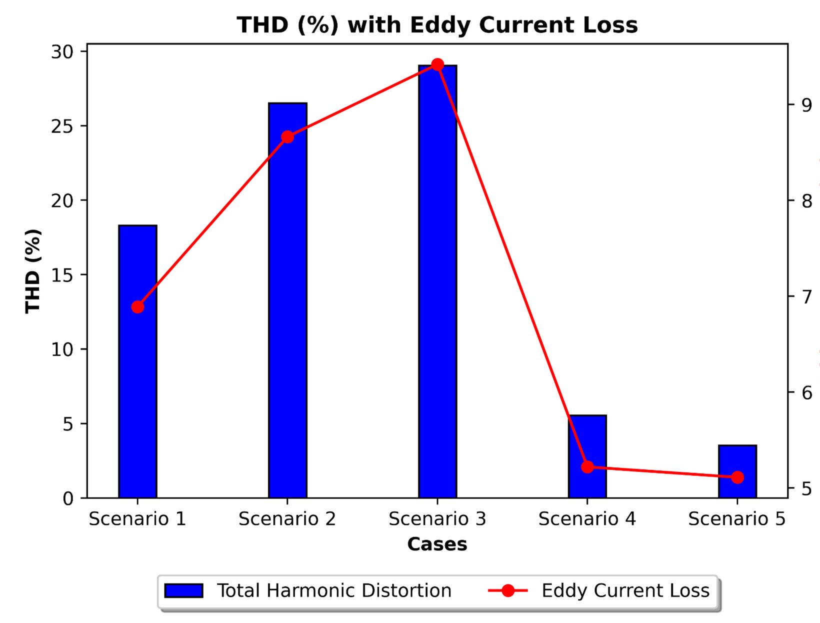
5 scenarios represented in the table represented the peak loads during different times of the day.



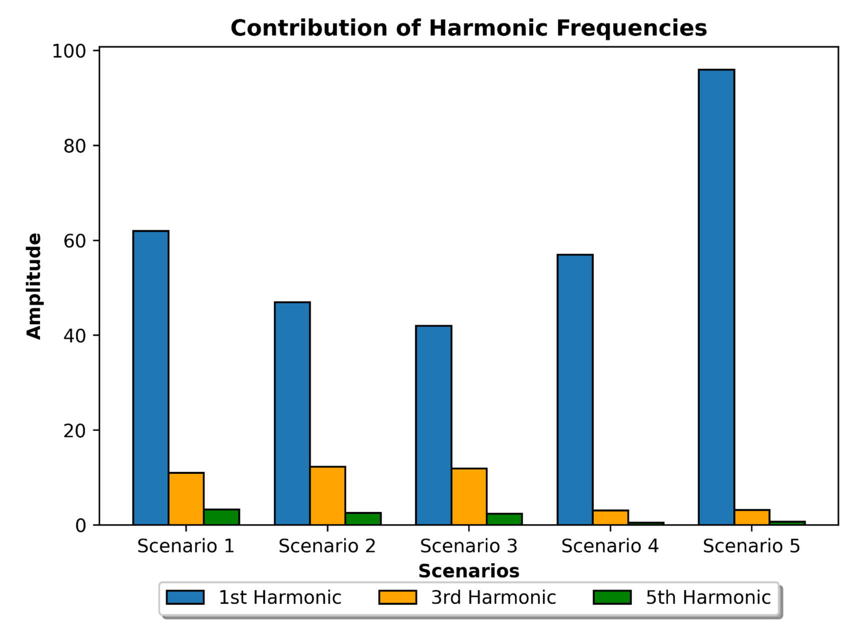
Load combination of 5 houses corresponding to a different scenario representing a peak load combination.



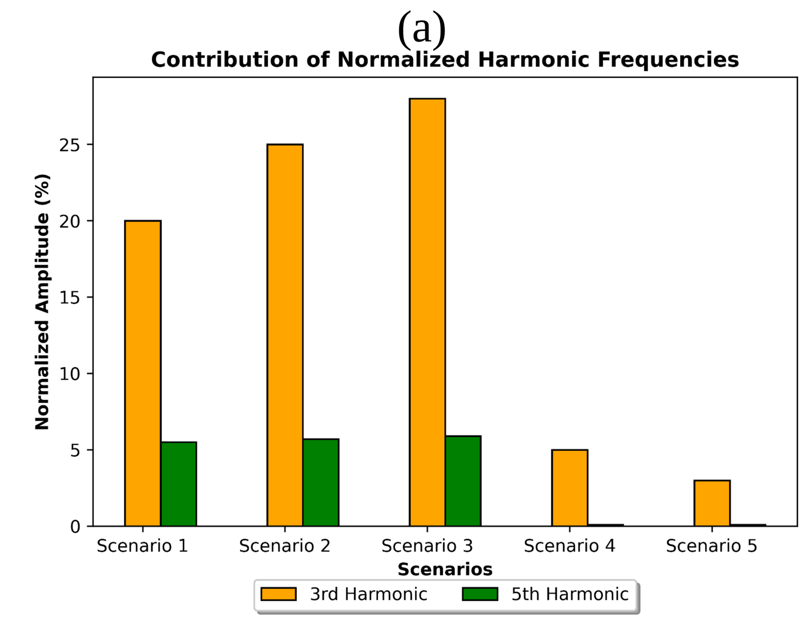
Equivalent transformer secondary current under different scenarios.



(a)



(b)



(c)

Scenarios	THD (%)	Tr_{EC} (%)	Derating (%)
1	18.30	6.89	85.59
2	26.51	8.66	78.59
3	29.05	9.41	75.88
4	5.55	5.22	98.01
5	3.52	5.11	98.95

(d)

(a) THD(%) along with eddy current losses for different load combinations and PV penetration. (b) Harmonic frequency spectrum of the secondary transformer under various load combinations and PV penetrations. (c) Variation of normalized frequency spectrum of 3rd & 5th harmonic with respect to fundamental current magnitude with different load and PV penetration scenarios. (d) Impact on transformer degradation in terms of eddy current loss and transformer derating.

CONCLUSIONS AND FUTURE WORK

❑ Transformers by operation are linear devices and non-linear loads make their operation non-linear, that degrades their performances over time.

❑ Integration of PV resources to compensate for the transformer loading had an **adverse effect** with increased levels of **3rd harmonic** for **scenario 2 and 3**.

❑ Addition of PV helps to **lower THD (%)** under low power electronic loading conditions.

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