Persistence of Excitation in an Online Monitoring of Transformer: A System Identification Perspective

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Abstract:

- For effective online monitoring to assess thermal performance and life expectancy, Top-oil temperature (TOT) and Hot spot Temperature (HST) should be accurately estimated.
- Thermal-electrical analogy is used for the model based on the Resistance-Capacitance (RC) circuit to approximate the evolution of thermal performance.
- The Gradient-based estimation guarantees the convergence of the parameter estimation error to zero only when the Persistence of Excitation (PE) condition holds for regressor signals.
- As the choice of input-output data used for parameter identification is crucial, the Design of Experiment (DoE) is generally performed in the laboratory to satisfy PE conditions.
- **Index terms**: HST, LoL, Persistence of excitation, Parameter estimation, TOT,

PE condition in Thermal Model

$$\underbrace{\frac{d\vartheta_{\tau o\tau}}{dt}}_{y} = \underbrace{\left(\frac{1}{\Gamma_{\tau o\tau}}\right)}_{P_1}\underbrace{(-\vartheta_{\tau o\tau}+\vartheta_{a\tau})}_{w_1}+\underbrace{\frac{\Delta\vartheta_{\tau o\tau R}}{(1+M)\Gamma_{\tau o\tau}}}_{P_2}\underbrace{1}_{w_2}+\underbrace{\frac{\Delta\vartheta_{\tau o\tau R}(M)}{(1+M)\Gamma_{\tau o\tau}}}_{P_3}\underbrace{L_{pu}^2}$$

$$y = \begin{bmatrix} w_1 & w_2 & w_3 \end{bmatrix}\begin{bmatrix} P_1 & P_2 & P_3 \end{bmatrix}^T = W^T(t)\,P$$

Gradient estimator for an LRE

$$\dot{\eta}(t) = \gamma W(t)[g - W^T(t)\eta] = \gamma W(t)\mu(t)$$

The gradient parameter error equation

$$\dot{m}(t) = -\gamma W(t)\mu(t) = -\gamma W(t)W^T(t)m(t)$$

The solution of parameter error equation

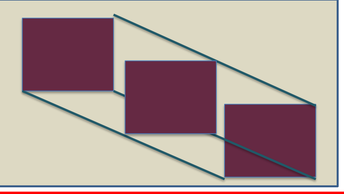
$$m(t) = exp\left[-\gamma\int_{t_0}^{t} W(\tau)W^T d\tau\right] m_0$$

Persistence of Excitation condition

$$\int_{t}^{t+T} W(\tau)W^T(\tau)d\tau \geq \rho I$$

Design of Experiments:

- Optimal input design to explore the complete environment
- Laboratory experiment and Hankel rank



Introduction:

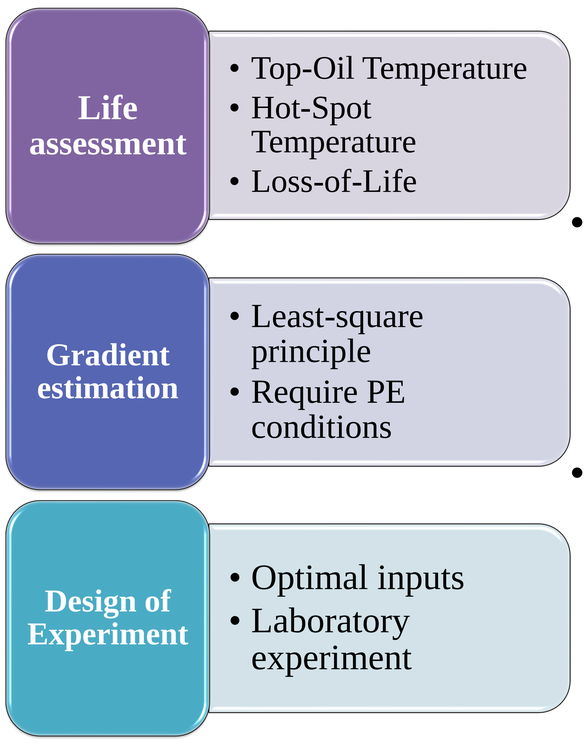


Fig. 1 Overall Background

- The TOT evaluation require extensive knowledge about the parameters of thermal model (The exponent ($\wp$), rated value of oil temperature gradient ($\Delta\vartheta\tau o\tau R$)), and rated oil time constant ($\Gamma\tau o\tau$).
- Due to dependence nature of LoL, HST, and TOT, it becomes necessary to estimate parameters accurately from data by the in-service transformer.
- Data set of input vector x = [$\vartheta\tau o\tau$ (k − 1), Lpu, $\vartheta a\tau$], and the output y = $\vartheta\tau o\tau$ (k) which are not sufficiently rich represent a key challenge in identifying the TOT model for an in-service transformer

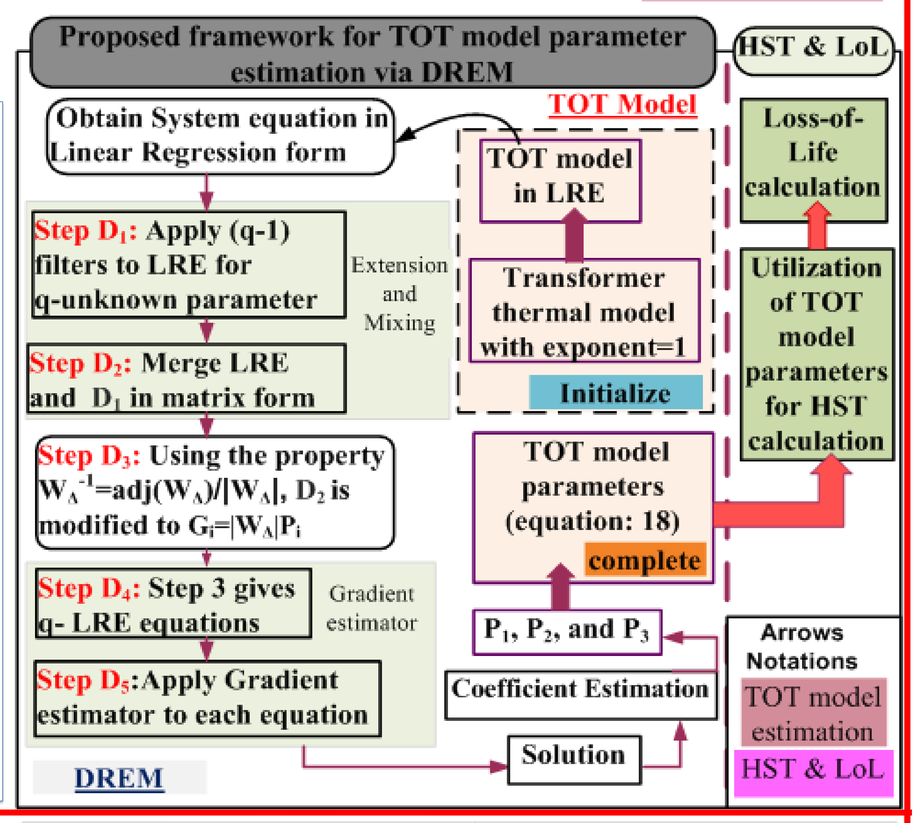
Proposed FTE & Estimation

MREM

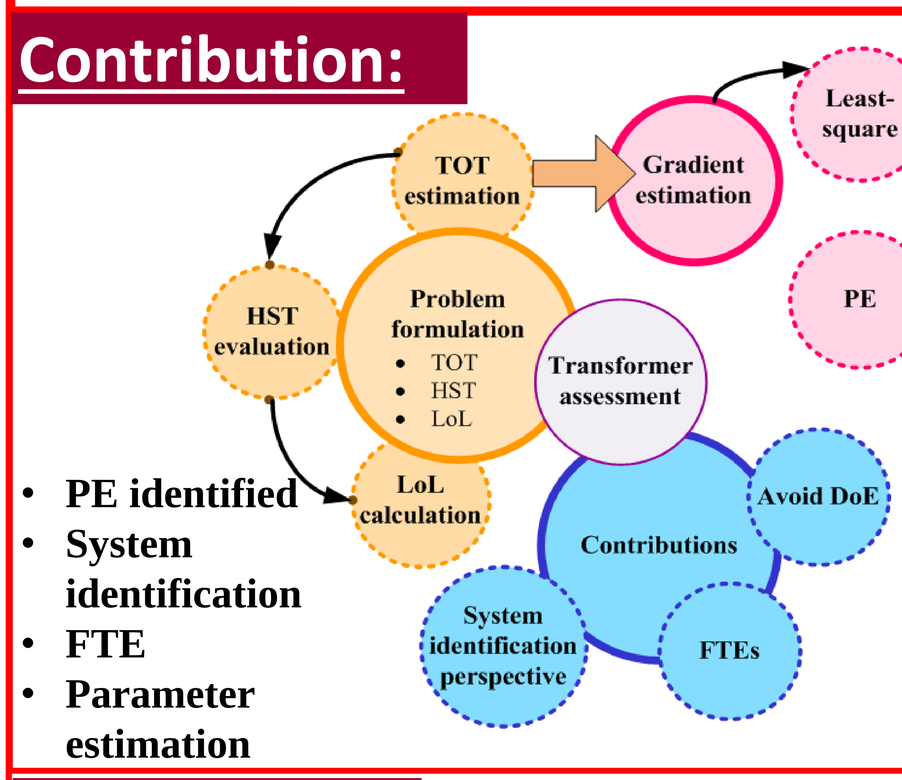
Procedure

- LRE
- Regressor multiplication
- LRE in Matrix
- Application of filter
- Matrix form
- Application of Gradient estimator
- Estimation of Parameters

DREM

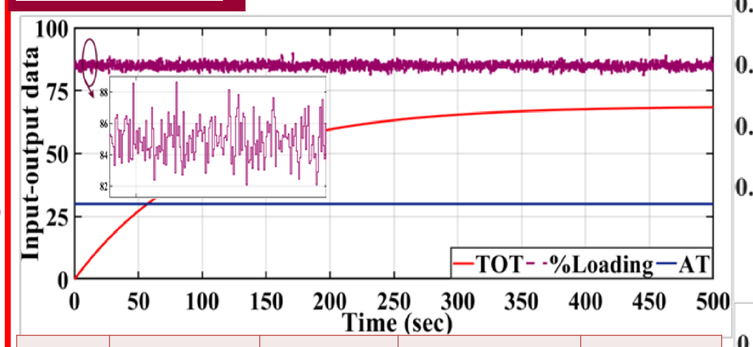


Contribution:

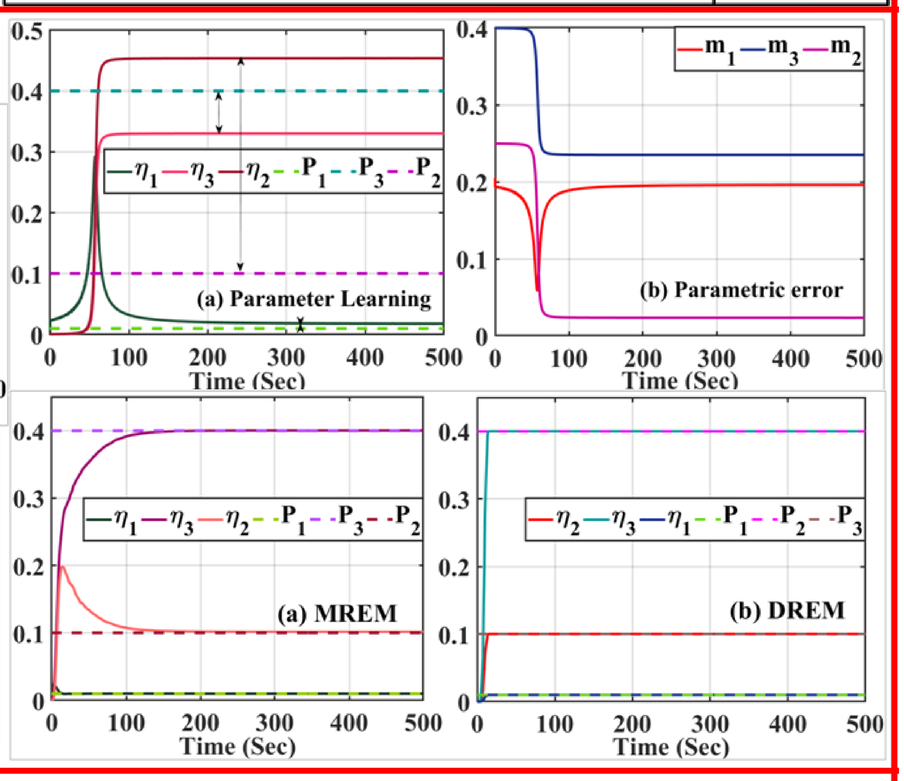


- PE identified
- System identification
- FTE
- Parameter estimation

Results



P	Actual	GE	MREM	DREM
P1	0.01	0	0.0084	0.0099
P2	0.1	0.0005	0.0405	0.097
P3	0.4	0.0058	0.399	0.39



References:

[1] D. Susa, M. Lehtonen, and H. Nordman, "Dynamic thermal modelling of power transformers," IEEE Trans on Power Delivery, vol. 20, no. 1, pp. 197–204, Feb. 2005

[2] B. C. Lesieutre, W. H. Hagman, and J. Kirtley, "An improved transformer top oil temperature model for use in an on-line monitoring and diagnostic system," IEEE Trans on Power Delivery, vol. 12, no. 1, pp. 249–256.

[3.] Swift, G., Molinski, T.S. and Lehn, W., 2001. A fundamental approach to transformer thermal modeling. I. Theory and equivalent circuit. *IEEE transactions on Power Delivery*, *16*(2), pp.171-175.

[4] Swift, G, "A fundamental approach to transformer thermal modeling. II. Field verification. *IEEE trans on PD.*

Publications:

[1.] **Syed Shadab**, J. Hozefa, K. Sonam, S. Wagh, and N. M. Singh, "Gaussian process surrogate model for an effective life assessment of transformer considering model and measurement uncertainties," Int Journal of Electrical Power & Energy Systems, vol. 134, p. 107401, 2022.

[2.] **Syed Shadab** "Persistence of excitation in an Online Monitoring of Transformers", Power and Energy Society (PES) General Meeting (GM), 2022 [In proceedings].

[3.] **Syed Shadab,** G. Revati, S. R. Wagh, and N. M. Singh, "Finite-time parameter estimation for an Online Monitoring of Transformer: A system Identification Perspective," Int Journal of Electrical Power & Energy Systems.