Identification of a best thermal formula and model for oil and winding 0f power transformers using prediction methods

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Abstract

System identification is about building models from data. A data set is characterized by several pieces of information: The input and output signals, the sampling interval, the variable names and units, etc. Similarly, the estimated models contain information of different kinds, estimated parameters, their covariance matrices, and model structure and so on. In this paper we collected Temperature of oil and winding in 230/63kv transformer of SARI Substation and considered the winding temperature for input in the model and oil temperature for out put. After that calculated their data by MATLAB software and get a new model with the good best fit for the heat transfer from core and winding to oil. For verification of were calculated results, has been simulated the process in COMSOL Software.

Index: best fit, simulation, identification, error, model

1. Introduction

The system identification problem is to estimate a model of a system based on the observed input-output data. Several ways to describe a system and to estimate such descriptions exist.

This paper provides a brief account of the most important approaches.

The procedure to determine a model of a dynamic system from observed input-output data involves three basic ingredients:

- The input-output data
- A set of candidate models (the model structure)
- A criterion to select a particular model in the set, based on the information in the data (the identification method)

The typical identification process consists of stages where you iteratively select a model structure, compute the best model in the structure, and evaluate this model's properties. This cycle can be itemized, as follows:

1) Design an experiment and collect input-output data from the process to be identified.
2) Examine the data. Polish the data by removing trends and outliers, and select useful portions of the original data. You can also apply filters to the data to enhance important frequency ranges.
3) Select and define a model structure (a set of candidate system descriptions), within which a model is to be found.
4) Compute the best model in the model structure according to the input-output data and a given criterion for goodness of fit.
5) Examine the properties of the model obtained. If the model is good enough, then stop; otherwise go back to step 3 to try another model structure. You can also try other estimation methods (step 4), or work further on the input-output data (steps 1 and 2).

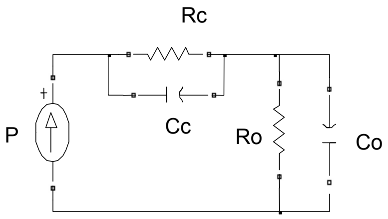
For step 2, the System Identification offers routines to plot the data, filter the data, and remove trends in the data, as well as to resample and reconstruct missing data.

For step 3, there are a variety of nonparametric models, the most common black-box input-output and state-space structures, as well as general tailor-made linear state-space models in discrete and continuous time.

For step 4, general prediction error (maximum likelihood) methods, as well as instrumental variable methods and subspace methods, are offered for parametric models, while basic correlation and spectral analysis methods are used for nonparametric model structures.

For examining the models in step 5, many functions are provided to compute and present frequency functions, poles, and zeros, as well as to simulate and predict with the model. There are also functions for transforming between continuous-time and discrete-time model descriptions.

In figure 1 a conventional thermal model is represented.



Rc: thermal resistance between core and oil

Ro: thermal resistance between oil and ambient

Cc: thermal capacitance core and winding

Cc: thermal capacitance oil

P: heat generation in core and winding per watt

Figure 1: Model of heat generation and transfer in power transformer in the above and so tank and windings&cores of power transformer, in the below.

The constructed thermal model is employed to predict the bottom-oil temperature θ_{oil-in} and top-oil temperature $\theta_{oil-out}$ that can be expressed by a set of ordinary, first-order differential equations. After comparing the matrix of the thermodynamics equations with the basic electric principles, the computation is undertaken using the following differential equations:

$$Pdt = G\theta dt + c_p m d\theta \qquad (1)$$

or $$P = G\theta + {}^{Cd\theta}\!/_{dt} \qquad (2)$$

where P is the heat power as a vector, G is the heat conductance matrix, C is the heat capacitance matrix, θ is the temperature rise vector, in is the mass of a specific object, cp is the specific heat capacity, and d is the differential operator.

2. Experimental Data

A thermal test have performed on 230/63/20 kv, 250MVA power transformers, in SARI substation, Iran. The result of test have used for input data of calculation and simulations.

Table 1: transformer data from IEEE guide 1995[17]

Description	Value	
No Load (W)	78,100	
Pdc losses (W)	411,786	
Eddy losse (W)s	41,200	
Nominal Voltage	118 kv	230kv
Pdc at HST location	467	527
Eddy current losses at HST	309(0.65pu)	157(0.3pu)
p.u. height to winding HST	1	1
Temperature Rise ºC		
Rated top oil rise	38.3	
Rated top duct oil rise	38.8	
Rated hot spot rise	58.6	50.8
Rated average winding rise	41.7	39.7
Rated bottom oil rise	16	
Initial top oil	38.3	
Initial top oil duct	38.3	
Initial average winding	33.2	
Initial bottom oil	28	
Initial hot spot	38.3	
Transformer components weights (kg)		
Mass of core and oil assembly	172,200	
Mass of tank	39,700	
Mass of oil	37,887	

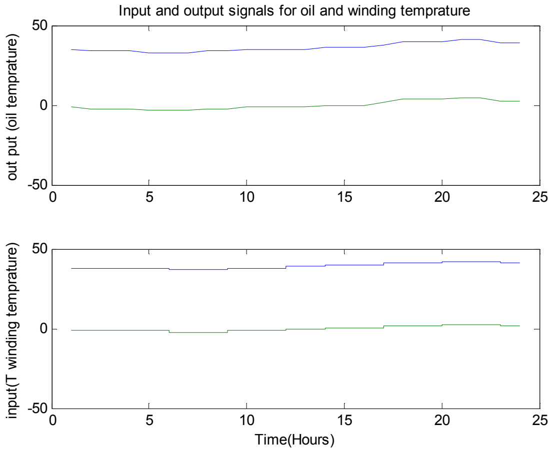


Figure2: Measured winding and oil temperature of 230/63/20kv SARI transformer no.1 (TV).

That group's of data that could not been available and hasn't been on nameplate or manual service catalog of power transformer has used by Table 1 data's, and they present the necessary data for calculation and simulations.

Table2: Temperature of oil and winding in 230/63/20kv SARI Substation at 21Feb. 2006

Temprature of oil and winding in 230/63kv Pounel Substation at 21FEB. 2006								Hours
T2				T1				
oil	winding			oil	winding			
	HV	LV	TV		HV	LV	TV	
39	40	41	36	35	42	41	38	1
38	39	40	36	34	41	40	38	2
38	39	40	36	34	41	40	38	3
38	39	40	36	34	40	39	38	4
37	38	39	36	33	38	38	38	5
37	38	39	36	33	37	37	37	6
36	37	38	36	33	36	37	37	7
38	38	38	36	34	38	37	37	8
39	38	38	36	34	39	38	38	9
40	39	39	35	35	40	38	38	10
40	39	39	35	35	40	39	38	11
41	40	41	35	35	41	39	39	12
41	40	41	36	35	41	40	39	13
42	41	42	37	36	42	41	40	14
42	41	42	37	36	42	41	40	15
42	41	42	37	36	42	41	40	16
43	42	43	38	38	43	42	41	17
43	43	44	39	40	45	44	41	18
44	44	44	39	40	45	44	41	19
45	45	45	40	40	45	44	42	20
45	45	45	40	41	46	45	42	21
44	45	45	40	41	47	45	42	22
44	44	44	39	39	47	44	41	23
44	45	44	39	39	46	44	41	24
45	45	45	40	41	47	45	42	MAX
36	37	38	35	33	36	37	37	MIN

Table3: Temperature of oil and winding in 230/63/20kv SARI Substation at 25 July 2006

Temprature of oil and winding in 230/63kv Pounel Substation at 25 July 2006								Hours
T2				T1				
oil	winding			oil	winding			
	HV	LV	TV		HV	LV	TV	
61	61	63	57	56	63	62	59	1
61	61	62	57	56	62	61	59	2
61	60	62	57	56	61	60	58	3
60	60	60	56	56	61	59	58	4
60	59	59	56	56	60	58	57	5
60	59	59	55	56	60	58	57	6
60	59	58	55	56	60	58	57	7
61	60	58	56	57	60	59	58	8
61	60	59	56	57	61	59	58	9
61	60	59	57	57	61	59	58	10
62	60	60	57	58	61	60	59	11
62	61	60	58	58	62	60	59	12
62	61	61	58	58	62	61	60	13
63	61	62	58	59	63	61	60	14
63	62	62	59	59	63	62	61	15
63	62	63	59	59	63	62	61	16
63	62	64	59	59	63	62	61	17
63	62	64	59	59	63	62	61	18
63	62	64	59	59	63	62	61	19
63	62	64	59	59	63	62	61	20
63	62	64	59	59	63	62	61	21
63	62	63	59	59	63	62	60	22
62	62	63	58	58	63	62	59	23
61	62	62	58	58	63	62	58	24
63	62	64	59	59	63	62	61	MAX
60	59	58	55	56	60	58	57	MIN

3. Theories and Model definition

3.1General Input-Output Models

A general input-output linear model can be written for a single-output system with an input u and output y, as follows:

A(q) y(t) = [B_i(q)/F_i(q)] u_i(t-nk_i) + [C(q)/D(q)] e(t)

Where u_i denotes input number i. There is an implied summation over all the inputs in the above expression. A, B_i, C, D, and F_i are polynomials in the shift operator (z or q). The general structure is defined by giving the time delays nk and the orders of the polynomials (i.e., the number of poles and zeros of the dynamic model from u to y, as well as of the noise model from e to y).
Most often the choices are confined to one of the following special cases:

ARX: A(q) y(t) = B(q) u(t-nk) + e(t)
ARMAX: A (q) y (t) = B (q) u (t-nk) + C (q) e (t)
OE: y(t) = [B(q)/F(q)] u(t-nk) + e(t) (Output Error)
BJ: y(t) = [B(q)/F(q)] u(t-nk) + [C(q)/D(q)] e(t) (Box-Jenkins)

The basic state-space model in innovations form can be written as:
X (t+1) = A x (t) + B u (t) + K e (t)
Y (t) = C x (t) + D u (t) + e (t)

Note that A(q) corresponds to poles that are common between the dynamic model and the noise model (useful if noise enters system "close to" the input). Likewise, F_i(q) determines the poles that are unique for the dynamics from input number i, and D(q) determines the poles that are unique for the noise.
These are all special cases of general linear input-output models. They correspond to linear difference equations relating the input to the output under various noise assumptions.
A prediction error/maximum likelihood method is used to estimate the coefficients of the polynomials by minimizing the size of the error term, e(t), in the above expressions. Several options govern the minimization procedure.

3-2.The ARX Model

The ARX model is a linear difference equation that relates the input u(t) to the output y(t) as follows:
y(t) + a_1 y(t-1) + ... + a_na y(t-na) = b_1 u(t-nk) + ... + b_nb u(t-nk-nb+1)

The structure is thus entirely defined by the three integers na, nb, and nk. na is the number of poles, nb+1 is the number of zeros, and nk is the pure time delay (the dead time) in the system. For a sampled data control system, typically nk=1 if there is no dead time.
For multi-input systems nb and nk are row vectors, where the i^{th} element gives the order/delay associated with the i^{th} input.

3-3. Model Output

With using of Temperature data's that has collected by performing of a test on oil and winding of a 230/63/20kv Transformer in SARI Substation, the winding temperature for input in the model and oil temperature for out put has been used in calculation and simulations.

In the next sections the results of calculation in MATLAB that models has been estimated in many cases, and simulation in COMSOL would has been described.

3-3-1.State-space model

$x(t+Ts) = A\,x(t) + B\,u(t) + K\,e(t)$

$y(t) = C\,x(t) + D\,u(t) + e(t)$

```
 A =
        x1          x2          x3           x4
x1    1.4537     0.97779     -0.88746     0.79613
x2   -0.92075    0.39492      1.4887     -0.7313
x3    0.80456   -0.35831      0.051135    0.81162
x4   -0.020607  -0.074647    -0.27479    -0.62393

B =
           u1
      x1    2.1079
      x2   -0.94638
      x3   -1.3377
      x4   -0.10788

 C =
     x1        x2        x3        x4
y1  1.1812   0.92276   0.49652   -0.75747

D =
            u1
      y1     0

 K =
           y1
      x1    3.3074
      x2   -4.4271
      x3    2.5696
      x4    0.14731

 x(0) =
      x1    73.586
      x2   -80.235
      x3    34.517
      x4   -6.1225
```

- Estimated using N4SID from table 1 data
- Loss function 7.51265 and FPE 37.5632
- Sampling interval: 1

3-3-2.Discrete-time IDPOLY model (ARX):

$A(q)y(t) = B(q)u(t) + e(t\,),$

$A(q) = 1 - 1.098\ (\pm 0.3115)\ q^{-1} + 0.4869\ (\pm 0.4678)\ q^{-2} - 0.6212\ (\pm 0.4525) q^{-3} + 0.5517\ (\pm 0.3386)\ q^{-4}$

$B(q) = 0.3419\ (\pm 0.4319)\ q^{-1} - 0.346\ (\pm 0.5567)\ q^{-2} + 0.1409(\pm 0.5868) q^{-3} + 0.1606\ (\pm 0.4587)\ q^{-4}$

- Estimated using ARX
- Loss function 0.425452 and FPE 0.850903
- Sampling interval: 1

3-3-3.Process model with transfer function

$$G(s) = \frac{K}{Tp1*s+1} * \exp(-Td*s)$$

With K = 7771.1 ± 7.3368e^(17)

Tp1 = 9.4869e ^ (5) ± 9.6618e^ (19)

Td = 30 ± 1.5629e^ (11)

- Estimated using PEM from data set of table1.
- Loss function 2.14608*e^(-025) and FPE 2.75925*e^ (-025)

3-3-4.Process model with transfer function with zero

$$G(s) = K * \frac{Tz*s+1}{Tp1*s+1} * \exp(-Td*s)$$

With K = -0.037547

Tp1 = 0.0010076

Td = 30

Tz = 34183

- Estimated using PEM from table 1
- Loss function 4.20726*e^(-29) and FPE 5.89016*e^(-29)

3-3-5.Discrete-time IDPOLY model (ARAMAX):

$y(t) = [B(q)/F(q)]u(t) + e(t)$

$F(q) = 1 - 1.81\ (\pm 0.05219)\ q^{-1} + 0.905\ (\pm 0.04991)\ q^{-2}$

$B(q) = 0.2859\ (\pm 0.1169)\ q^{-1} - 0.1988\ (\pm 0.1111)\ q^{-2}$

- Estimated using PEM
- Loss function 0.57436 and FPE 0.829632
- Sampling interval: 1

4- Result and discussions

The plots have shown the simulated (predicted) outputs of selected models. The models are fed with inputs from the Validation Data set, whose output is plotted in black (in white on a black background).

The plot takes somewhat different forms depending on the character of the validation data. This could be Time domain data.

Then the simulated or predicted model output is shown together with the measured validation data (figure3).

In all the cases, the percentage of the output variations that is reproduced by the model is displayed at the corner of the plots. The higher number means the better model.

The precise definition of the fit is:

FIT = [1 – NORM(Y – YHAT)/NORM(Y – MEAN(Y))]*100

Where Y is the measured output and YHAT is the simulated/predicted model output. The time span over which the fit is measured can be changed under the Options sub-menu Customized time span for fit.

There are sub-menus under the Options menu, which allow you to choose between simulated and predicted model output.

There are also options to show measured and model outputs together or to show the difference between them.

An intuitive interpretation of a K-step ahead predicted output is to see it as a result of a simulation, using the actual input that was started at the correct (measured) output level K samples earlier. K is called the prediction horizon.

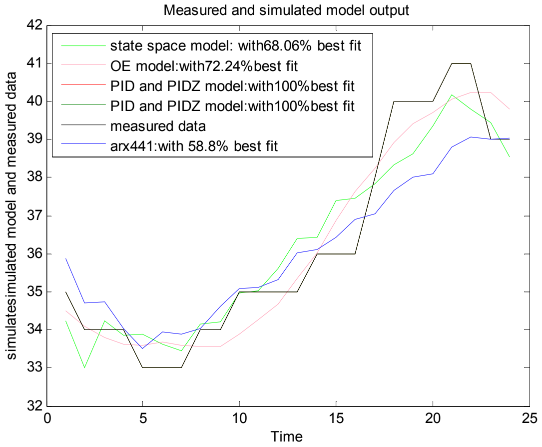


Figure3: Measured and simulated winding and oil temperature model of 230/63/20kv SARI transformer no.1 (TV).

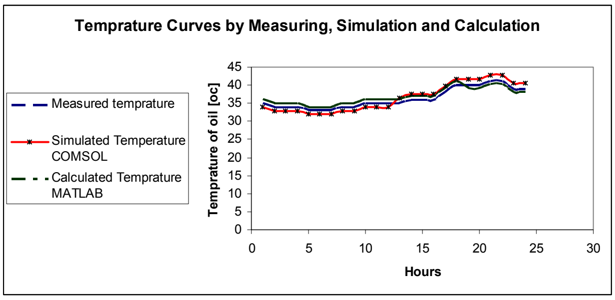


Figure 4: Comparison Measured, Simulated and calculated of Oil Temperatures.

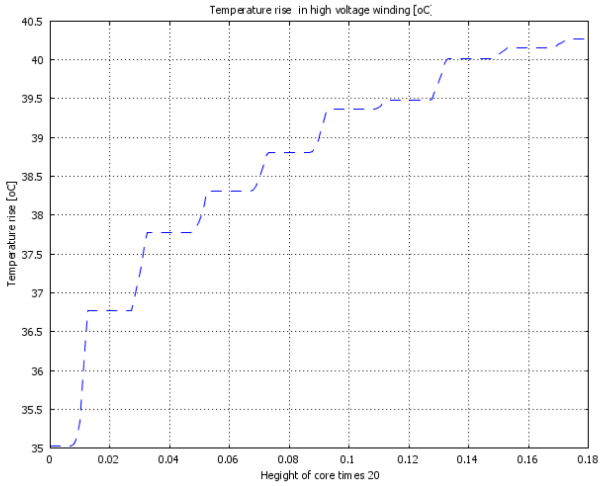


Figure5: simulated HV winding temperature of 230/63kv SARI transformer no.1 (TV), in COMSOL software.

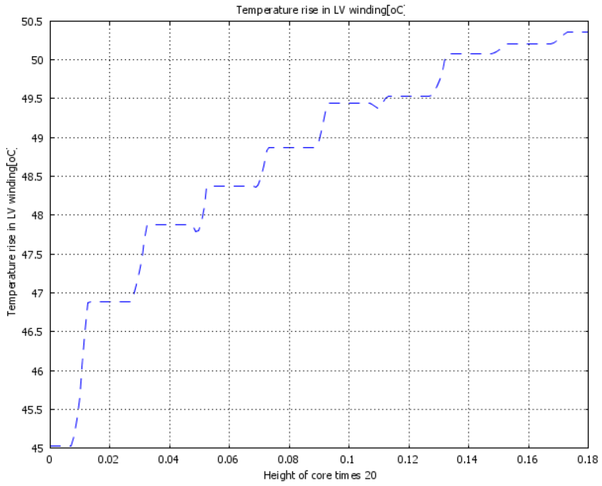


Figure6: simulated LV winding temperature of 230/63kv SARI transformer no.1 (TV), in COMSOL software.

By simulation in COMSOL that is shown in figures 5 and 6 it can be seen that the temperature of LV windings is higher than HV windings, because the LV carry out the higher current, this results has a good fits with measured data's. and so figure 6 is shown that the measured, simulated and calculated data has a good best fits.

5- Conclusion

A power transformer thermal model has been developed based on the analogy between thermal dynamics and electric circuits. The proposed thermal model can calculate continuously temperatures of the main parts of an ONAN/OFAF cooled power transformer under various ambient and load conditions. The model parameters can be obtained by the estimations search only based on the on-site measurements, instead of the experimental methods and off-line tests.

In the top of contexts we can see that the Process model of transfer function with zero is a best method for get a model for heat transfer from winding to oil and oil to ambient. It has a good best fit with highest coordination. It is shown in figure 3.

It is shown in figure3. of course with conversion of discrete to continuous, the data versus of continuous would obtain.

In figure 4 shown that the tolerances of simulation and calculation with measured data are less than 4%.
It shown that new model has a good best fit.

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Jafar Mahmoudi was born in Tehran, Iran. He received the B.Sc., M.Sc. Degree in Sharif University and PhD degrees from KTH University, Stockholm, Sweden. Currently, he is a Professor with the Department of Public Technology Engineering in MdH University, Västerås, and Sweden.His major research focus is development of new technology and methods for industrial energy optimization with special focus on heat and mass transfer. He has years of theoretical & experimental- experience on this. He also has a broad technical background encompassing thermodynamic, numerical methods and modeling (CFD computation) as well as materials science. This in combination with his industrial experience has served as a solid basis to build upon in expanding his research activities and focusing on relevant and current industrial issues.

Over the last 10 years his focus has been on the practical and industrial application of the above mentioned methods, an effort conducted in a large number of industrial projects. In this, his teaching experience has proved invaluable.