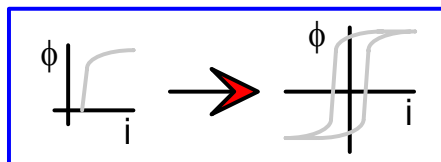


# Hysteresis Fitter

hfit1



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## 1 Description and Parameters

The hysteresis model (Hysteretic reactor device) available in EMTP is defined by two nonlinear equations:

$$C_{\text{sat}} = \left[ \lambda_{\text{unsat}} - \frac{\lambda_{\text{sat}}}{S_{\text{sv}}} - X_{\text{sv}} \right] \left[ S_{\text{sh}} \lambda_{\text{unsat}} - \lambda_{\text{sat}} + Y_{\text{sh}} \right] \quad (1.1)$$

and

$$C_{\text{hyst}} = \left[ i - \frac{\lambda_{\text{unsat}}}{S_{\text{hv}}} - X_{\text{hv}} \right] \left[ S_{\text{hh}} i - \lambda_{\text{unsat}} + Y_{\text{hh}} \right] \quad (1.2)$$

As a first step it is required to provide a fitting method for determining the parameters of these 2 equations. The purpose of the Hysteresis Fitter is to define the 2 equations from the magnetizing curves of power transformers. Three types of data are needed: saturation characteristic, parameters for minor loops shape and fitting control parameters.

Further information on the hysteresis model and information related to the fitting process can be found in [1] which is also referring to [2]-[8].

### 1.1 Saturation characteristic fitting

Saturation (or magnetizing) characteristic of a power transformer is used to find the saturation function parameters of equation (1.1). As explained in the Hysteretic Reactor device documentation, this equation gives the shape of the major hysteretic loop. The parameter  $S_{\text{hv}}$  is also determined by this method.

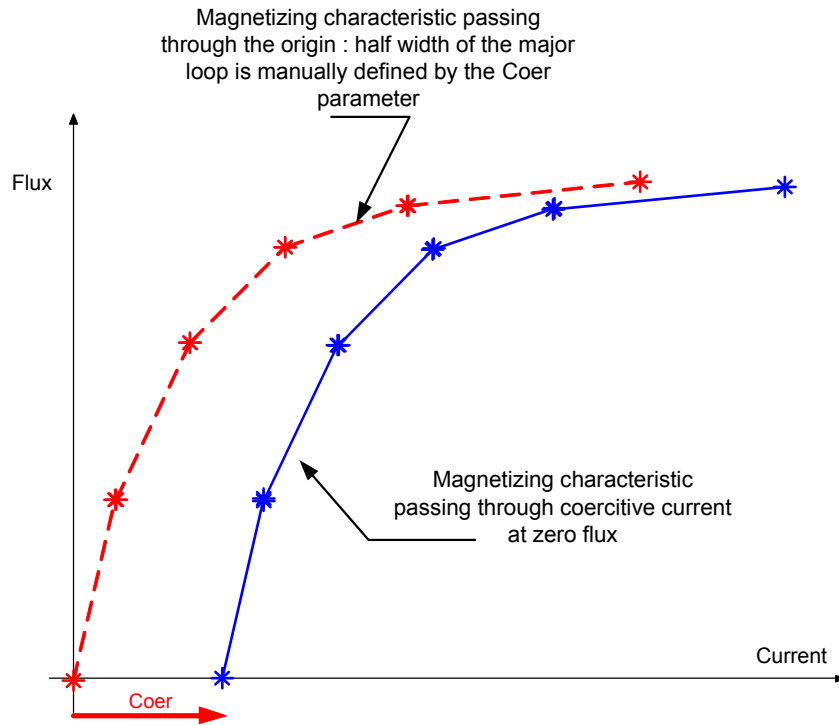
The fitting method used in the Hysteresis Fitter is a least squares method. The fitting process finds the parameters:

- $S_{sv}$  : vertical asymptote slope of the saturation equation.
- $S_{sh}$  : horizontal asymptote slope of the saturation equation.
- $Y_{sh}$  : y-axis intercept of the horizontal asymptote of the saturation equation.
- $X_{sv}$  : x-axis intercept of the vertical asymptote of the saturation equation.
- $S_{hv}$  : vertical asymptote slope of the hysteresis equation.

The hysteresis fitter assumes that the magnetizing characteristic is symmetrical for positive and negative fluxes. As a consequence the characteristic for negative fluxes is not used.

Optional input methods are available (see Figure 1):

- the upward branch of hysteresis main loop (called “offset characteristic”)
- the upward branch of hysteresis main loop passing through the origin (called “centered characteristic”). The half width of the major loop is defined by Coer (constant C).



**Figure 1 Sample saturation characteristics: 2 ways to define the same hysteresis loop**

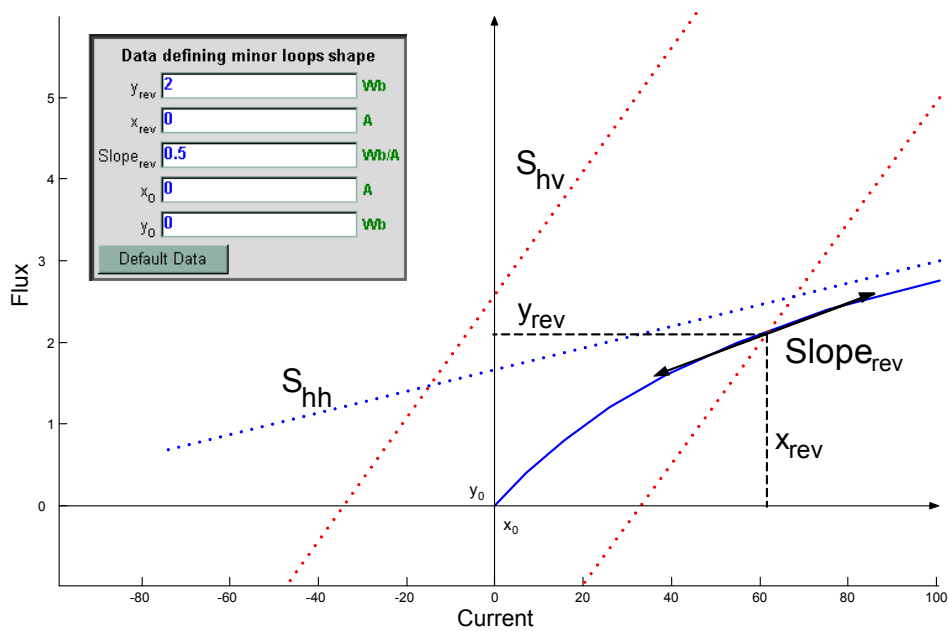
The Nonlinear Characteristic section is used to enter the magnetizing current versus flux characteristic. The current and flux data must be monotonically increasing. The data is taken as entered and tested for errors in the Hysteresis Fitter function. The user has to enter at least 4 segments to define this characteristic. The default number of data rows for the characteristic is 50, but the user can increase this size by selecting a row (click on the row number) and hitting the key “Insert”. Blank rows (empty rows) will be automatically eliminated at the following opening of device data forms.

## 1.2 Minor loop data

Minor loop shape is described by the hysteresis equation (1.2). Out of saturation area minor loop shapes are completely independent of saturation parameters. That is why the fitter needs minor loop data:

- $y_{rev}$  : the y-coordinate of the reversal point of a given loop.
- $Slope_{rev}$  : slope at the reversal point  $(x_{rev}, y_{rev})$ .
- $y_0$  : y-coordinate of a reversal point in a trajectory where the reversal point is given by  $(x_{rev}, y_{rev})$  and  $Slope_{rev}$ . This point is, as a consequence, on the same hyperbolic curve than  $(x_{rev}, y_{rev})$ .
- $x_0$  : x-coordinate of a second point in a trajectory where the reversal point is given by  $(x_{rev}, y_{rev})$  and  $Slope_{rev}$ .

When this data is not available, the provided default values have been tested for producing acceptable results in most cases. The user can modify the default data through the data entry form (see Figure 2).



**Figure 2 Data to model minor loop shapes**

The higher is the value of  $y_{rev}$  the thinner are the minor loops. It is normal to obtain such a result because of the second point on the minor loop  $(x_0, y_0)$  chosen to be at the origin, the reversal point  $(x_{rev}, y_{rev})$  is not very far from the origin. Users can change manually this value to obtain better fitting of data.

The other parameters for minor loop modeling do not substantially modify the shape of minor loops. The default values can be chosen for most cases.

### 1.3 Fitting control parameters

The hysteresis fitter uses a least-squares method for finding the saturation function parameters of equation (1.1). Three parameters control the convergence of this method:

- The convergence rate: Controls the convergence rate of the solution during optimization. Default is 10000.
- Maximum number of iterations: Maximum number of iterations in the fitting process. Default is 500.
- Convergence tolerance: Default is 0.1% of the smallest current value in the user-supplied flux-current characteristic.

## 2 Data files

Data file selections are made on the Run this case tab.

In order to generate model data it is necessary to save this device data into a Case Data File which will be automatically submitted to the Hysteresis Fitter function solver. After choosing to run this case, the user must provide a valid Case Data File name. The previously entered Case Data File can be reused if it is shown as available. The Hysteresis Fitter function takes the Case Data File and produces the Model Data File (model data). The model data is referenced and used in the Hysteretic reactor device.

Since the entered data is submitted directly to the Hysteresis Fitter function, it is not allowed to enter undetermined values using variables.

### 2.1 Case Data file format (.dat extension)

This file is selected by the user. It has the “.dat” extension. It is strongly recommended to locate this file in the directory of the design. This simplifies transferring designs between computers since EMTWorks can automatically use relative paths.

All the parameters needed in the hysteresis fitter solver are stored. An example is shown below:

```
10000 500 0.1 0.1 5.0 0 0.5 0 0
0.0 0.0
0.231601416 959.0286441
1.574423316 1065.587382
2.410307016 1118.866751
4.113251916 1172.146121
6.761646116 1225.42549
66.50517565 1278.702754
```

Field	Description
10000	The convergence rate
500	Maximum number of iterations
0.1	Convergence tolerance
0.1	Coer (C): Coercitive current (half width of the major loop) only for centered characteristic
5.0	$Y_{rev}$
0	$X_{rev}$
0.5	$Slope_{rev}$
0	$x_0$
0	$y_0$
Current Flux data	The Current-Flux data rows. Separated by a blank character.

### 2.2 Model Data file (.hys extension)

This file is the output of the fitting function. It can be used directly by the Hysteretic reactor device. An example is given by:

```
6185.47493098294 25.1843517244845
0.330209348504752 0.10000000000000000

6005.16002976328 8.030691362329453E-005
1300256.58673522 1248.82669431818
```

Field	Description
6185.47493098294	S <sub>hv</sub>
25.1843517244845	S <sub>hh</sub>
0.330209348504752	C <sub>hyst</sub>
0.1	Coer
6005.16002976328	S <sub>sv</sub>
8.030691362329453E-005	S <sub>sh</sub>
1300256.58673522	C <sub>sat</sub>
1248.82669431818	Y <sub>sh</sub>

### 2.3 Fitting results file (\*.fit extension)

A fitting results file is generated to compare input data and fitted values. First column is input flux, second is input current and the third is re-calculated current. When the fitting process is finished a comparison plot can be produced by double clicking on (reopening) the Hysteresis fitter device and clicking on the enabled link "View fitting results from previous run".

## 3 Example

This example demonstrates how to convert and reuse old EMTP-V3 data for the Type-96 hysteretic reactor in new Hysteresis Fitter. This example of data fitting and usage in the Hysteretic reactor device is available in the EMTPWorks Examples directory in the design ferro\_demo\man\_ferro\_case.ecf. The modeled transformer is located in the subnetwork "SILVER\_230\_66".

### 3.1 Saturation characteristic

An example of Type-96 data for a 230-66 kV, 50 MVA power transformer is given below. This is also typical data that can be available from measurements.

```

C Hysteresis reactor Type-96
C [BUS1][BUS2][BUS1][BUS2]<Iste><Phis><Prem>
C 3456789-123456789-123456789-123456789-123456789-
96          8888.          00.000
C <---Courant--><-----Flux----->
C coercitive current = 0.062 A
-0.45000000E+00 -0.28317647E+03
-0.30000000E+00 -0.28147059E+03
-0.13500000E+00 -0.27550000E+03
-0.60000000E-01 -0.26952941E+03
-0.22500000E-01 -0.26441176E+03
 0.75000000E-02 -0.25417647E+03
 0.26250000E-01 -0.24223529E+03
 0.43500000E-01 -0.22176471E+03
 0.52500000E-01 -0.18764706E+03
 0.60000000E-01 -0.13647059E+03
 0.75000000E-01  0.91264706E+02
 0.82500000E-01  0.12623529E+03
 0.10500000E+00  0.17058824E+03
 0.13500000E+00  0.20470588E+03
 0.16350000E+00  0.22176471E+03
 0.21375000E+00  0.23882353E+03
 0.29250000E+00  0.25417647E+03

```

0.40125000E+00	0.26611765E+03
0.52500000E+00	0.27464706E+03
0.75000000E+00	0.28317647E+03
0.12000000E+01	0.29000000E+03
0.16500000E+01	0.29170588E+03
.99990000E+04	

This magnetization characteristic is actually the upward trajectory of the main hysteretic loop. This characteristic must be entered in the Hysteresis Fitter Nonlinear Characteristic section (see Figure 3). It is noticed that since the zero flux point is mandatory with the offset characteristic, the first row of data has been interpolated.

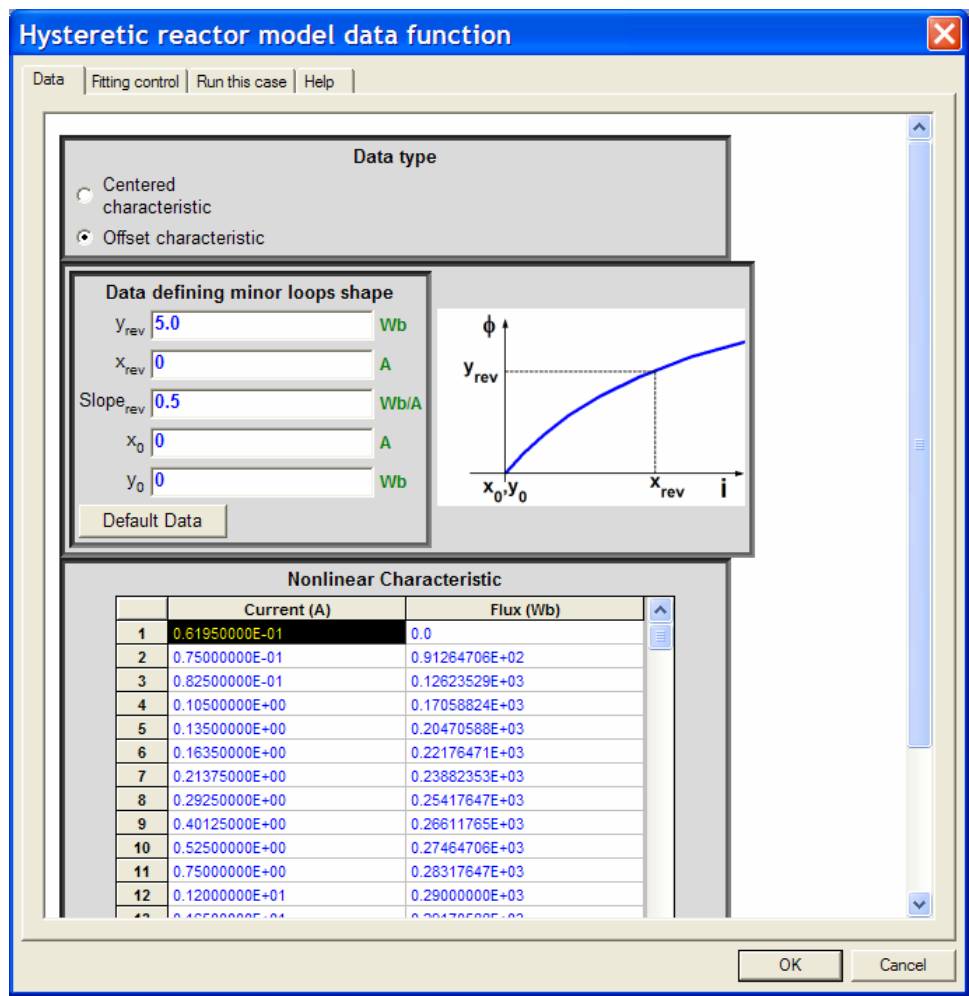
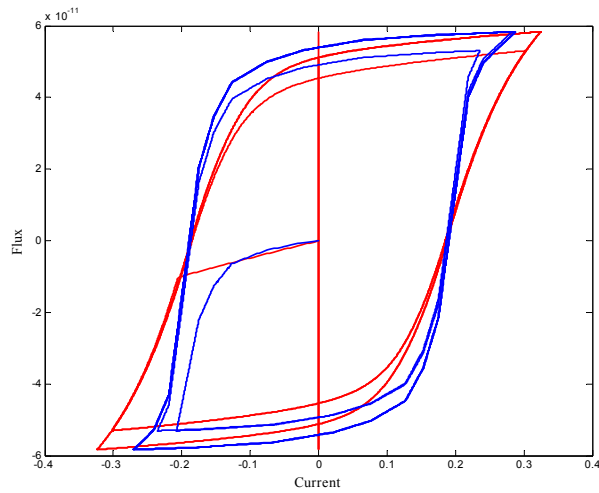


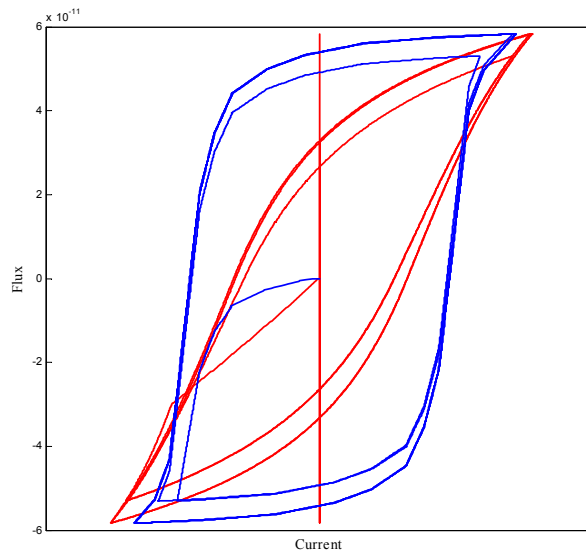
Figure 3 Hysteresis fitter data tab: main data

### 3.2 Minor loops data

The choice of  $y_{rev}$  is important for determining the shape of minor loops. Simulations have been performed to visualize the effect of  $y_{rev}$ . They lead to the conclusion that  $y_{rev}$  must be chosen in the unsaturated part of the hysteresis loop. This variable is appropriate to model the minor loops in the unsaturated area. The comparisons have been carried out on the shape of minor loops. The reference was the shape given by Type-96 hysteresis model (blue dashed line in Figure 4 and Figure 5).



**Figure 4 Effect of  $y_{rev}$  on the shape of minor loops :  $y_{rev} = 3\%$  of maximum flux**



**Figure 5 Effect of  $y_{rev}$  on the shape of minor loops:  $y_{rev} = 80\%$  of maximum flux**

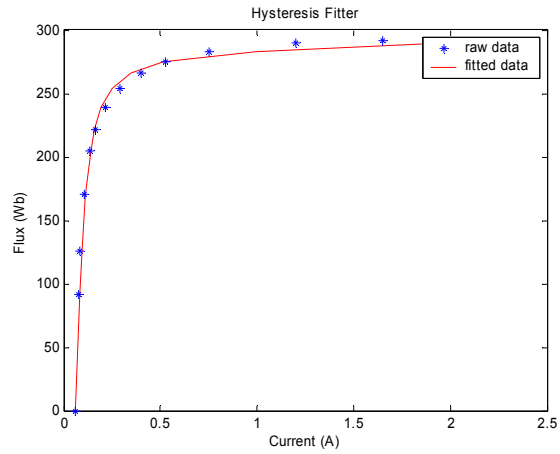
The higher is the value of  $y_{rev}$  the thinner are the minor loops. It is normal to obtain such a result because of the second point on the minor loop  $(x_0, y_0)$  chosen to be at the origin, the reversal point  $(x_{rev}, y_{rev})$  is not very far from the origin. Users can change manually this value to obtain better fitting of data.

The other parameters for minor loop modeling do not substantially modify the shape of minor loops. The default values can be chosen for most cases.



### 3.3 Results

The fitting results obtained by clicking on “View Fitting results from previous run” are shown in Figure 6.



**Figure 6 Fitting results example**

The loading of the Model Data file into the Hysteretic reactor device is shown in Figure 7.

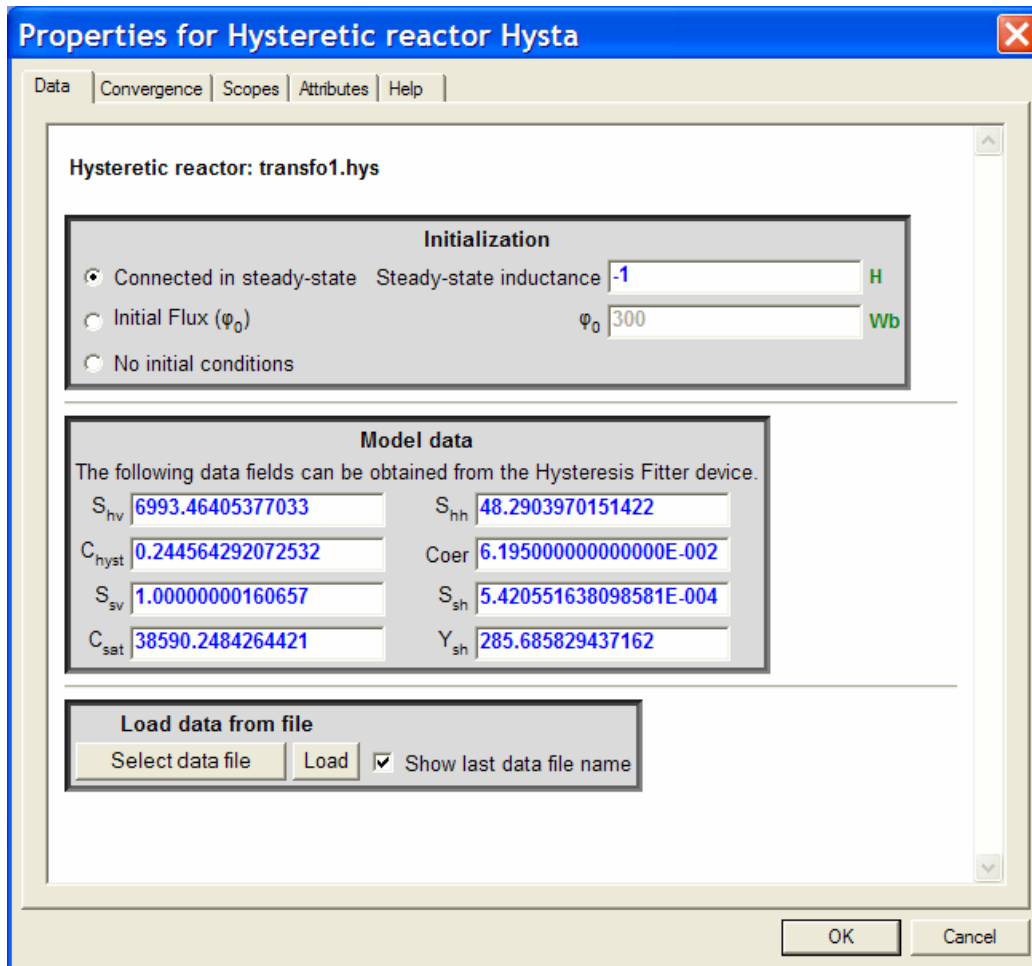


Figure 7 Hysteretic reactor model data

## 4 References

- [1] S. Denetière, J. Mahseredjian, M. Martinez, M. Rioual and A. Xémard, “On the implementation of a hysteretic reactor model in EMTP”, Proceedings of the 5<sup>th</sup> International Conference on Power Systems Transients, September 28th – October 2, 2003, New Orleans, LA.
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- [6] D. N. Ewart, "Digital Computer Simulation Model of a Steel-Core Transformer", IEEE, Transactions on Power Delivery, Vol. PWRD-1, No. 3, July 1986, pp. 174-183.
- [7] A. Wright, A. and Carneiro Jr., S. - "Analysis of Circuits Containing Components with Cores of Ferromagnetic Material" - Proceedings IEE, Vol 121, n 12, December 1974, pp. 1579-1581.
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