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| **CT/PT Calibration** |
| OpenECA Analytic Design Document |
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# **Statement of Work**

The analytic of instrument transformers(CT/PT) calibration is aiming to use linear Least Squares Estimation method to estimate the measurement error of the transducers. The alpha version of the program of this analytic firstly takes PSS\E simulated PMU measurements as input; then, analyzes the topology of the aimed power network; thirdly starting from one of the buses taken as the calibration starting bus that equipped with revenue PT, conducts single transmission line CT/PT calibration; finally propagate the accuracy to the whole system based on its tree topology. The alpha version program is designed to be operating without openECA platform.

# **Introduction**

The voltage and current measurements one get from the PMUs might not be the exactly accurate values, which is because of the measurement ratio errors of the instrument transformers (CT/PTs) and the errors added by PMUs. Since PMUs only provides digital signals, the data should have been quantized by some scale before sent to the energy management system. Both the errors brought by CT/PTs and PMUs is going to influence the accuracy of the calculation of the line impedance as well as other system monitoring and analysis works. Therefore, one need to first know the components of the errors, then utilize estimation methods to find out the exact error to find the true state of the system.

# **Program Architecture (Alpha Version)**

## *Data Structure*

The data structure of the alpha version controller is shown as follows:





## *Data Flow*



# **Program Details (Alpha Version)**

## *Program Process*

1. PSS\E power system operation simulation

Use PSS\E to conduct power flow based on the IEEE 118-bus power system and the morning load pick-up curve to generate the voltages of the 345KV buses and currents flowing though corresponding transmission lines.

1. Raw data processing

Read in CSV file generated by Python and PSS\E.

1. Building error model (For test plan)

Add CT/PT measurement errors and PMU errors to the raw data of voltages and currents based on the derived error model; record the positive sequence errors and the true line impedance and susceptance.

1. System topology analysis

Analyze the system topology based on the from-bus and to-bus information of the concerned lines; find the order of calibration propagation.

1. CT/PT calibration

Conduct the CT/PT calibration starting from the 345KV bus and corresponding line that equipped with revenue transducers; use the injection propagation method aforementioned to calibrate the whole 345KV system.

# **Demonstration**

## *Raw Data Generation*

In this section, the PSS\E simulation is conducted to generate voltage and current data of the concerned power system. The PSS\E is accessed through Python.

1. Locate in to the folder maned as ***Step\_1\_VI\_Acquisition***; run the file ***IEEE\_118\_data\_generation\_main.py*** to start generating voltage and current measurements data.
2. The generated voltage and current data can be found in the file named as ***VI\_Measurement\_All\_345KV\_Buses\_Peak.csv***; copy this file and paste it into the ***Step\_2\_Error Model***folder.

## *Error Model Construction*

In this section, the CT/PT and PMU errors are added into the simulated data to construct the error model.

1. Run ***Matlab\_CSV\_adapter\_IEEE\_118.m*** through Matlab to acquire the bus information, voltage and current simulated data from the CSV file, ***VI\_Measurement\_All\_345KV\_Buses\_Peak.csv***; the results include

1) the 345KV bus number set, saved in ***Bus\_number\_set\_345KV.mat***,

2) the true values of the positive sequence voltages on each 345 KV buses, saved in ***V\_true\_value\_positive\_sequence.mat***,

3) the true positive sequence currents flowing through all the lines, two-winding transformers, and three-winding transformers connected to the 345KV buses, saved in ***I\_true\_value\_positive\_sequence.mat***, ***I\_true\_value\_positive\_sequence\_trn.mat***, and ***I\_true\_value\_positive\_sequence\_gen.mat*** respectively,

4) the from-bus numbers and to-bus numbers of each transmission line, two-winding transformers, and three-winding transformers connected to the 345KV buses, saved in ***line\_bus\_info\_all\_lines.mat***, ***line\_bus\_info\_trn.mat***, ***line\_bus\_info\_gen.mat***.

1. Run ***Line\_data\_generation\_IEEE\_118.m*** through Matlab to acquire the power system network information, save the true value of the voltages and currents of each line or transformer equivalent line, and construct the error model introduced previously; the network information is saved in ***AC\_line\_info.mat*** which is formed as 11 column vectors, i.e. **[line number, line ID, line type, from bus number, KV1, KI1, to bus number, KV2, KI2, Z, y]**, as well as the bus number information of all the 345KV transmission lines, saved in ***line\_bus\_info\_345KV.mat***; each transmission line or transformer equivalent line is assigned a line number, and the three-phase true value of the voltages and currents of each line is saved in the files named as ***line\_(line number)\_true\_3\_phase.mat***; the true positive sequence values are saved in the files named as ***line\_(line number)\_true\_positive\_sequence.mat*** in the format of **[from-bus voltages, from-bus currents, to-bus voltages, to-bus currents]**; the positive sequence values added errors are referred to as measured value and are saved in the files named as ***line\_(line number)\_measured\_positive\_sequence.mat*** with the same format as true value files; the total line number is 24 in the test case.
2. Run ***True\_impedance\_calculation\_IEEE\_118.m*** through Matlab to acquire 345KV transmission lines’ impedances and susceptances and assign such data to the 10th and 11th column of ***AC\_line\_info.mat*** respectively and save the **AC\_line\_info** matrix in the file ***AC\_line\_info\_true\_value\_Zy.mat***.
3. Copy the following files and paste it into the ***Step\_3\_CTPT Calibration*** folder: ***AC\_line\_info\_true\_value\_Zy.mat***,

***Bus\_number\_set\_345KV.mat***,

***line\_(every linenumber)\_measured\_positive\_sequence.mat,***

***line\_(every line number)\_true\_positive\_sequence.mat,***

***line\_(every line number)\_true\_3\_phase.mat (optional),***

***line\_bus\_info\_345KV.mat***.

## *CTPT Calibration*

In this section, the CT/PT calibration is conducted based on the simulated data throughout the 345KV subsystem within the IEEE 118 system.

1. Run ***CT\_PT\_calibration\_IEEE\_118.m*** through Matlab to start the impedance calibration process; notice that only run the following part of the code at the first time of the tests based on the same accurate bus to save the original voltage and current data of that bus and corresponding line.

%----------------------------------------------------%

line\_name=['line\_',num2str(original\_accurate\_line\_number), '\_measured\_positive\_sequence.mat'];

VI\_origin\_struct=load(line\_name);

VI\_measurement\_set = VI\_origin\_struct.VI\_measurement\_set;

line\_name=['line\_',num2str(original\_accurate\_line\_number),'\_measured\_positive\_sequence\_origin.mat'];

save(line\_name,'VI\_measurement\_set');

%----------------------------------------------------%

1. The Results are saved in the file named as ***line\_estimation\_results.mat*** in the form of ***[line number, from bus number, KV1\_hat, KI1\_hat, to bus number, KV2\_hat, KI2\_hat, Z, y],*** and the errors of the calibration are shown in the command window of Matlab as follow:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| line\_number | KV1\_error | KI1\_error | KV2\_error | KI2\_error |
| \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |
| 10 | 0+0i | 0.00040057+0.00013761i | 1.6929e-06+8.4113e-07i | -0.00021291+0.0011885i |
| 9 | 8.584e-07+6.792e-07i | -2.4843e-05+4.6566e-05i | 1.3021e-06+5.2792e-07i | -5.503e-05-2.2845e-05i |
| 6 | 1.0863e-07+5.7767e-07i | -0.00033709+0.0012504i | -0.00013771+0.00012165i | -0.00086444+0.00077404i |
| 8 | 5.3731e-07+4.4439e-07i | -0.012391-0.0032769i | -4.4827e-05-2.9944e-05i | -0.01115-0.0046912i |
| 5 | -0.00014586+0.00011735i | 0.00028095-0.0003915i | -0.0001269+0.00012148i | 6.8097e-05-0.00099755i |
| 7 | -4.4232e-05-3.0314e-05i | -0.14917+0.037664i | -0.00044129+7.6225e-05i | -0.14002+0.019552i |
| 2 | -0.00013314+0.00011124i | -0.00037344+0.0011114i | -0.00015294+0.0001398i | 0.00016024+0.0015098i |
| 4 | -0.00012835+0.00011273i | -0.0019483-0.00053381i | -0.00021409+0.00013982i | -0.0019852+0.00025517i |
| 1 | -0.00014735+0.00014621i | 0.00025017-6.2754e-05i | -0.00013432+0.00013596i | 0.00018329-0.00017233i |
| 3 | -0.00013189+0.00014263i | -0.0004051-0.0009068i | -0.00014682+0.00013647i | -0.00071951-0.00069915i |

Note: For some of the lines in IEEE 118 bus system, there are generators that connect to the relevant buses directly, which is not feasible in real-world power system. There is a good reason to believe that such scenario that generator -> line -> bus -> line -> bus connection should has negative influence to the estimation accuracy. That is why the estimation results of the Line 7 current correction factors are larger than other lines. Besides, given the propagation process, the estimation error of the previous pi-section will surely affect the consecutive ones, i.e. accumulation effect of the errors. Therefore, the later the lines are visited, the larger the estimation errors will be. For the further versions of the application, the algorithms will be improved to provide more accurate results.