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| **Transmission Line Impedance Calibration** |
| OpenECA Analytic Design Document  *Test Results* |
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# **Work Description**

In order to realize the analytic of transmission line impedance calibration, we firstly use PSS\E to conduct the power flow of the IEEE standard 118-bus system to gather the simulated voltage and current data; then, realize the functionality including system topology analysis, single transmission line impedance calibration, and whole system calibration on Matlab to validate the methodology. The alpha version program is designed to be operating without openECA platform.

# **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. Transmission line impedance calibration

Conduct the transmission line impedance 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.

# **Test Results(Alpha Version)**

## *Data Structure*

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





## *Data Flow*



## *Impedance Calibration Test Results*

## *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\_PQI.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. Locate in to the folder maned as ***Step\_2\_Error Model.***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 129 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\_Impedance 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***.

## *Transmission Line Impedance Calibration*

In this section, the transmission line impedance calibration is conducted based on the simulated data throughout the 345KV subsystem within the IEEE 118 system.

1. Locate in to the folder maned as ***Step\_3\_Impedance Calibration*.** Run ***line\_parameter\_estimation\_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\_hat, y\_hat],*** and the errors of the calibration are shown in the command window of Matlab as attached table.

## *CTPT Calibration Results Analysis*

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. 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.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| line\_number | KV1\_error | KI1\_error | KV2\_error | KI2\_error | Z\_pu\_error |
| \_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ | \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ |
| 10 | 0+0i | 0+0i | -8.9665e-08+6.4759e-08i | 3.3729e-05+0.00031885i | -3.875e-06-2.2941e-06i |
| 9 | -9.354e-07-8.6411e-08i | -0.054176-0.00059463i | -2.5268e-07+5.4999e-07i | -0.053696-0.0020156i | 5.0668e-05+0.00091915i |
| 6 | -1.4385e-06+5.4042e-07i | -0.048562-0.003765i | -0.00011939+3.0773e-05i | -0.048432-0.0062498i | -9.3247e-05+0.0049665i |
| 8 | -1.0321e-06+4.2567e-07i | -0.039879-0.090114i | 2.2211e-05-7.1517e-06i | -0.041844-0.090051i | -0.0028379+0.0012278i |
| 5 | -0.0001226+2.5583e-05i | 0.022484+0.054404i | -0.00010721+3.6383e-05i | 0.023412+0.054581i | -0.0029328-0.0010324i |
| 7 | 2.1753e-05-6.4653e-06i | -0.041025-0.085287i | -1.9731e-05-1.0317e-05i | -0.039203-0.10122i | -0.0019038+0.0008451i |
| 2 | -0.00010823+2.8655e-05i | 0.022379+0.085188i | -0.00012491+4.5585e-05i | 0.023679+0.087327i | -0.0042015-0.0010638i |
| 4 | -0.0001055+3.0809e-05i | -0.0077874+0.011213i | -0.00010639+5.3453e-05i | -0.0077156+0.011843i | -0.0009939+0.0007427i |
| 1 | -0.00012286+5.0807e-05i | -0.023302-0.021114i | -0.00011483+4.8006e-05i | -0.022492-0.021357i | -0.00057764+0.00075118i |
| 3 | -0.00011492+5.251e-05i | -0.021822-0.021623i | -0.0001167+6.4248e-05i | -0.022818-0.019937i | -0.00061303+0.00080305i |

# **From Alpha to Beta**

## *Application Realization*

The alpha version of the application is built on the Matlab platform. The calculation are based on the input data from CSV files.

For the beta version, the openECA platform will be integrated into the application. The input data will be formed as the standard measurement streams on openECA. C# project will be developed based on the data feeds from the openECA. The system configuration will be created and analyzed. The functionality of the Transmission Line Impedance Calibration will also be realized as C# code.

The similar functionality test on Alpha version will be conducted again on the C# project.

## *User Interface Design and Realization*

The user interface will be developed. Such interface will be designed as a universal media of all the three analytics including CT/PT Calibration, Transmission Line Impedance Calibration, and Real-time Impedance Calculation. The system topology will be demonstrated and the calculation results of different analytics will also be demonstrated.