

# A Test Case for GIC harmonics Analysis

## EPRI GICharm v1.0

EPRI GIC harmonics analysis tool

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CIGRE Grid of the Future Conference

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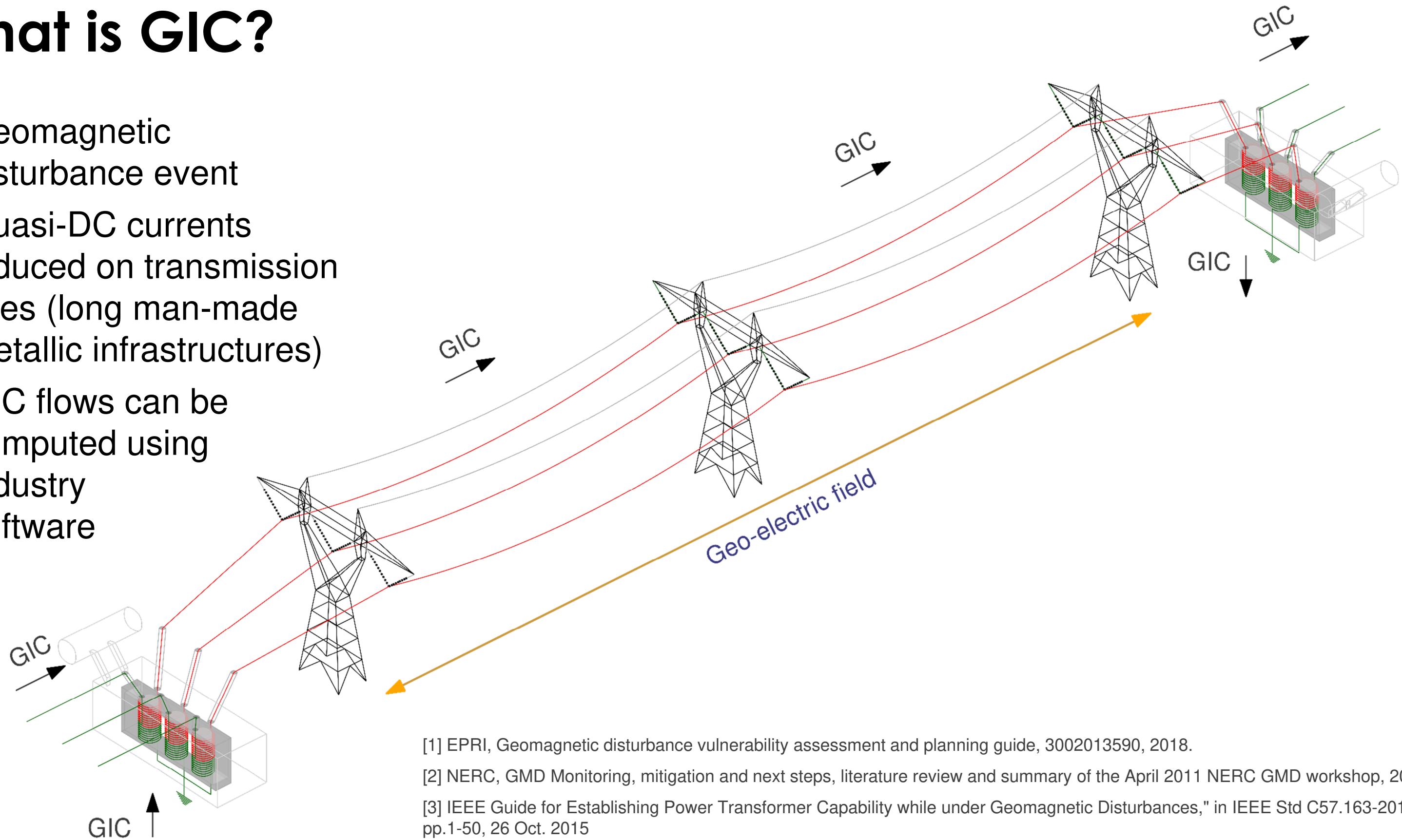


# Agenda

- What is GIC and GIC related harmonics?
- EPRI GICcharm
- Test case for GIC harmonics analysis
- Additional test cases to explore

# What is GIC?

- Geomagnetic disturbance event
- Quasi-DC currents induced on transmission lines (long man-made metallic infrastructures)
- GIC flows can be computed using industry software



[1] EPRI, Geomagnetic disturbance vulnerability assessment and planning guide, 3002013590, 2018.

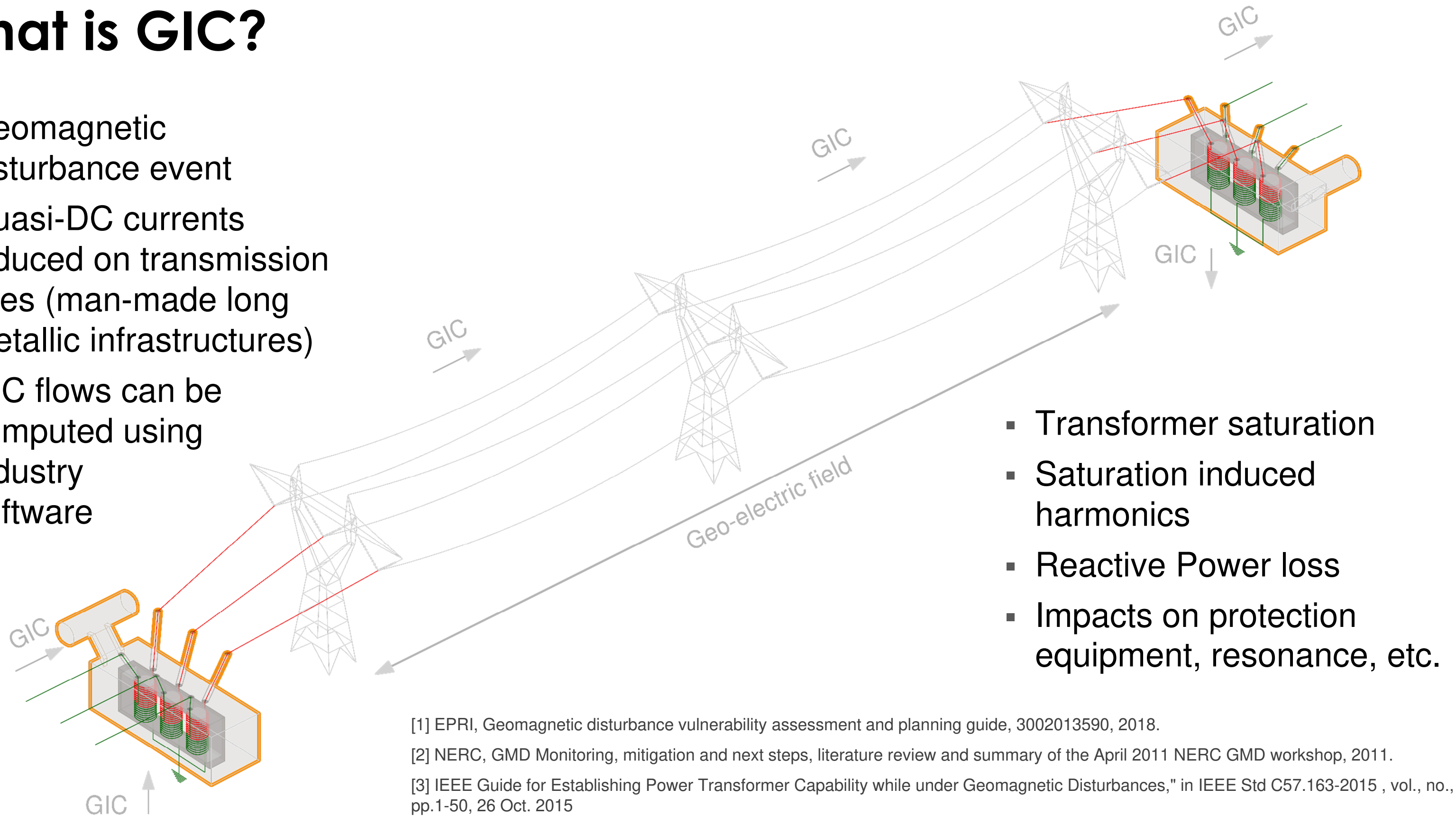
[2] NERC, GMD Monitoring, mitigation and next steps, literature review and summary of the April 2011 NERC GMD workshop, 2011.

[3] IEEE Guide for Establishing Power Transformer Capability while under Geomagnetic Disturbances," in IEEE Std C57.163-2015 , vol., no., pp.1-50, 26 Oct. 2015



# What is GIC?

- Geomagnetic disturbance event
- Quasi-DC currents induced on transmission lines (man-made long metallic infrastructures)
- GIC flows can be computed using industry software



- Transformer saturation
- Saturation induced harmonics
- Reactive Power loss
- Impacts on protection equipment, resonance, etc.

[1] EPRI, Geomagnetic disturbance vulnerability assessment and planning guide, 3002013590, 2018.

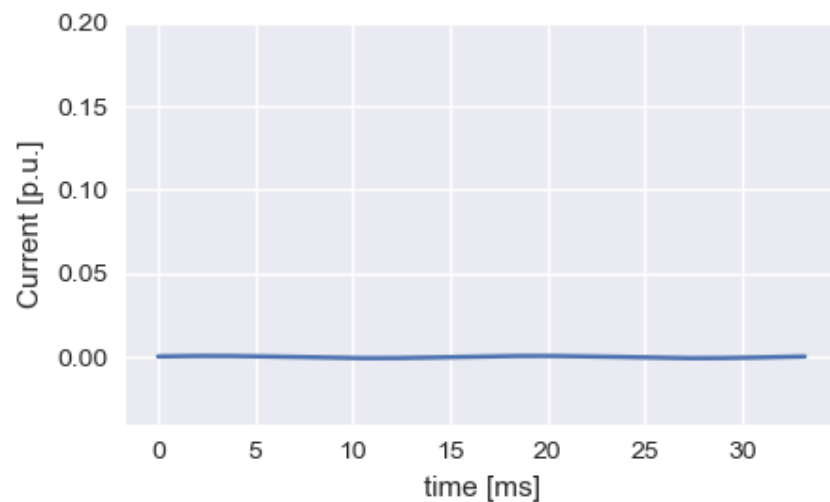
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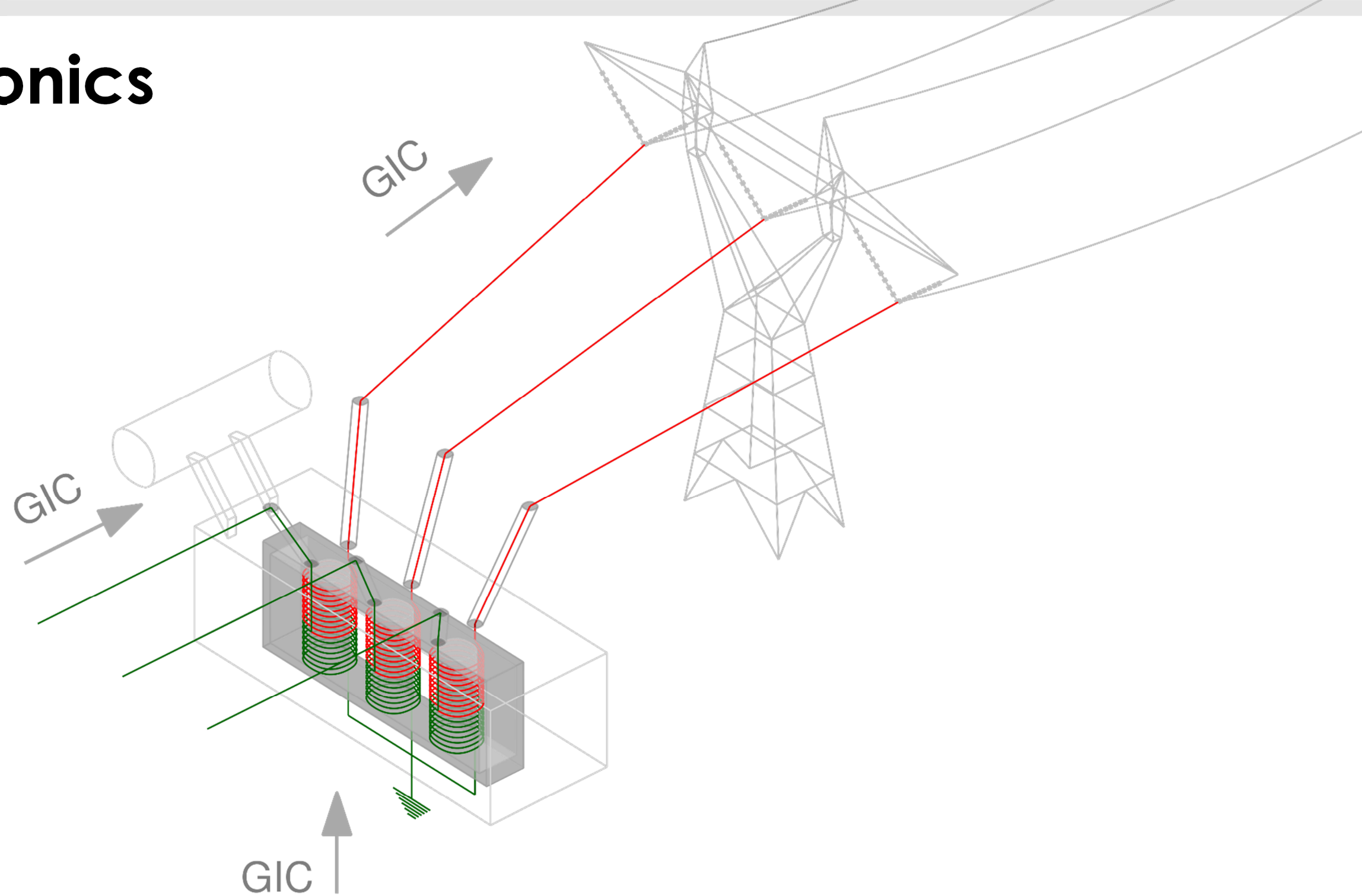


# GIC related harmonics

- Transformer core saturation
- Excitation currents and reactive power losses

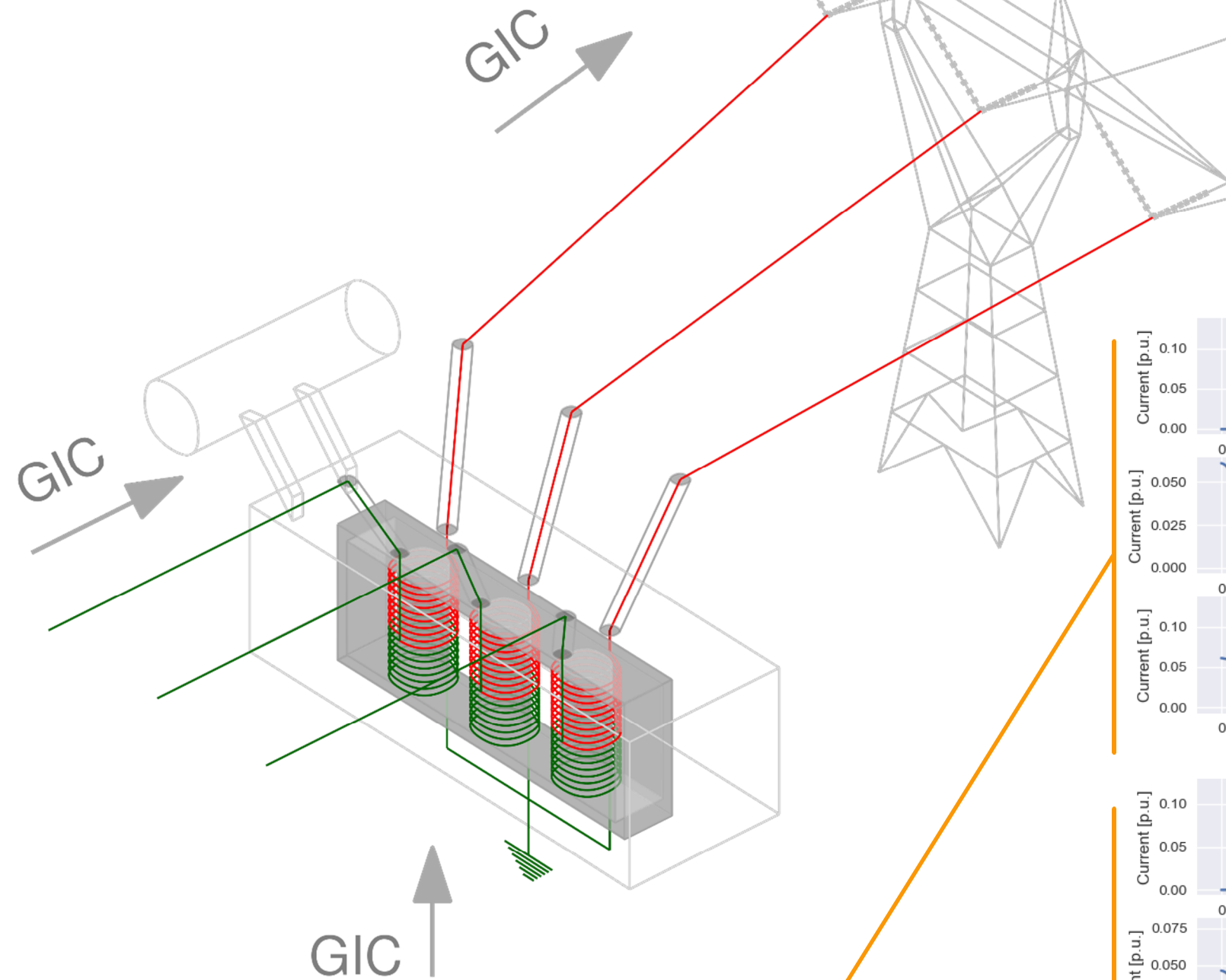
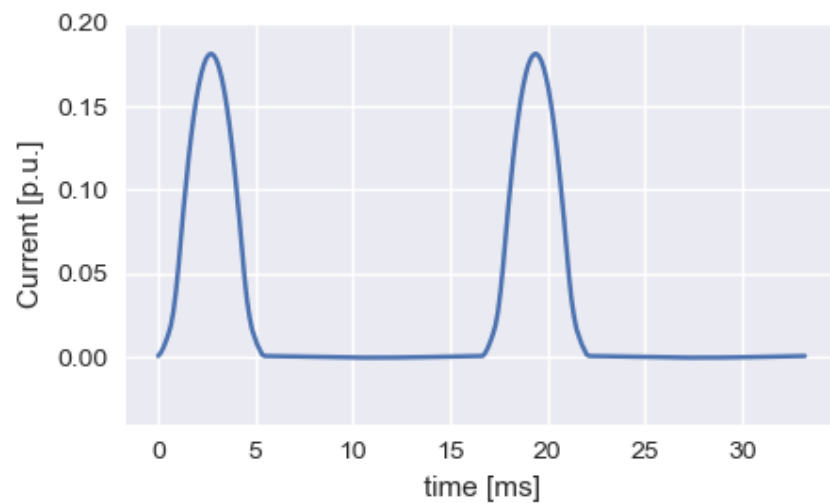
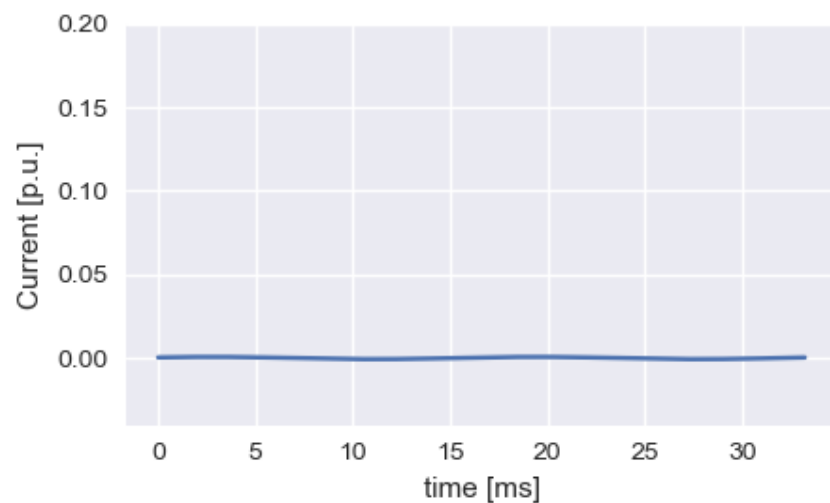


Excitation currents  
Normal operation



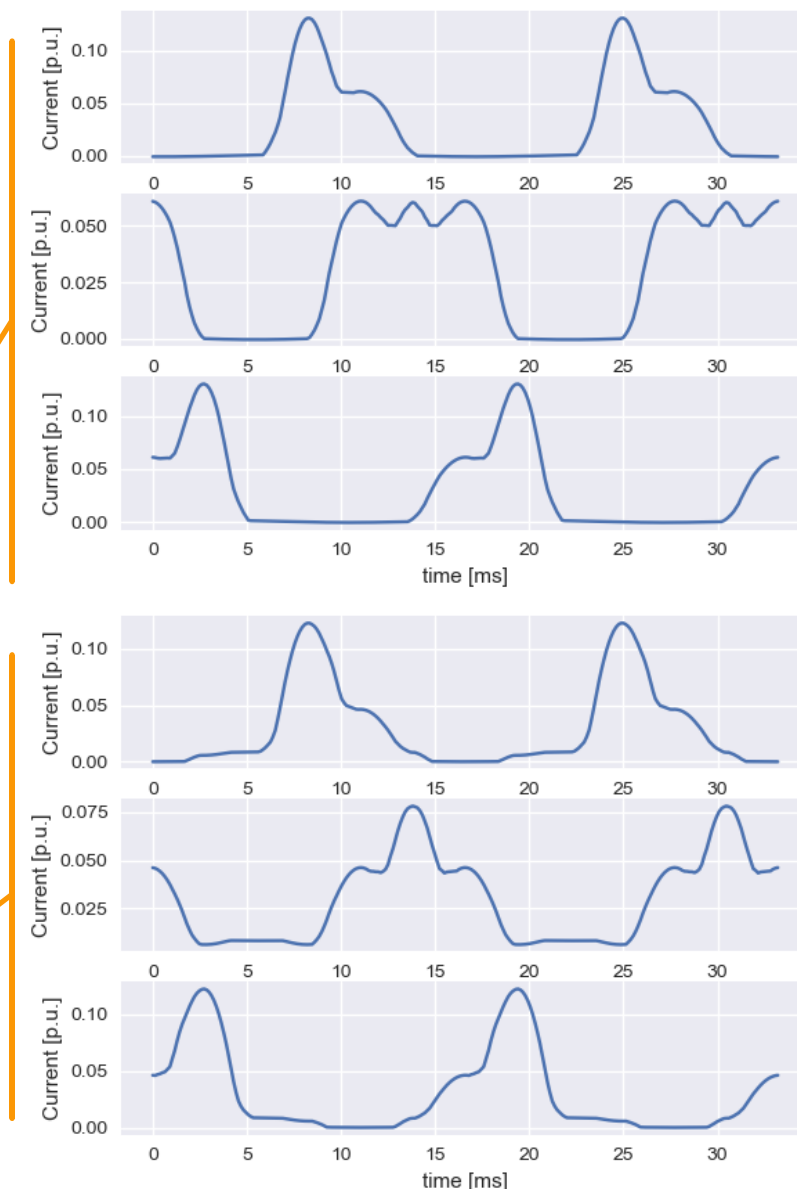
# GIC related harmonics

- Transformer core saturation
- Excitation currents and reactive power losses



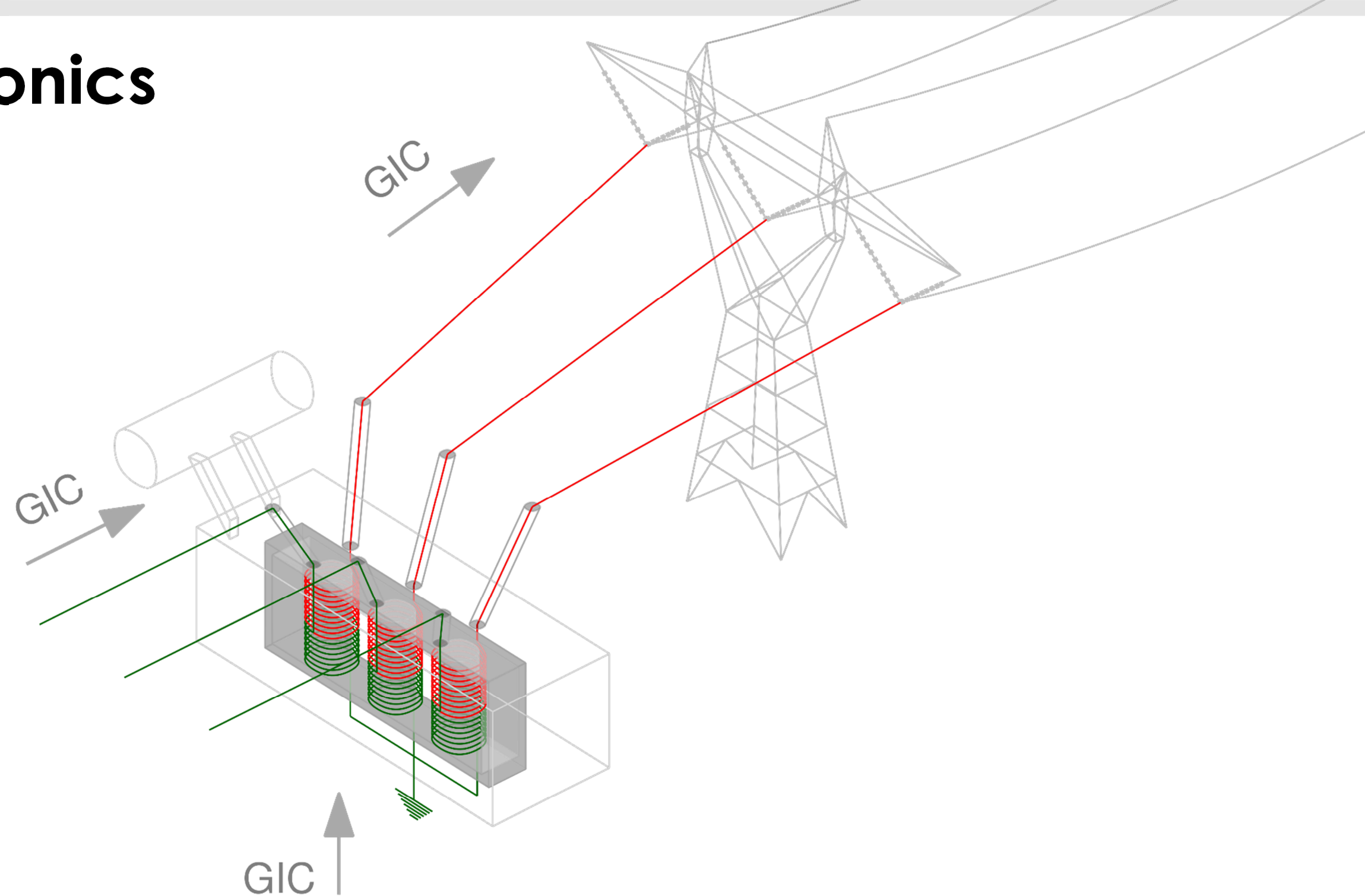
Excitation currents half-cycle saturation

Core-dependent



# GIC related harmonics

- Transformer saturation
- Excitation currents and reactive power losses
- Core topology dependence
- How to handle hundreds of transformers in the bulk power system?
- Lack of tools to assess the impact of GIC related harmonics in the bulk power system





# EPRI GICcharm v1.0

# EPRI GICcharm v1.0

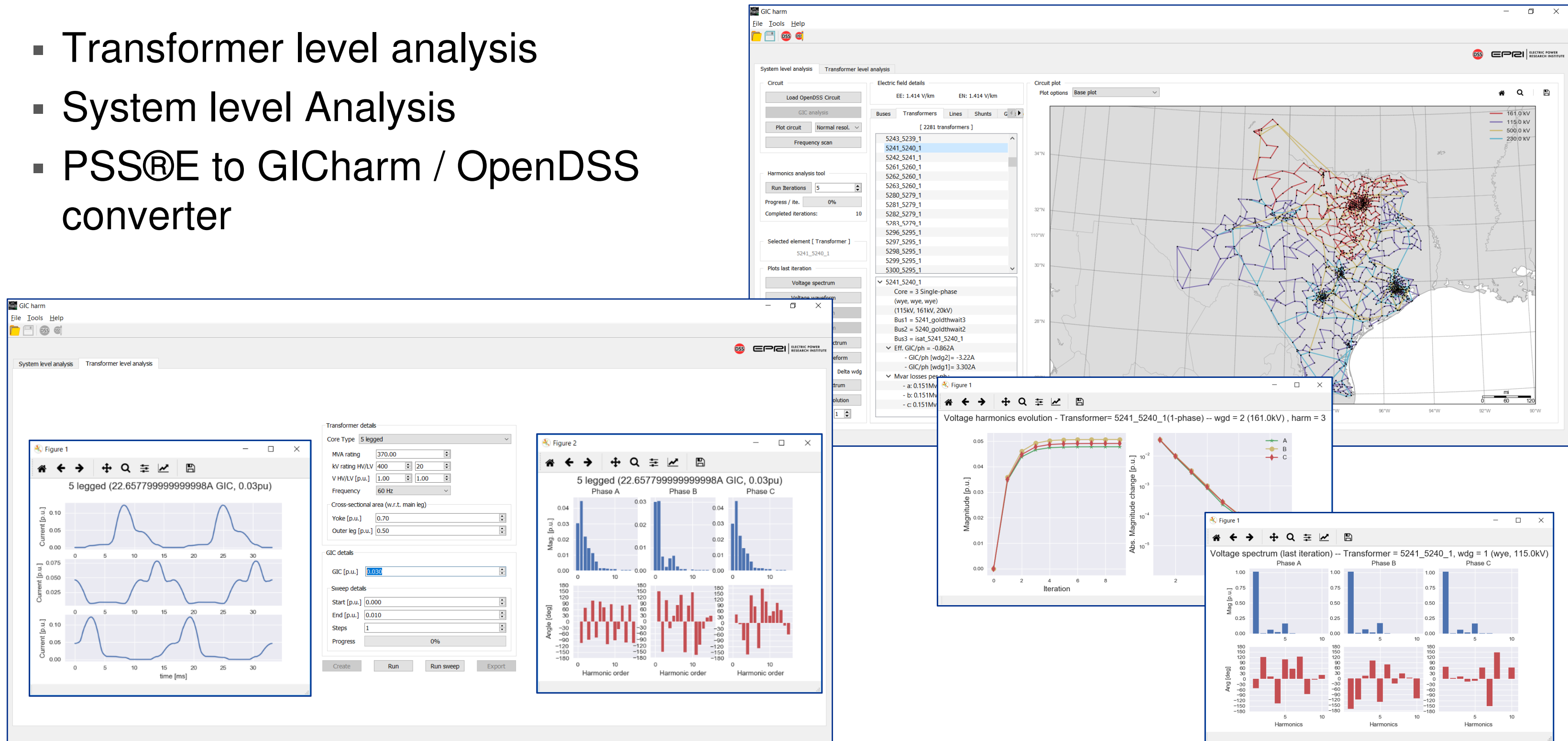
- Software tool to assess the impact of GIC related harmonics
- Beta version available to the public
- Will be released as an Open source software
- Capable of extensive system modeling
- Capable of accurate representation of saturated transformers
- Works with the EPRI OpenDSS simulation software engine
- Accepts system model information from PSS®E vendor software

Available on [epri.com](http://epri.com) Product ID#  
3002014854



# GICharm built-in capabilities

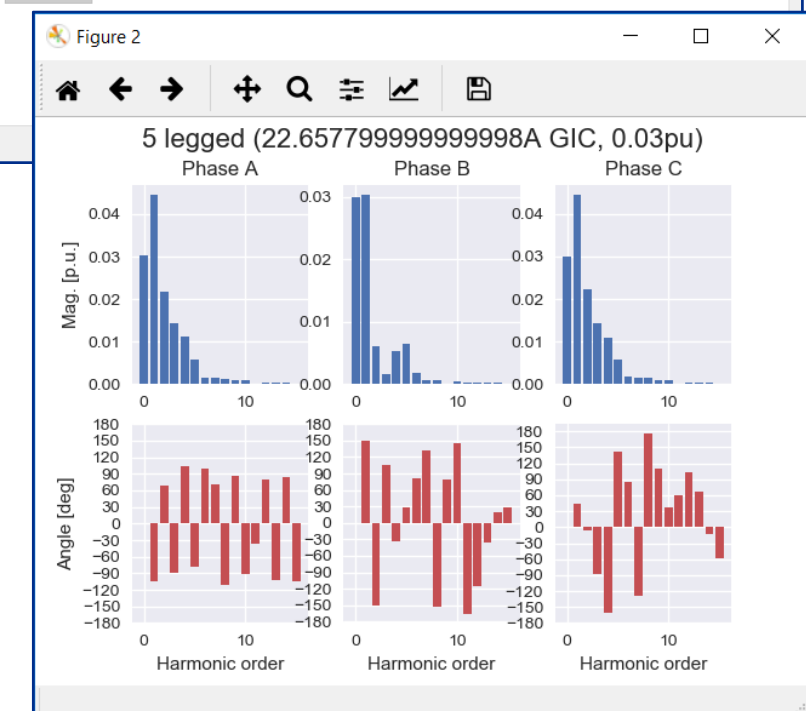
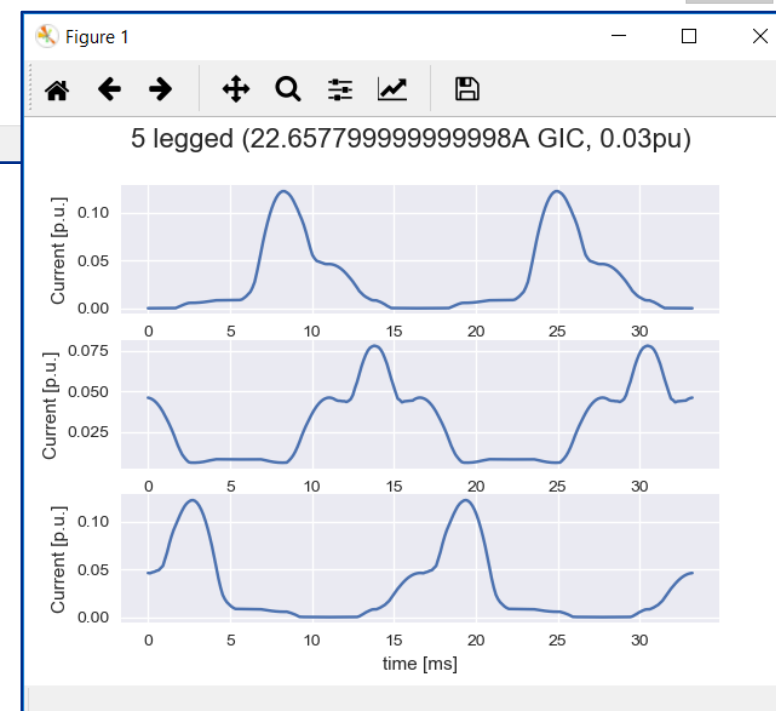
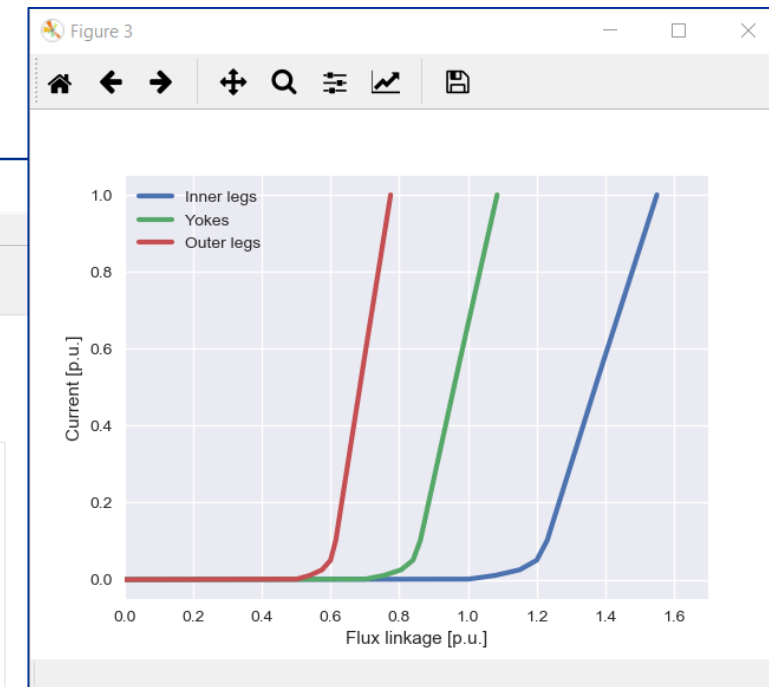
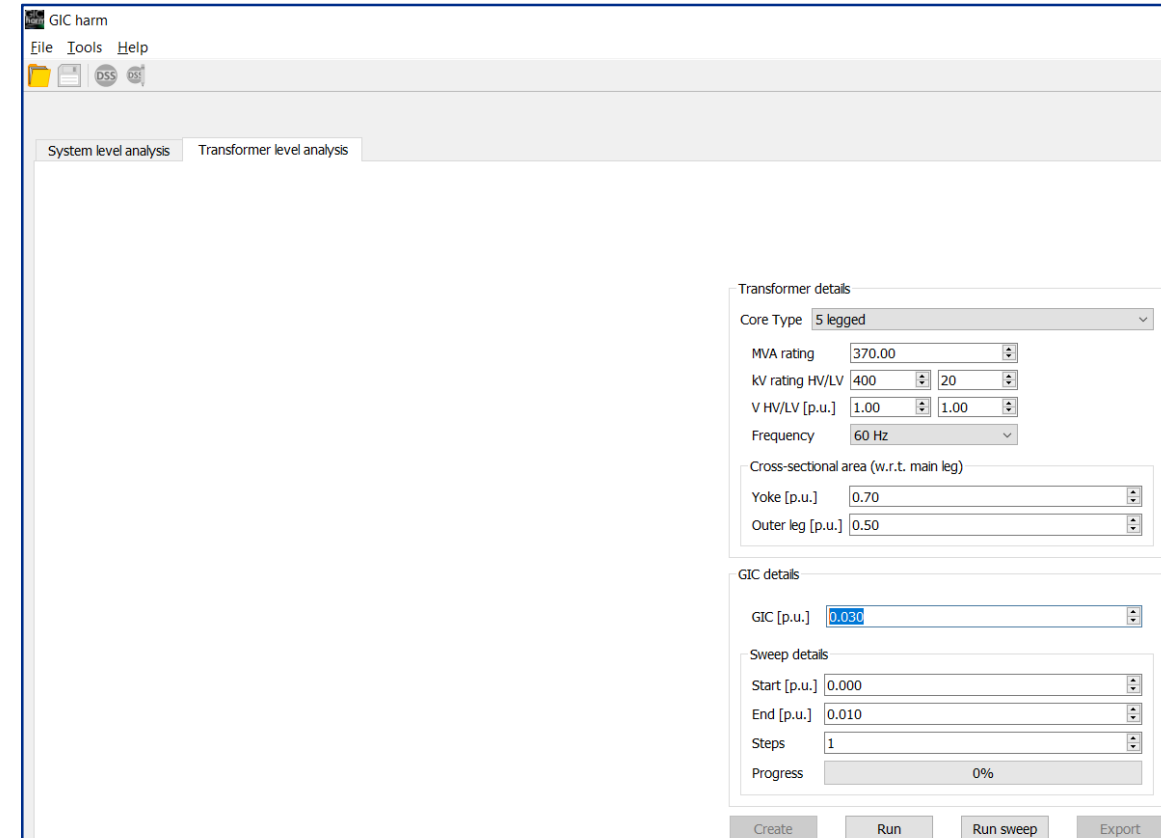
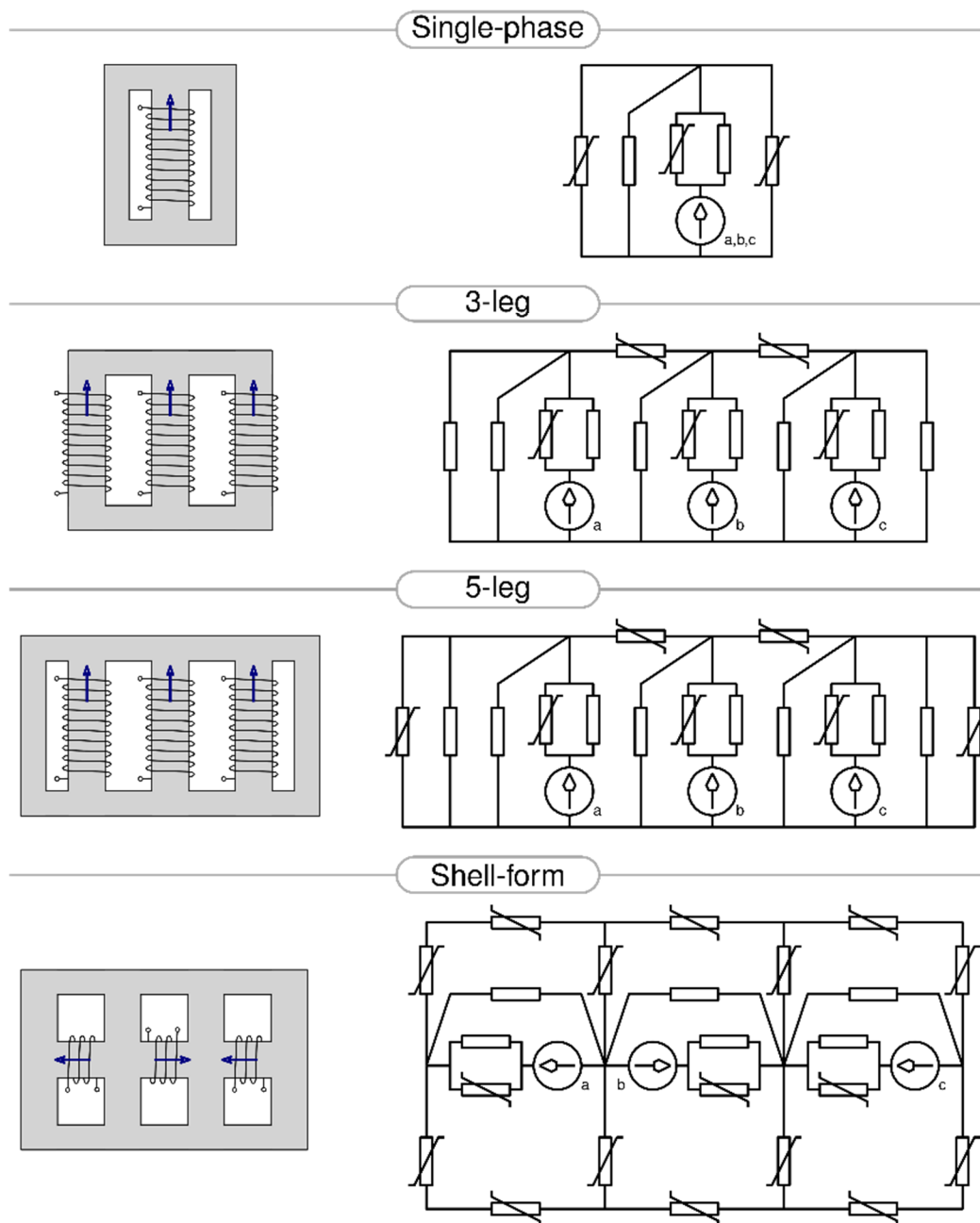
- Transformer level analysis
- System level Analysis
- PSS®E to GICharm / OpenDSS converter





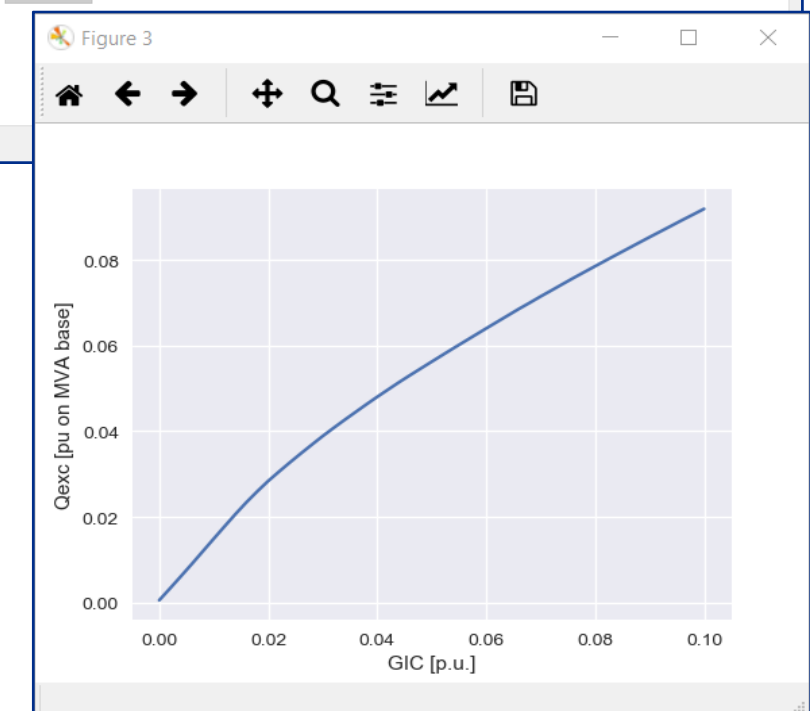
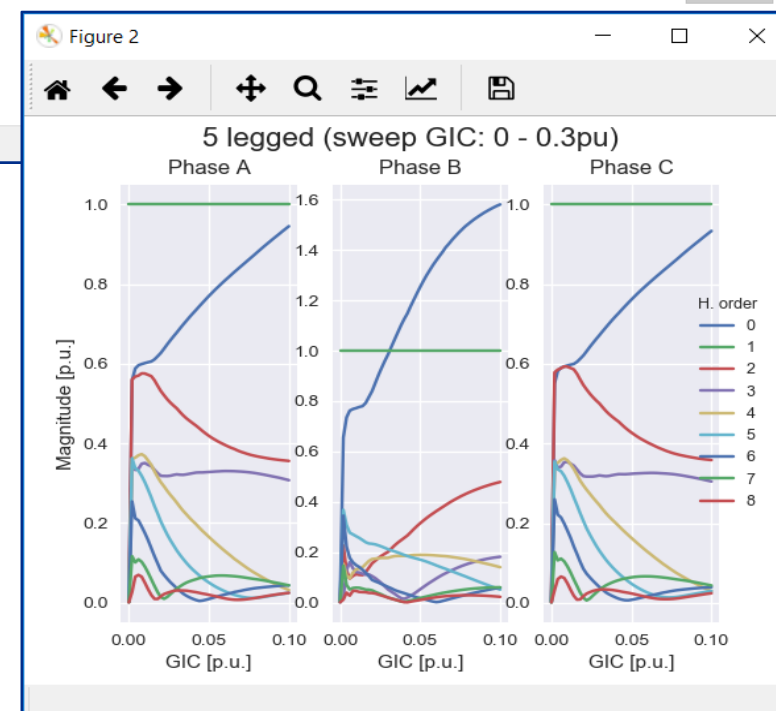
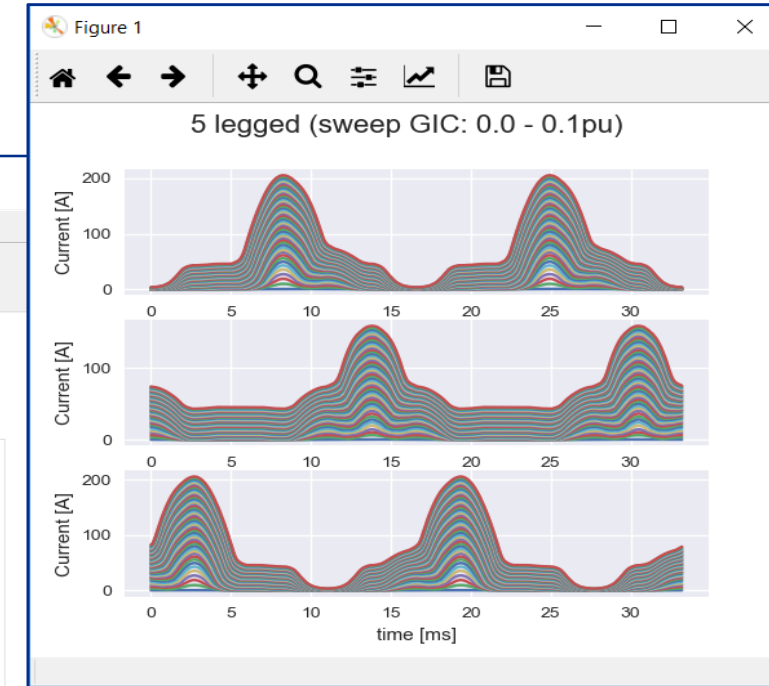
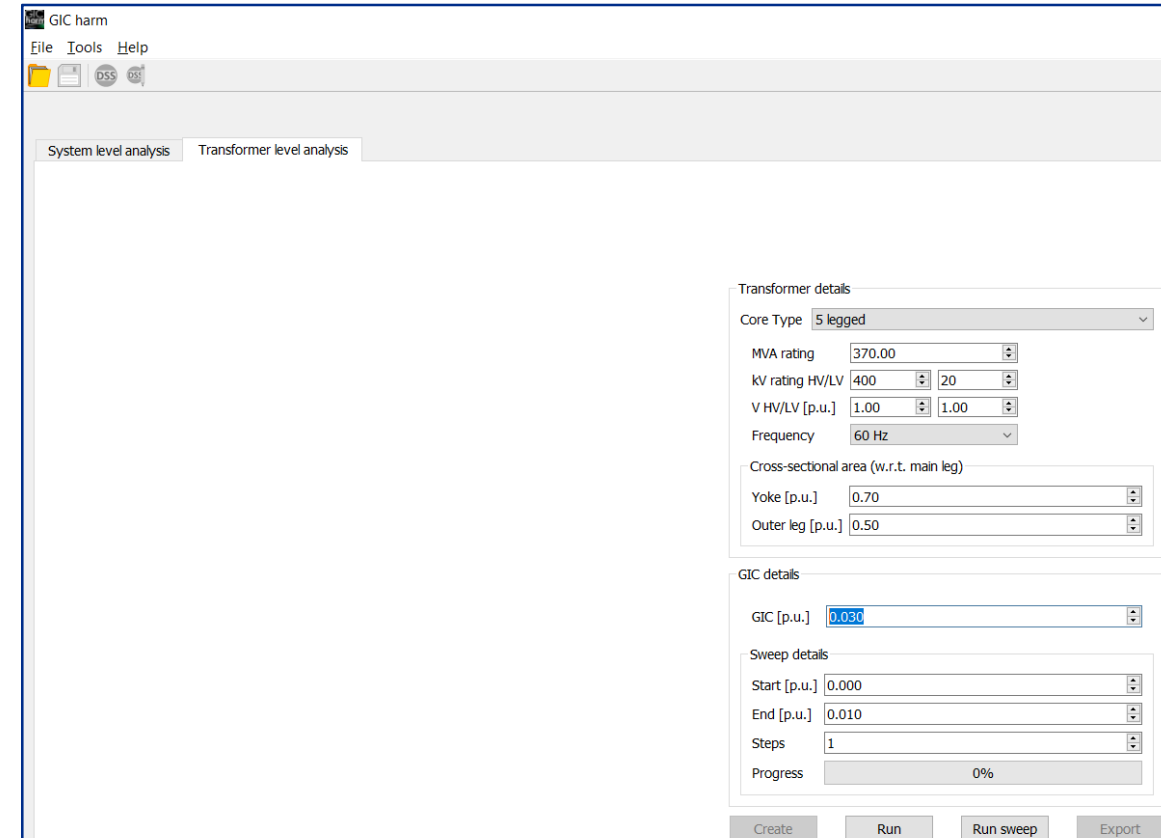
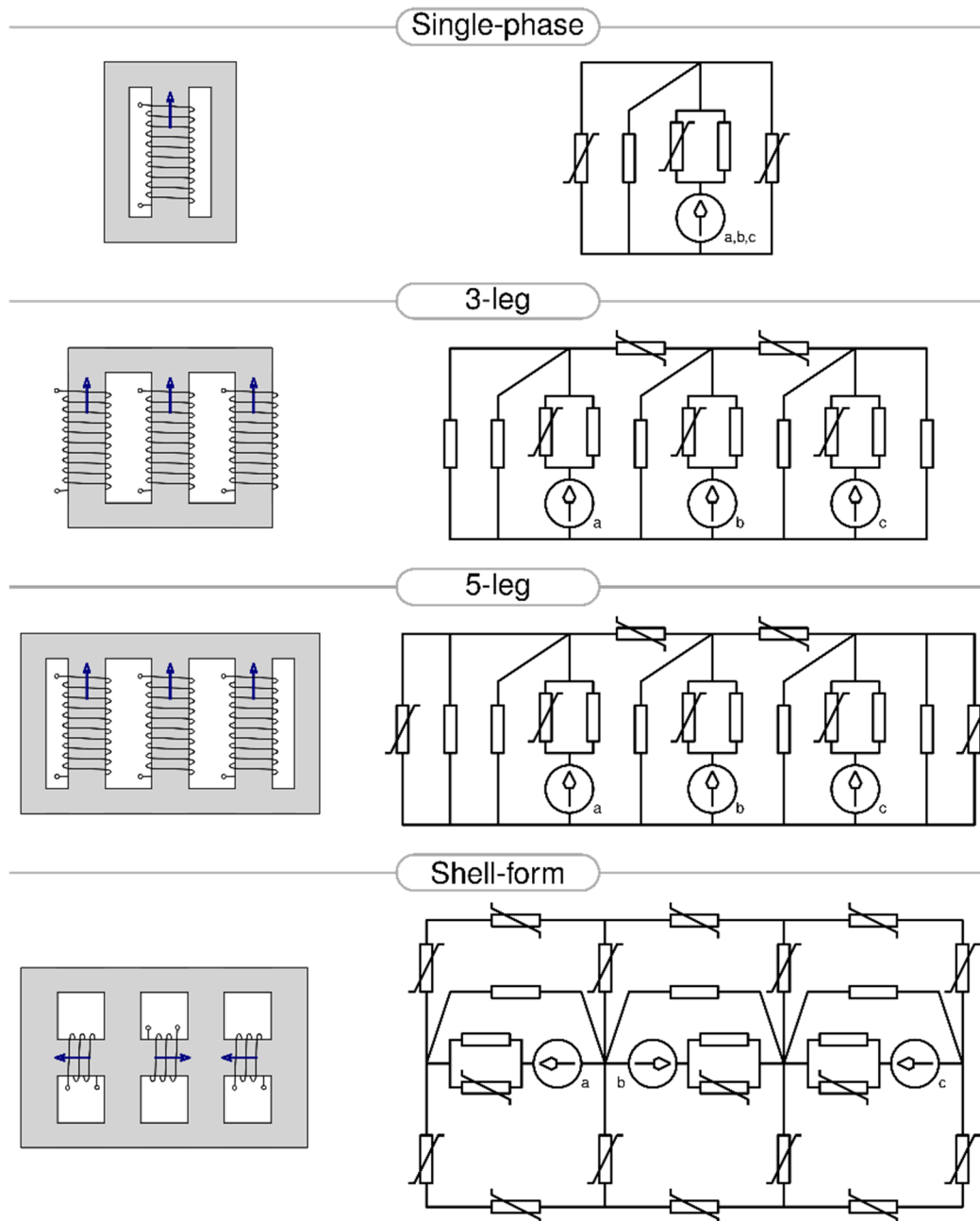
# Transformer level Analysis

- Non-linear saturation analysis
- Time domain analysis
- Magnetic circuit modeling



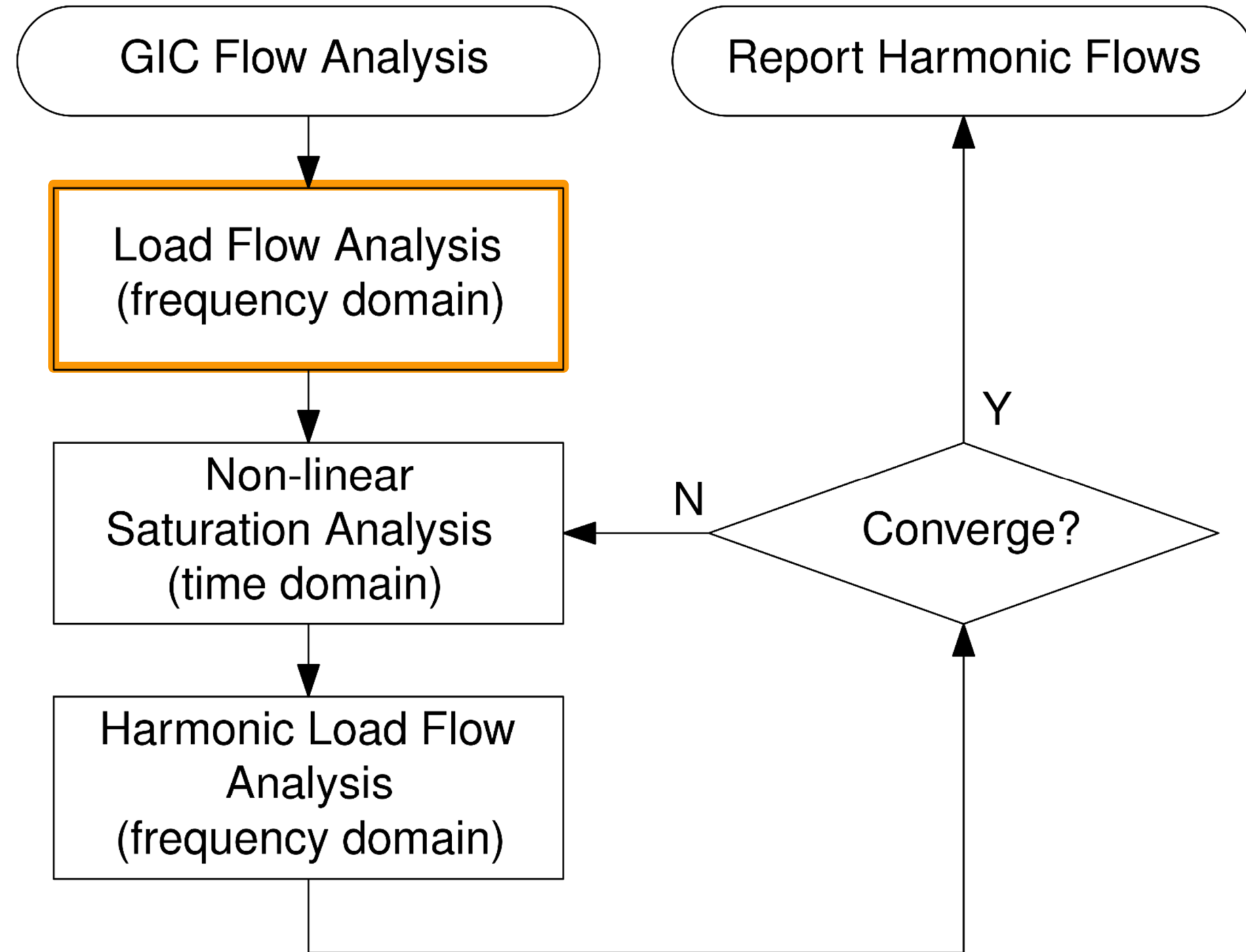
# Transformer level Analysis

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# System level Analysis

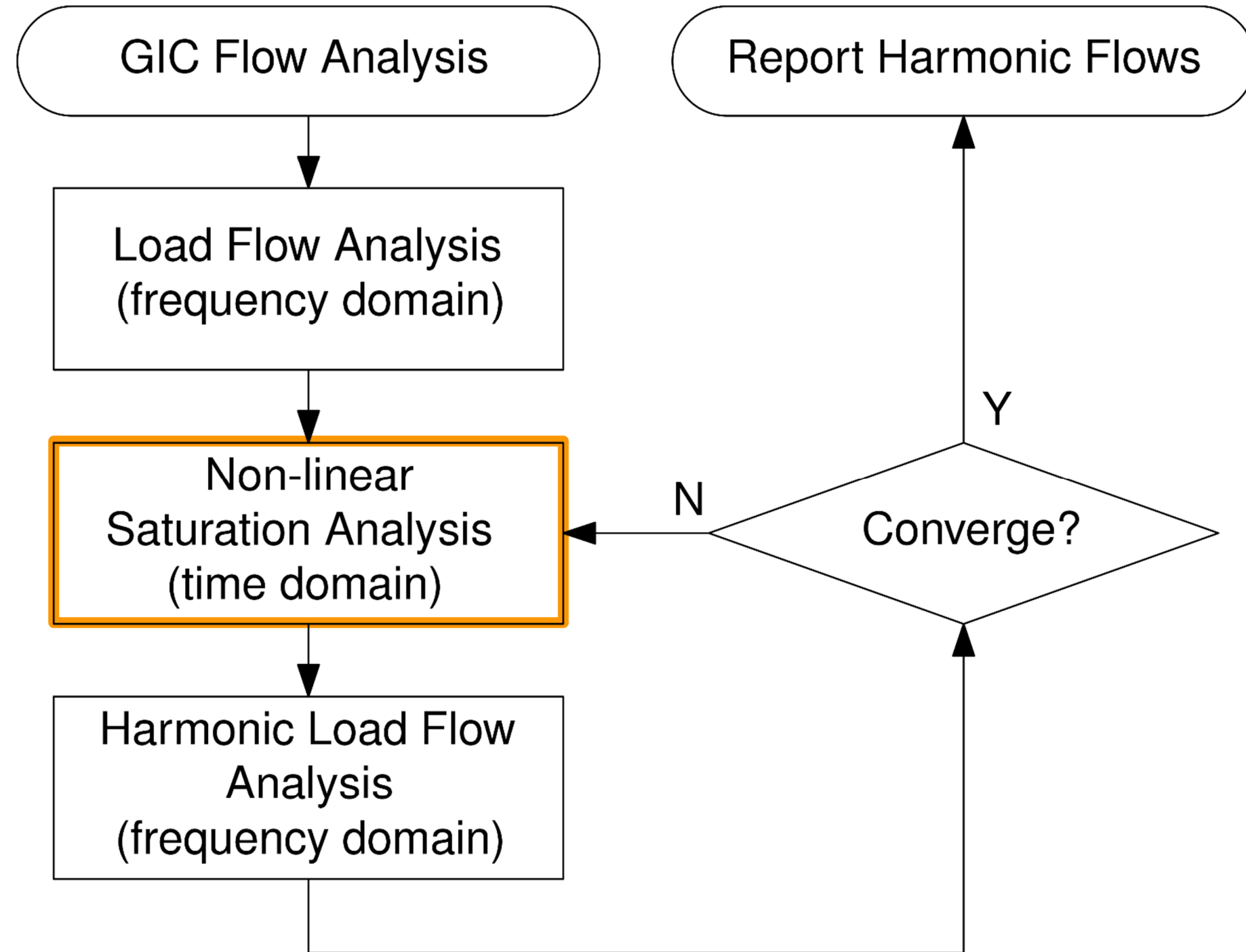
- Pre-event system state is determined by a load flow. Can be determined by an external source (PSS®E)
- GIC flows are determined from geo-electric field parameters





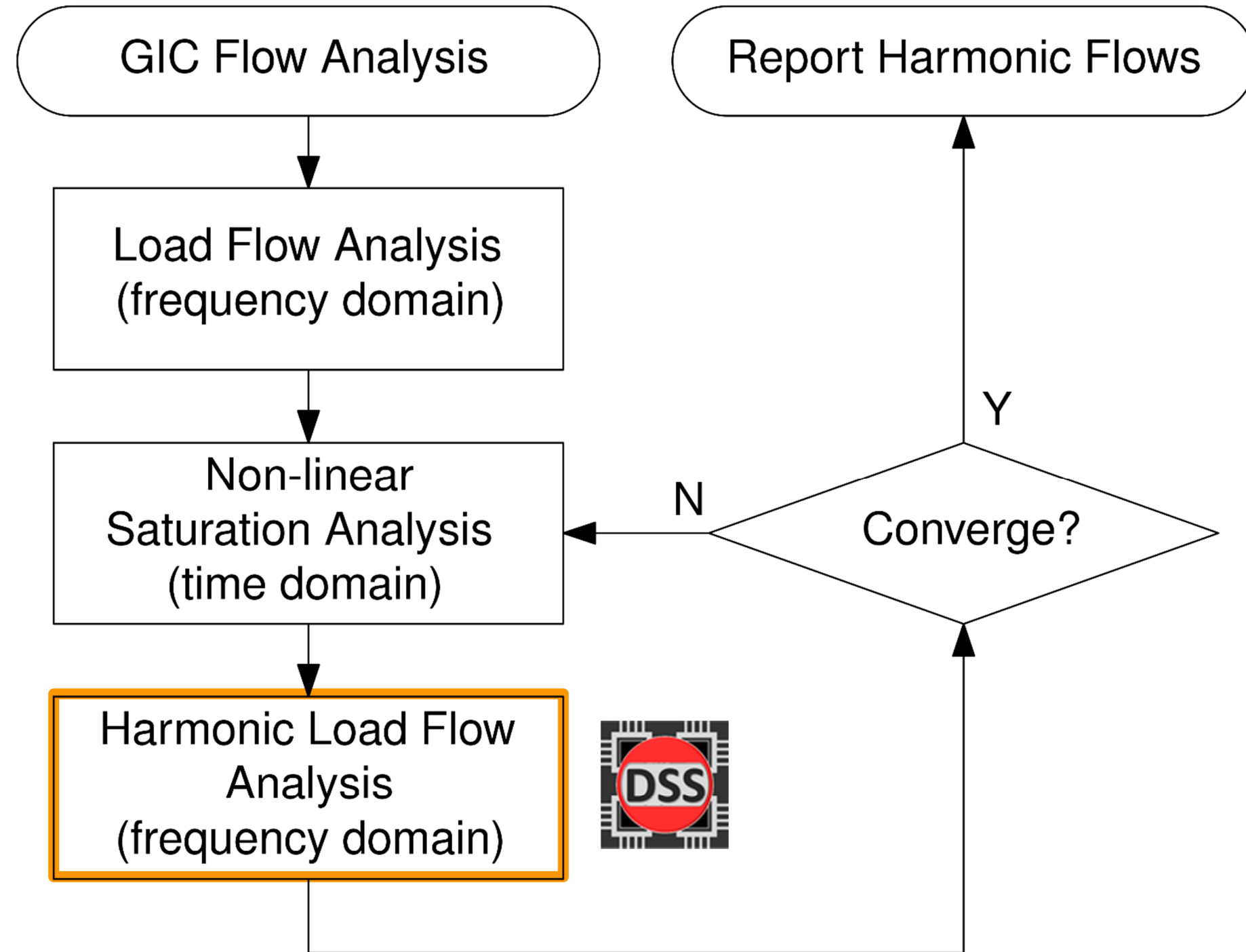
# System level Analysis

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- GIC flows are determined from geo-electric field parameters
- Transformer level analysis performed for each transformer in the system



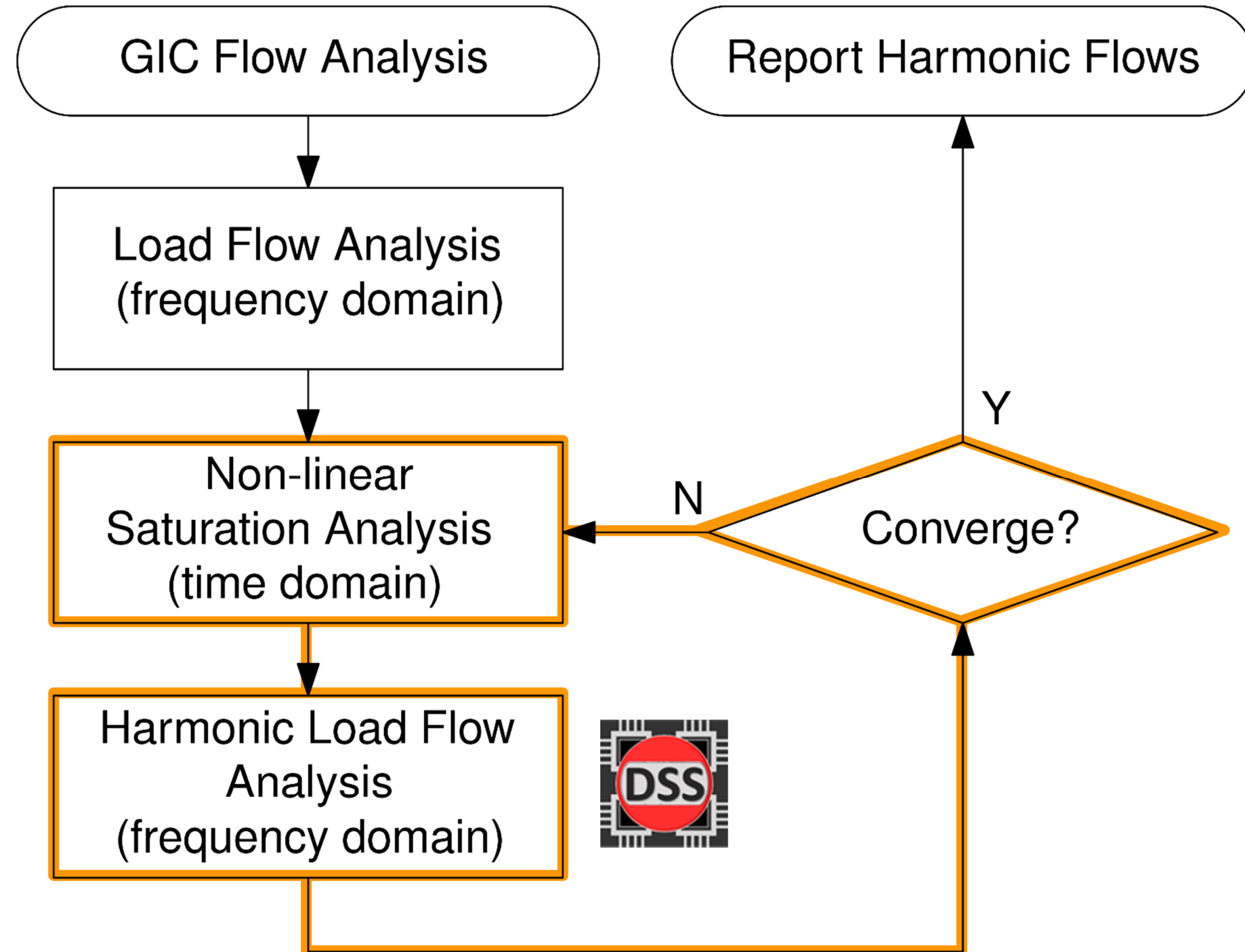
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- Harmonic load flow to determine voltage harmonic distortion throughout the system



# System level Analysis

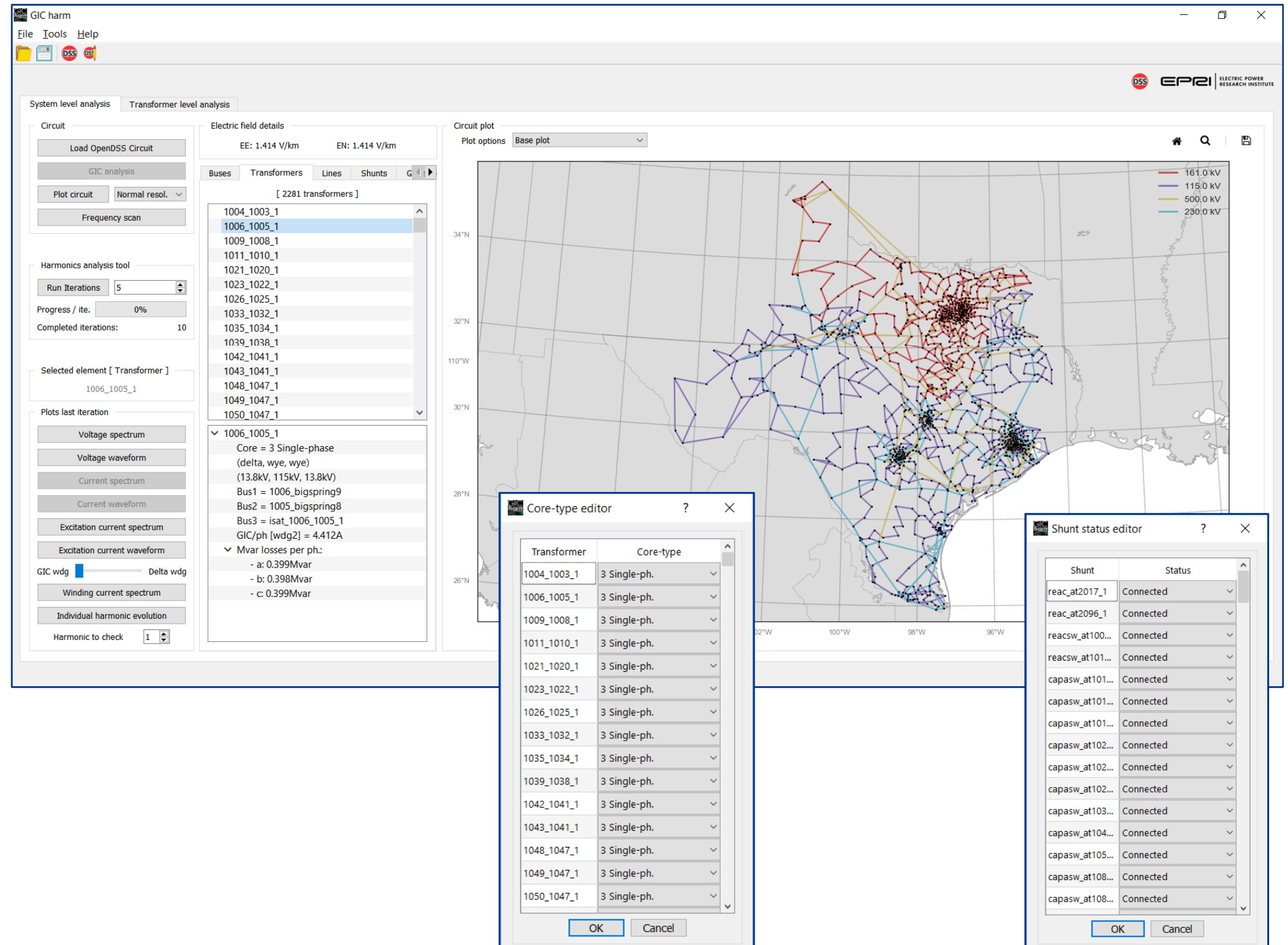
- Pre-event system state is determined by a load flow. Can be determined by an external source (PSS®E)
- GIC flows are determined from geo-electric field parameters
- Transformer level analysis performed for each transformer in the system
- Harmonic load flow to determine voltage harmonic distortion throughout the system
- Repeat until convergence criteria is reached





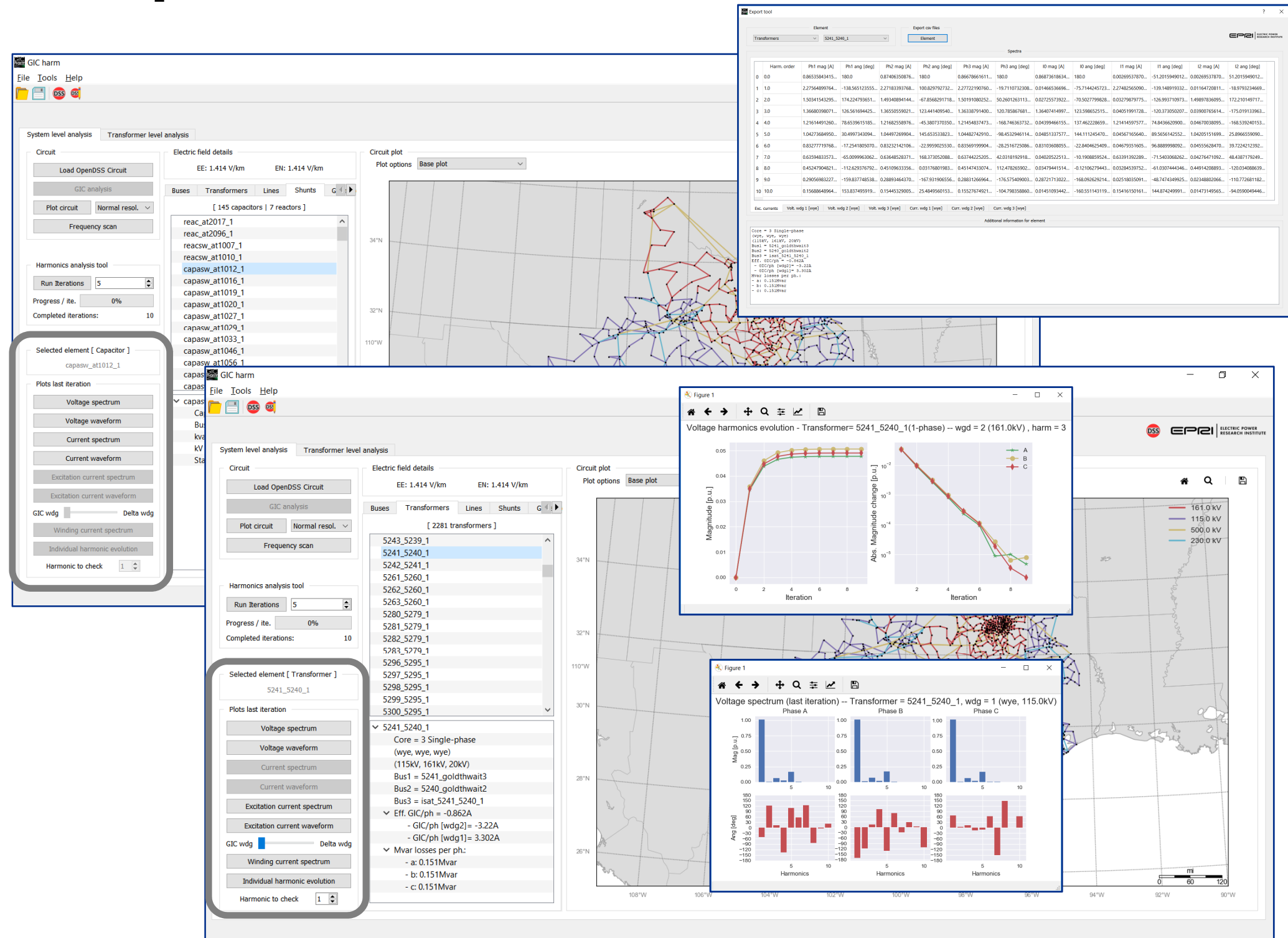
# System level Analysis – Explore system details

- Tool allows to explore relevant elements:
  - Buses
  - Transformers
  - Lines
  - Shunts
  - Generators
- Allows the user to consider different scenarios by changing:
  - Transformer core topologies
  - Geo-electric field components
  - Connect / disconnect Capacitor banks



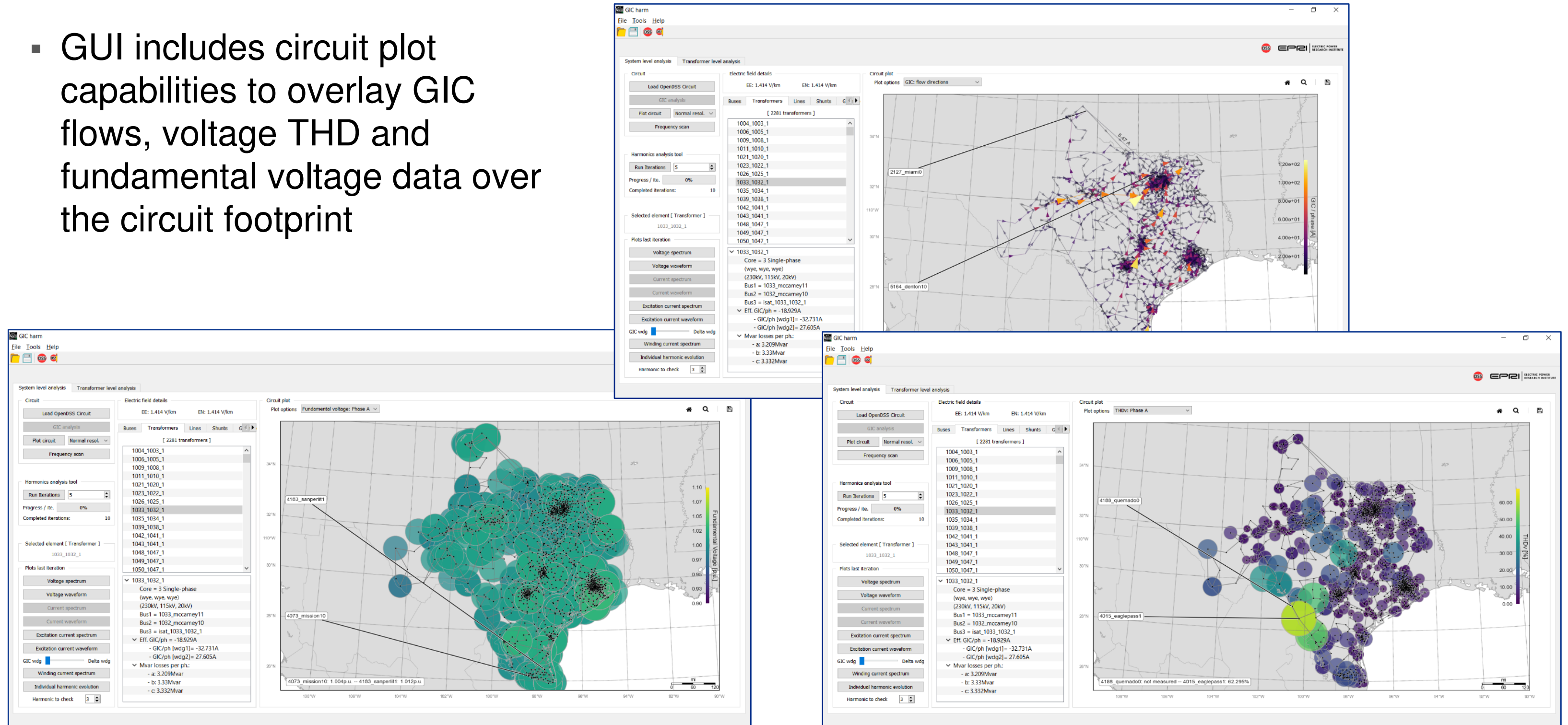
# System level Analysis – Explore simulation results

- Explore simulation results with waveforms and spectra of voltage and current for:
  - Transformer windings
  - Capacitors and reactors
  - Generators
- For transformers
  - Evolution of the harmonic content of voltage through the iterations of the harmonic loop
- Export results to csv files: The tool includes a built-in tool to export user-selected results.



# System level Analysis – Explore simulation results

- GUI includes circuit plot capabilities to overlay GIC flows, voltage THD and fundamental voltage data over the circuit footprint





# PSS®E to OpenDSS converter

- Data imported from PSS®E *\*.raw* and *\*.gic* files
- Data cleaning after import
- Data conversion to regular and GICharm *\*.dss* files

```

1 Clear
2
3 var @EEO = 1.4142 !(2 sqrt)
4 var @ENO = 1.4142 !(2 sqrt)
5
6 New Circuit.activsg2000_gicharm
7 ~ basekv=13.8 phases=3 pu=1.0574073894772034 angle=(11.736214969083537 30 -) frequency=60 baseMVA=1625.16 puZ1=[0.001
8 ~ bus1=7098_wadsworth3
9 New monitor.source_gv_md0 vsource.source 1 mode = 0
10
11 /**** Conversion from PSS/E RAW data file ****/
12
13 /**** Circuit elements definition ****/
14
15 [**** ---- Choose either generators.dss or gens_as_vsrgs.dss ****/
16 !redirect generators.dss ! definitions for generators
17 redirect generators_as_vsrgs.dss ! definitions for generators
18 redirect dc_and_facts_equiv_elements.dss ! definitions for dc and facts elements from pss/e
19
20 redirect lines.dss ! definitions for lines
21 redirect gic_sources.dss ! definitions for gic sources
22 redirect transformers.dss ! definitions for transformers
23 redirect transformers_mag_nonlin_loads.dss ! definitions for mag. nonlin. loads
24 redirect loads.dss ! definitions for loads
25 redirect shunts.dss ! definitions for reactors and capacitors
26 redirect sw_shunts.dss ! definitions for switched reactors and capacitors
27 redirect generator_step_ups.dss ! definitions for GSUs for initially HV generators
28 redirect dc_equiv_step_ups.dss ! definitions for GSUs for initially HV DC equiv. element
29 redirect generator_gsu_mag_nonlin_load.dss ! definitions for Gsu mag. nonlin. loads
30 redirect dc_equiv_gsu_mag_nonlin_load.dss ! definitions for Gsu (for dc equiv.) mag. nonlin. loads
31 redirect load_transformers.dss ! definitions for transformers for initially HV loads
32
33 redirect monitors.dss
34 redirect monitors_gsu.dss
35 redirect monitors_dc_equiv_gsu.dss
36 redirect monitors_transformers_loads.dss
37 redirect monitors_shunts.dss
38
39 /**** Voltage bases for all buses ****/
40 Set VoltageBases = [13.8, 115.0, 230.0, 22.0, 500.0, 161.0, 20.0, 24.0, 13.2]
41 Calcv
42 redirect confirm_kv_bases.dss
43
44 [/*
45 ! Solve mode = snap
46 Solve mode = direct
47 */

```

PSS/E to OpenDSS converter

Load PSS/E files

Save OpenDSS files

RAW

GIC

Regular files

GIC Harmonics tool

DSS

EPRI

ELECTRIC POWER RESEARCH INSTITUTE

PSS/E element description

|    | I    | NAME            | BASKV | BASKV_old | IDE | AREA | ZONE | OWNER | VM         | VA                | NVHI | NVLO | EVHI | EVLO |
|----|------|-----------------|-------|-----------|-----|------|------|-------|------------|-------------------|------|------|------|------|
| 0  | 1001 | 1001_odessa20   | 115.0 | 115.0     | 1   | 1    | 9    | 1     | 0.97943562 | -22.7348429999... | 1.1  | 0.9  | 1.1  | 0.9  |
| 1  | 1002 | 1002_presidio20 | 115.0 | 115.0     | 1   | 1    | 9    | 1     | 1.01273644 | -18.088545        | 1.1  | 0.9  | 1.1  | 0.9  |
| 2  | 1003 | 1003_odonnell1  | 115.0 | 115.0     | 1   | 1    | 9    | 1     | 1.00926292 | -17.0867          | 1.1  | 0.9  | 1.1  | 0.9  |
| 3  | 1004 | 1004_odonnell2  | 230.0 | 230.0     | 2   | 1    | 9    | 1     | 1.0130707  | -18.9339980000... | 1.1  | 0.9  | 1.1  | 0.9  |
| 4  | 1005 | 1005_bigspring8 | 115.0 | 115.0     | 1   | 1    | 9    | 1     | 1.00557613 | -16.077157        | 1.1  | 0.9  | 1.1  | 0.9  |
| 5  | 1006 | 1006_bigspring9 | 13.8  | 13.8      | 2   | 1    | 9    | 1     | 1.0        | -13.9055910000... | 1.1  | 0.9  | 1.1  | 0.9  |
| 6  | 1007 | 1007_vanhorn0   | 115.0 | 115.0     | 1   | 1    | 9    | 1     | 1.01999998 | -18.467213        | 1.1  | 0.9  | 1.1  | 0.9  |
| 7  | 1008 | 1008_iraan20    | 115.0 | 115.0     | 1   | 1    | 9    | 1     | 1.01928508 | -8.605208         | 1.1  | 0.9  | 1.1  | 0.9  |
| 8  | 1009 | 1009_iraan21    | 13.8  | 13.8      | 2   | 1    | 9    | 1     | 1.00924015 | -5.309597         | 1.1  | 0.9  | 1.1  | 0.9  |
| 9  | 1010 | 1010_presidio10 | 115.0 | 115.0     | 1   | 1    | 9    | 1     | 1.01999998 | -16.792355        | 1.1  | 0.9  | 1.1  | 0.9  |
| 10 | 1011 | 1011_presidio11 | 22.0  | 22.0      | 2   | 1    | 9    | 1     | 1.0202111  | -15.009826        | 1.1  | 0.9  | 1.1  | 0.9  |

SYSTEM-WIDE

BUS

LOAD

FIXED SHUNT

GENERATOR

BRANCH

TRANSFORMER

AREA

ZONE

OWNER

SWITCHED SHUNT

substation [gic]

bus substation [gic]

transformer [gic]

branch [gic]

Activity log

```
dict_keys(['SYSTEM-WIDE', 'BUS', 'LOAD', 'FIXED SHUNT', 'GENERATOR', 'BRANCH', 'TRANSFORMER', 'AREA', 'ZONE', 'OWNER', 'SWITCHED SHUNT'])

*.gic file path: C:/Users/ /ACTIVSg2000_GIC_data.gic
# Reading *.gic file ... #

# Populating table for substation #
# Populating table for bus substation #
# Populating table for transformer #
# Populating table for branch #

# ----- These are the types of elements found in the gic file ----- #

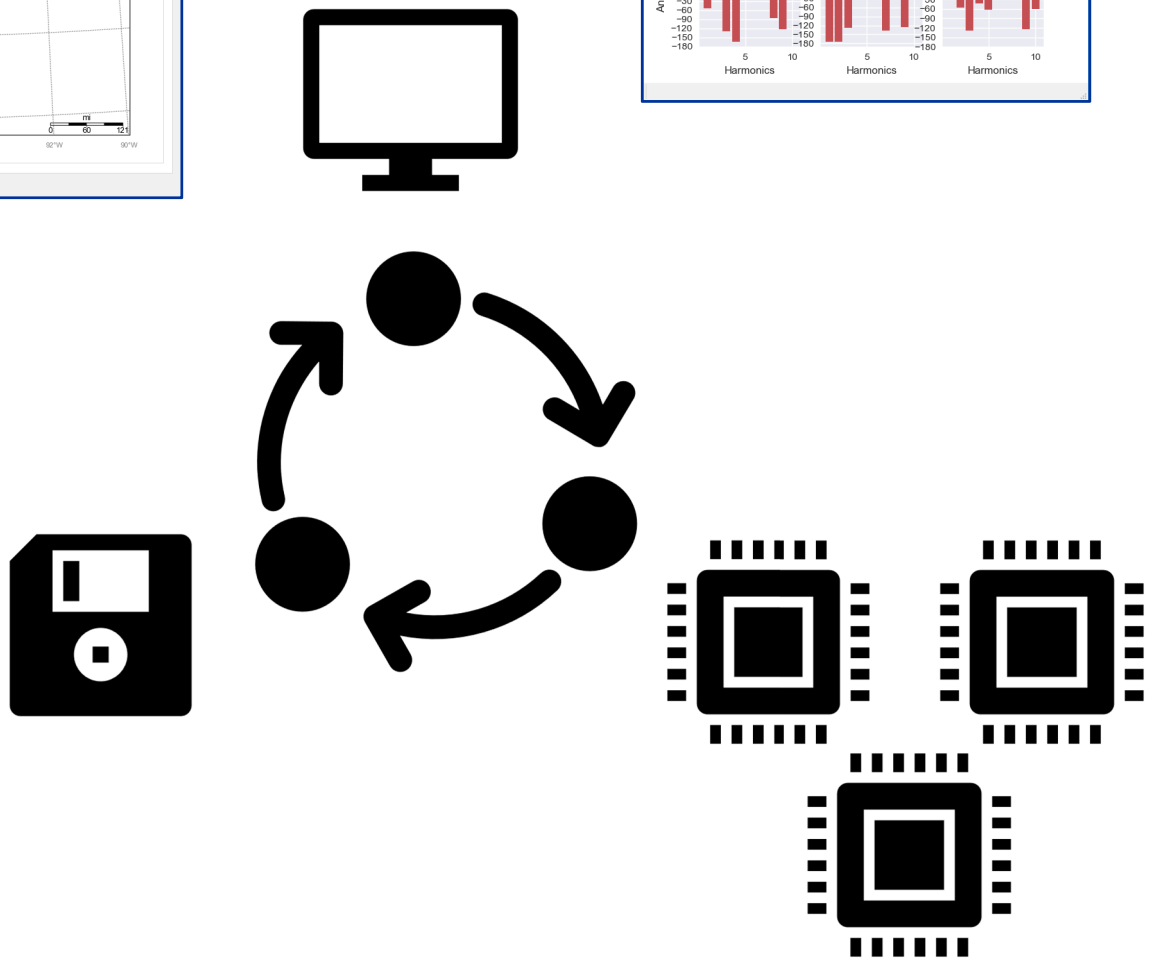
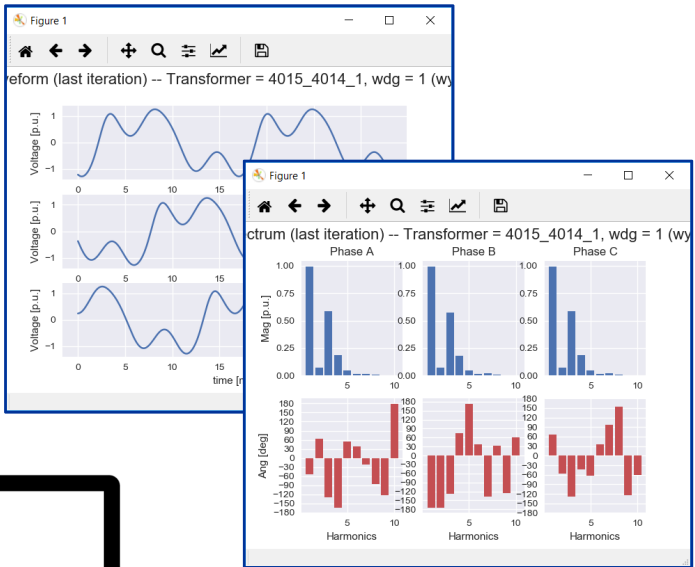
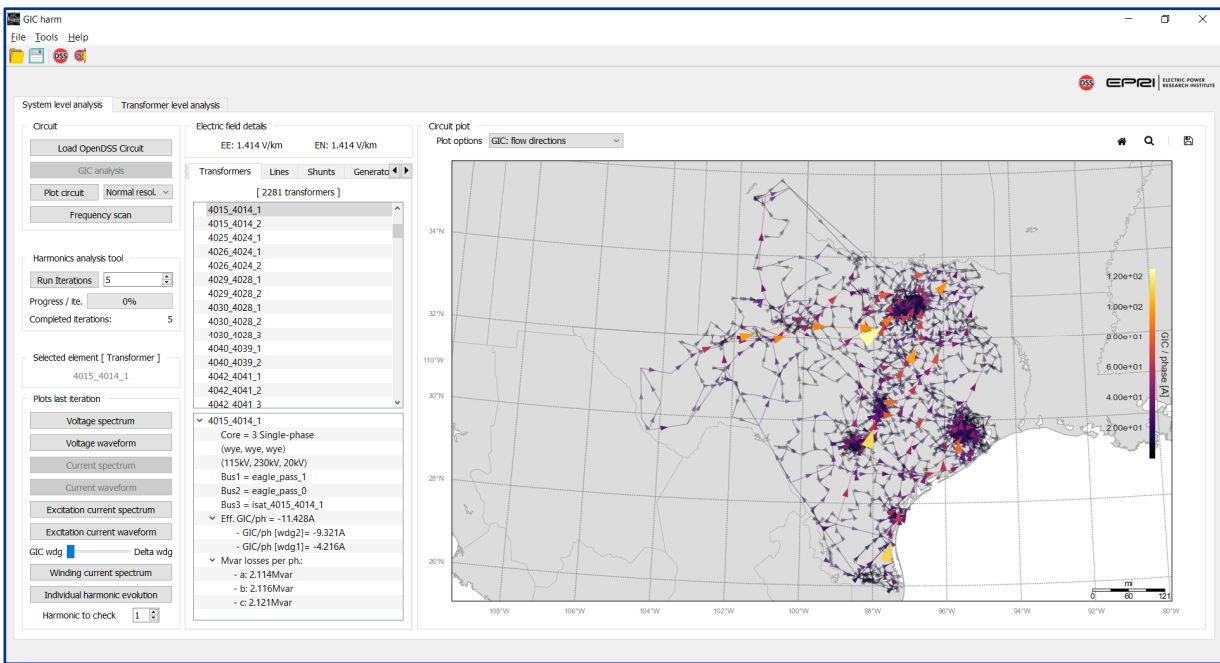
dict_keys(['substation', 'bus substation', 'transformer', 'branch'])
```

100%

Done!

# Data management - SQLite database & Serial files

- Each transformer non-linear saturation analysis is solved using parallel processing (more cores - higher speed)
- Transformer data is kept in serial files on local disk
- Circuit data and visualization information are kept in SQLite local database



| Name                  | Date modified     |
|-----------------------|-------------------|
| EPRI_GIC_harm_db.db   | 8/8/2019 11:31 AM |
| 1004_1003_1.pkl       | 8/8/2019 11:30 AM |
| 1004_1003_1_pass0.pkl | 8/7/2019 10:13 AM |
| 1004_1003_1_pass1.pkl | 8/7/2019 10:19 AM |
| 1004_1003_1_pass2.pkl | 8/7/2019 10:27 AM |
| 1004_1003_1_pass3.pkl | 8/7/2019 10:34 AM |
| 1004_1003_1_pass4.pkl | 8/7/2019 10:42 AM |
| 1006_1005_1.pkl       | 8/8/2019 11:30 AM |

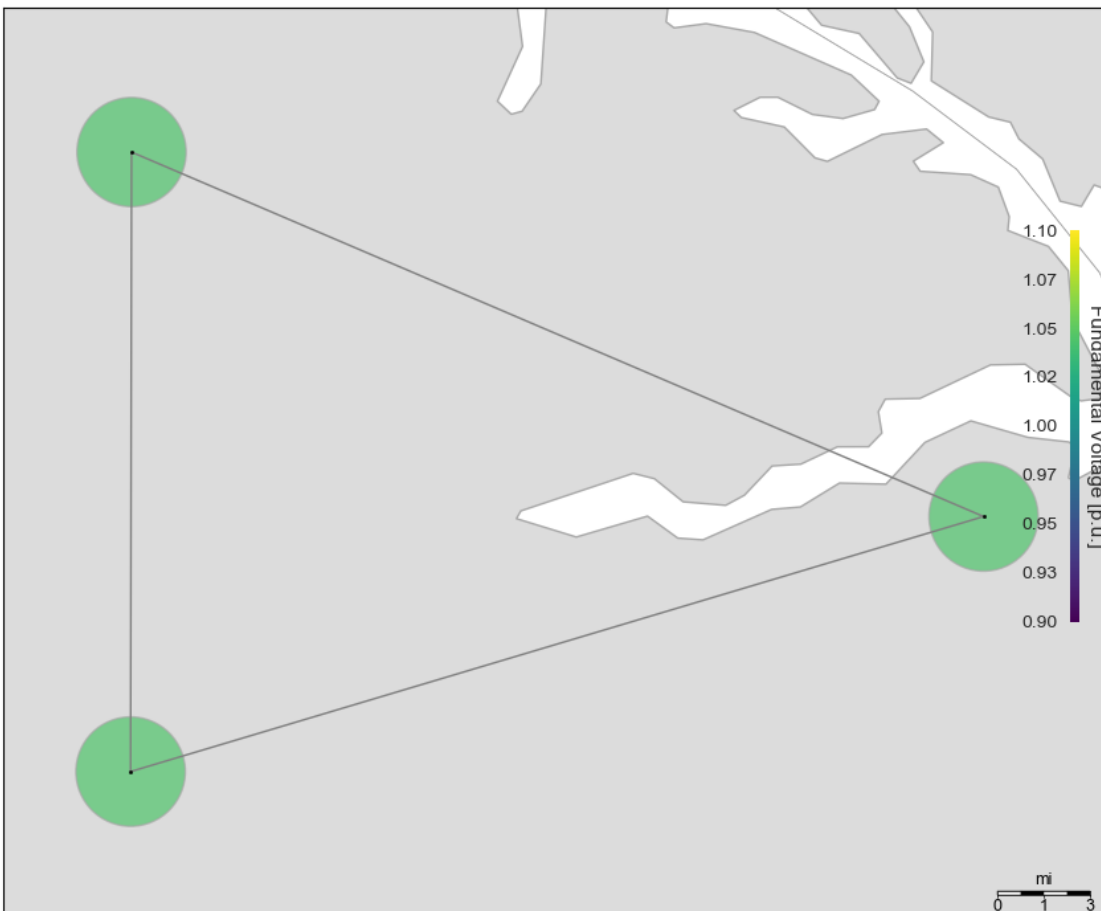
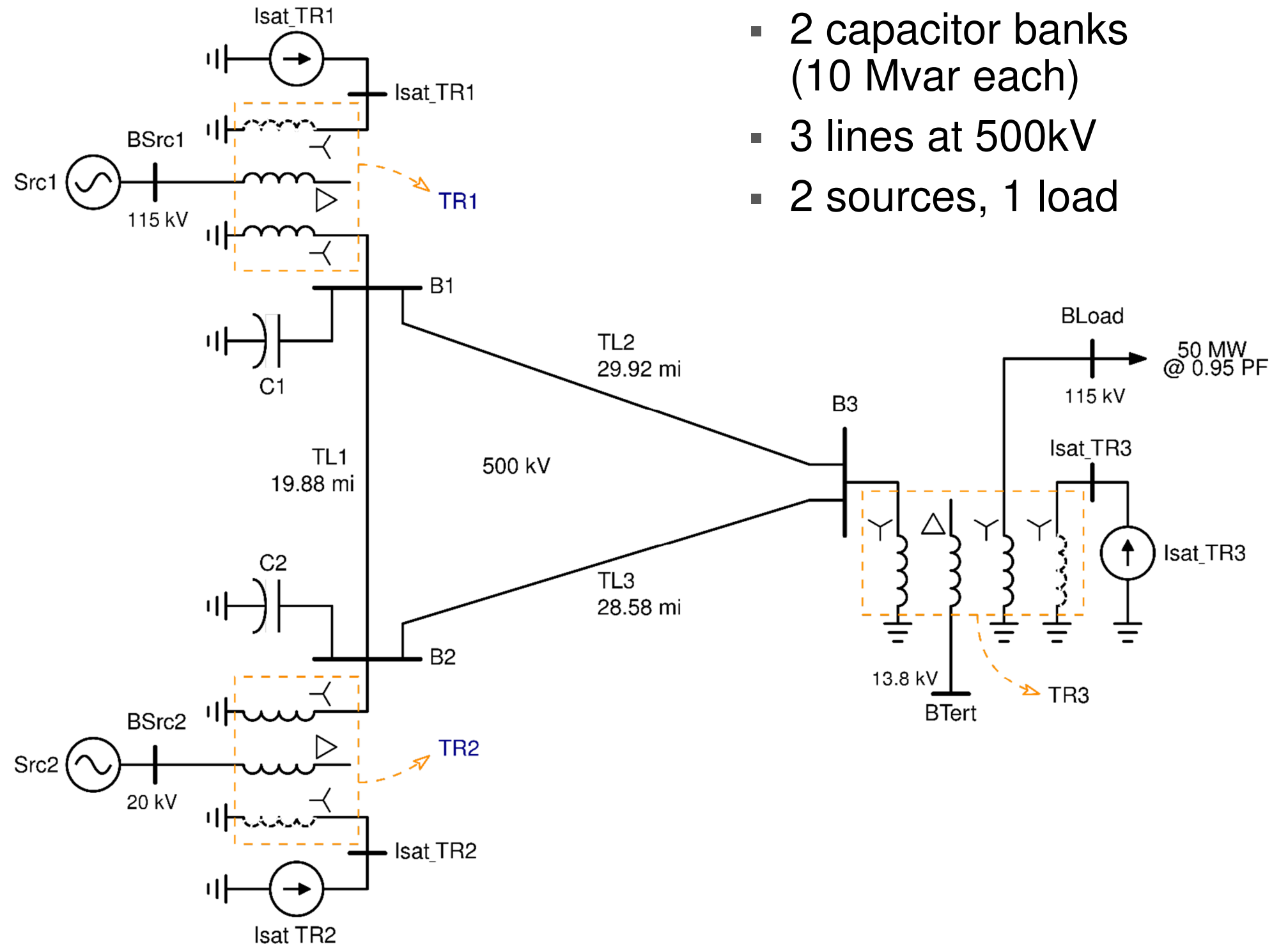


# Test Case for GLC harmonics analysis

# Test Case for GIC harmonics analysis

- 3 bus benchmark case to provide a reference for other researchers
- Fictitious location at the Northeast of Georgia, US

- 3 transformers (3-leg, 5-leg and bank of 3 single-phase core form)
- 2 capacitor banks (10 Mvar each)
- 3 lines at 500kV
- 2 sources, 1 load



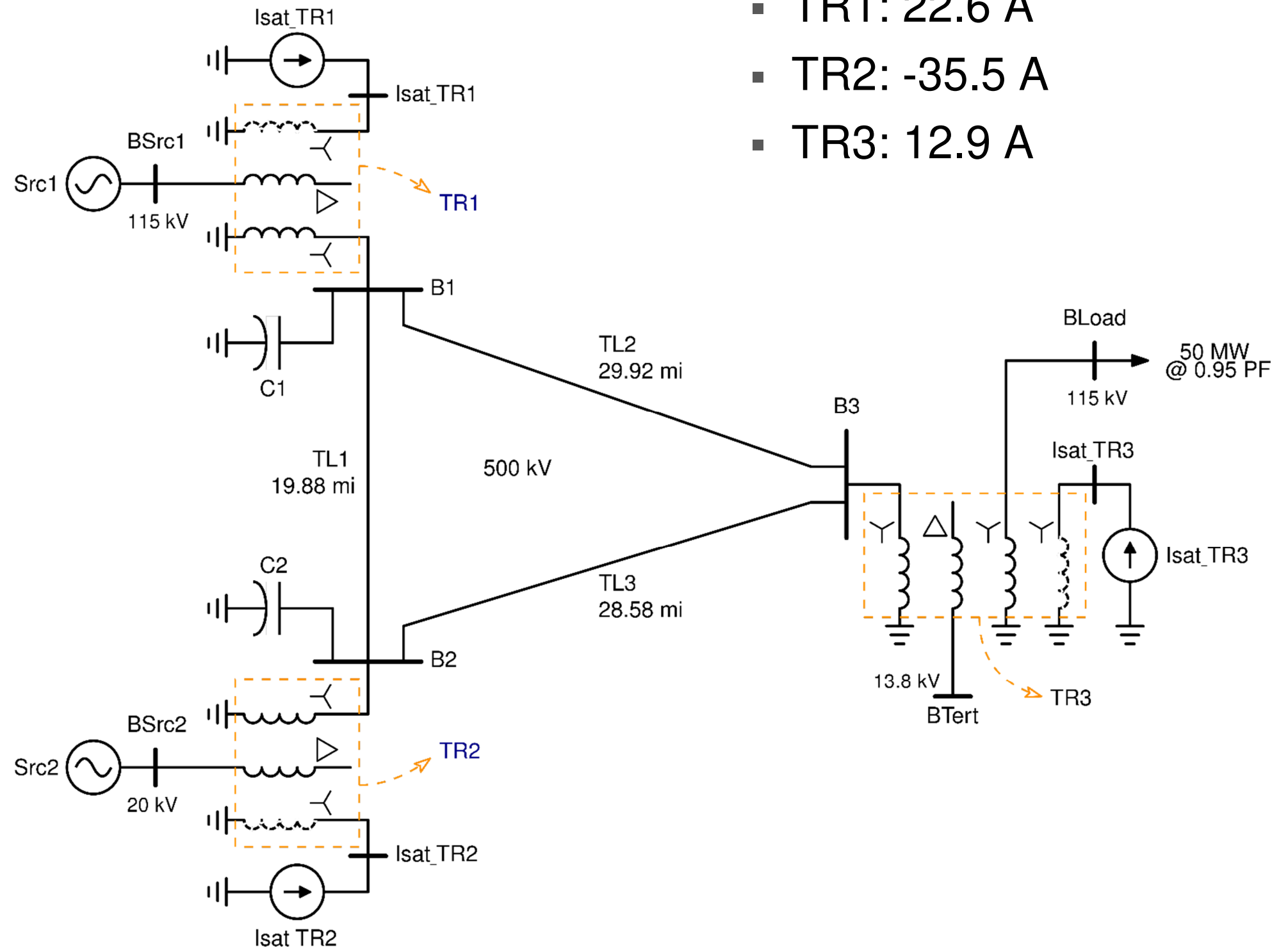
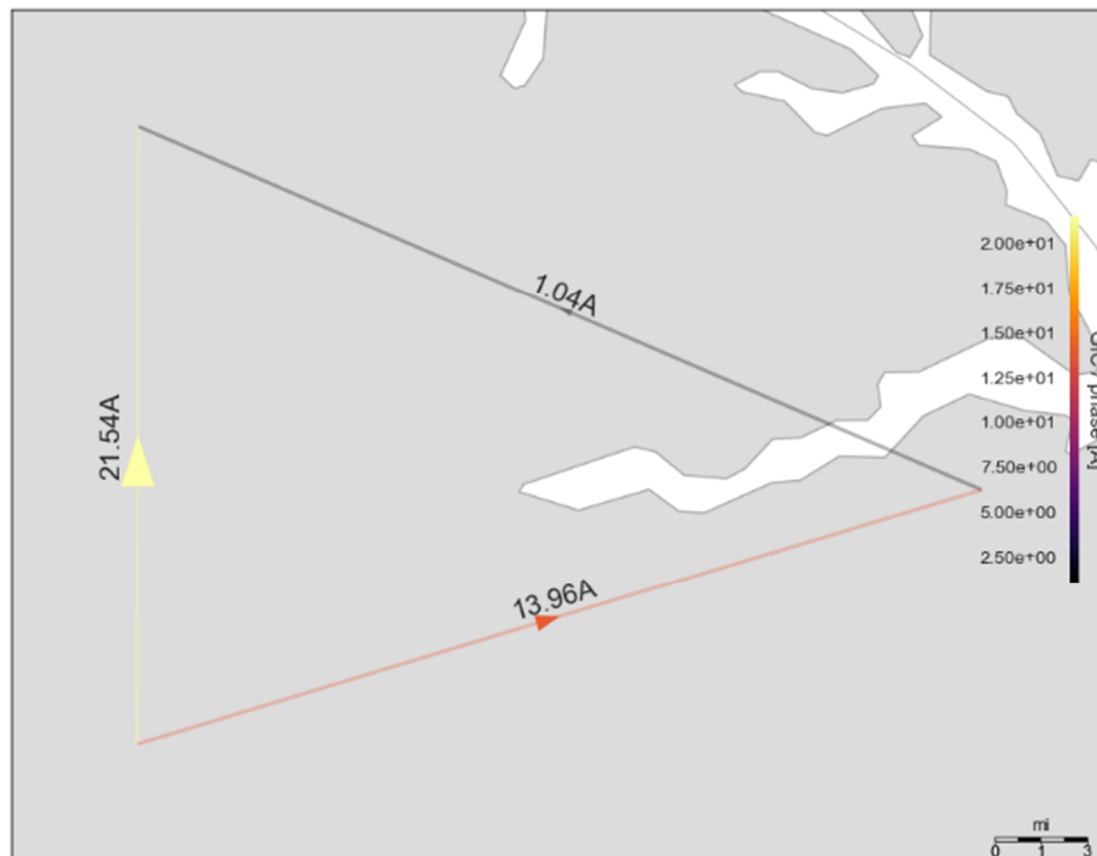
# Test Case for GIC harmonics analysis

Default study information:

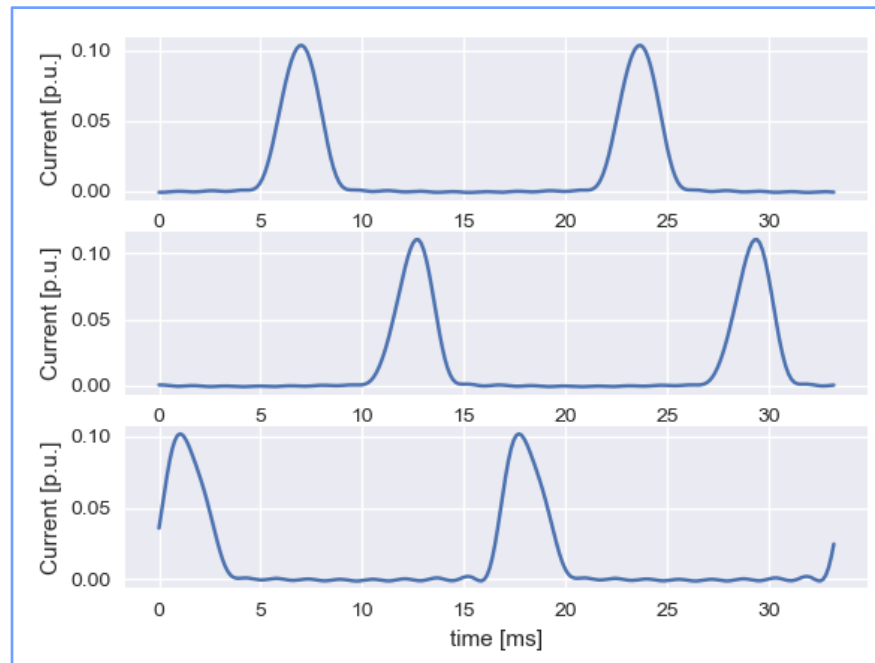
- 2 V/km geo-electric field (eastward and northward components of  $\sqrt{2}$  V/km each)
- GIC flows:

Transformers see these GIC flows:

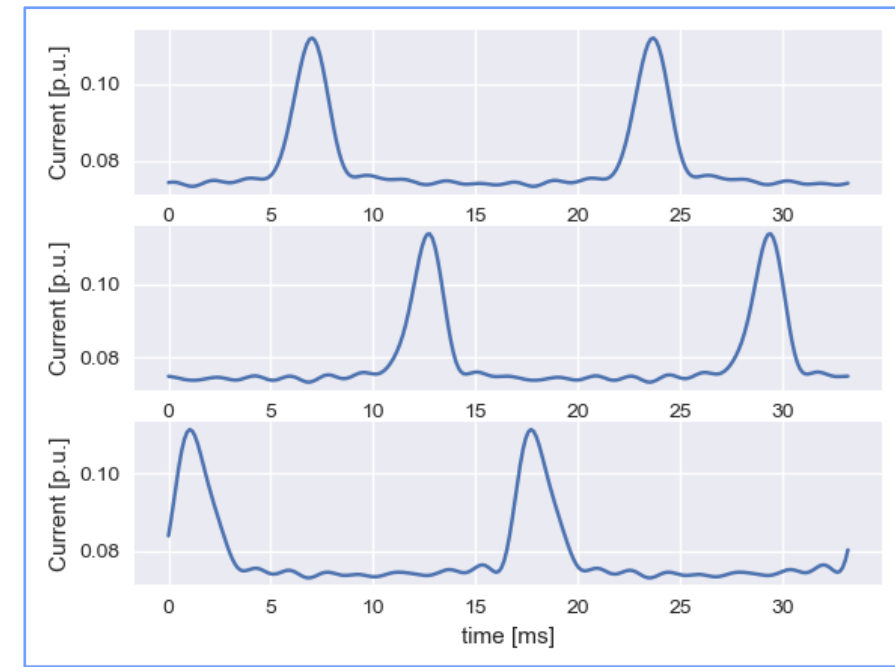
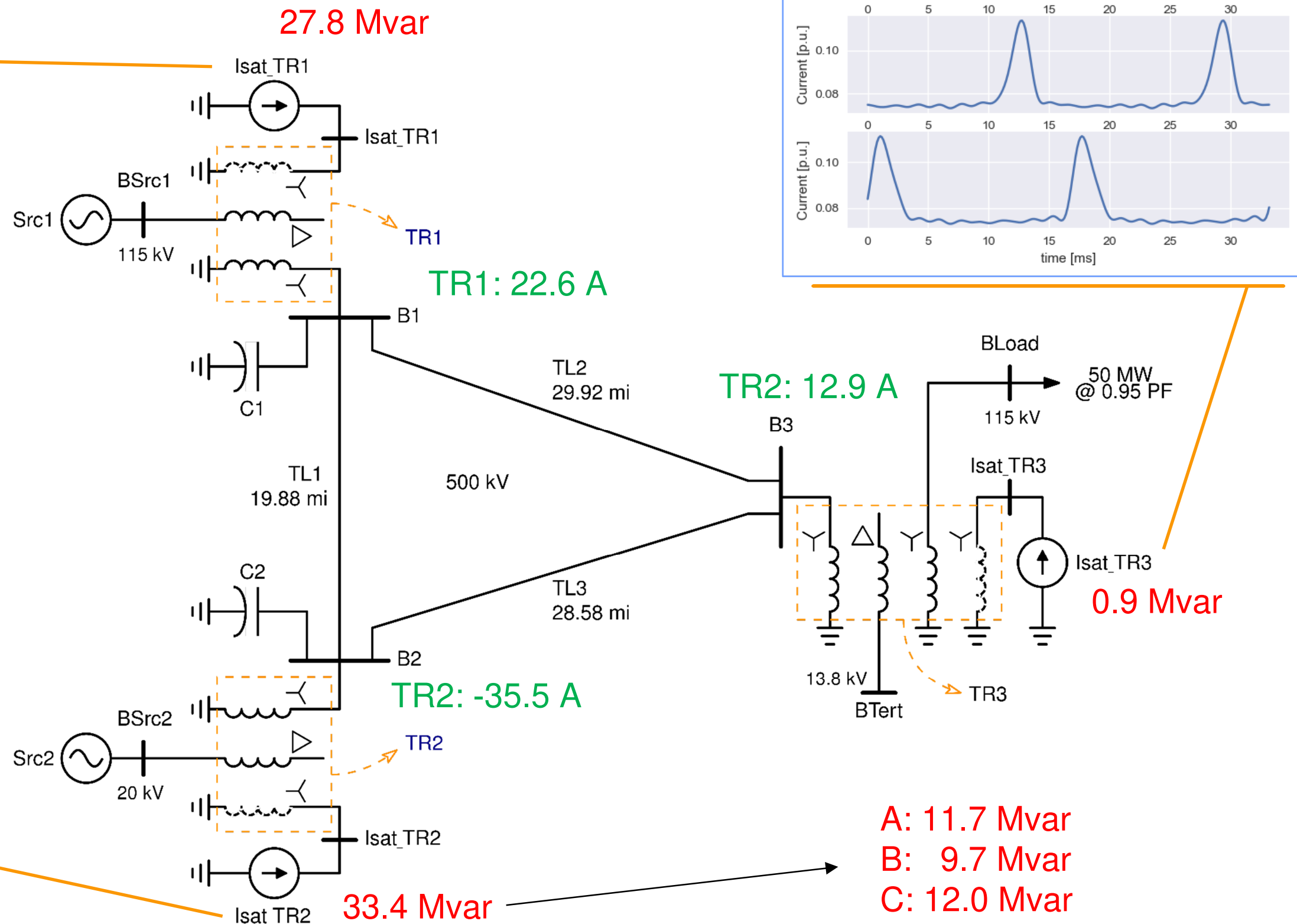
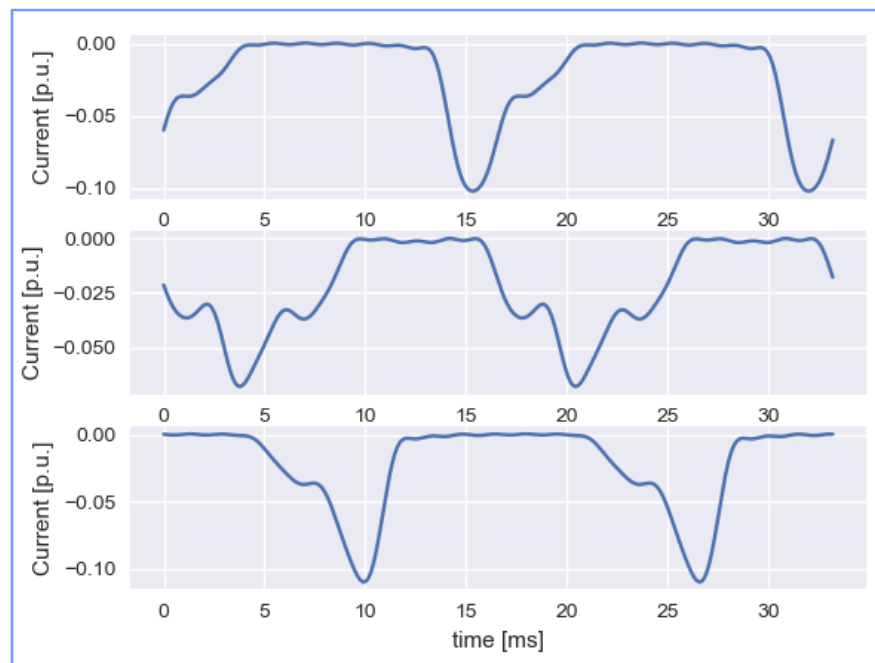
- TR1: 22.6 A
- TR2: -35.5 A
- TR3: 12.9 A



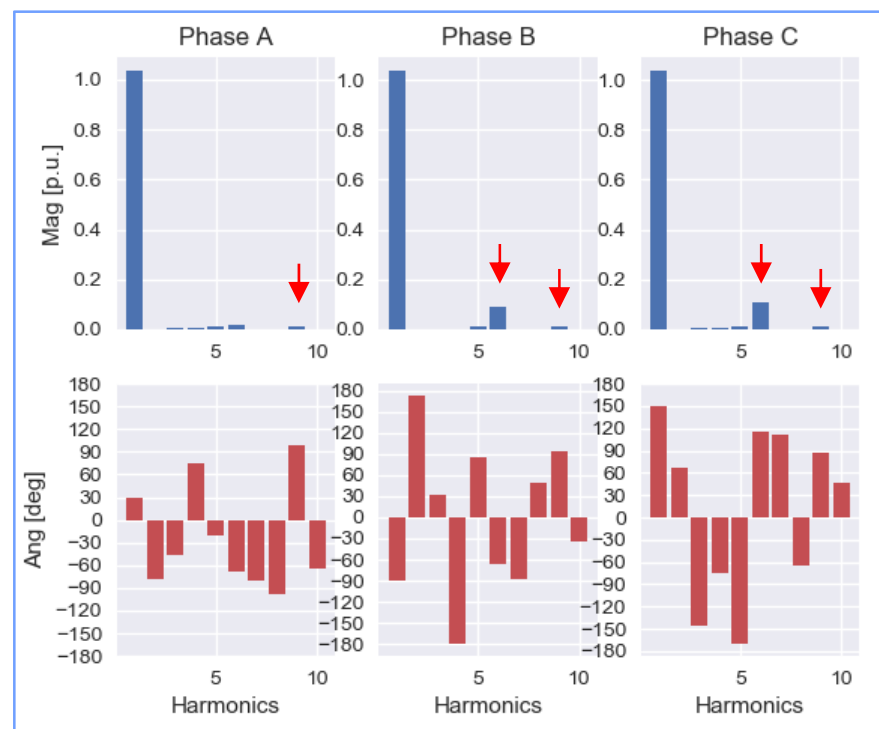
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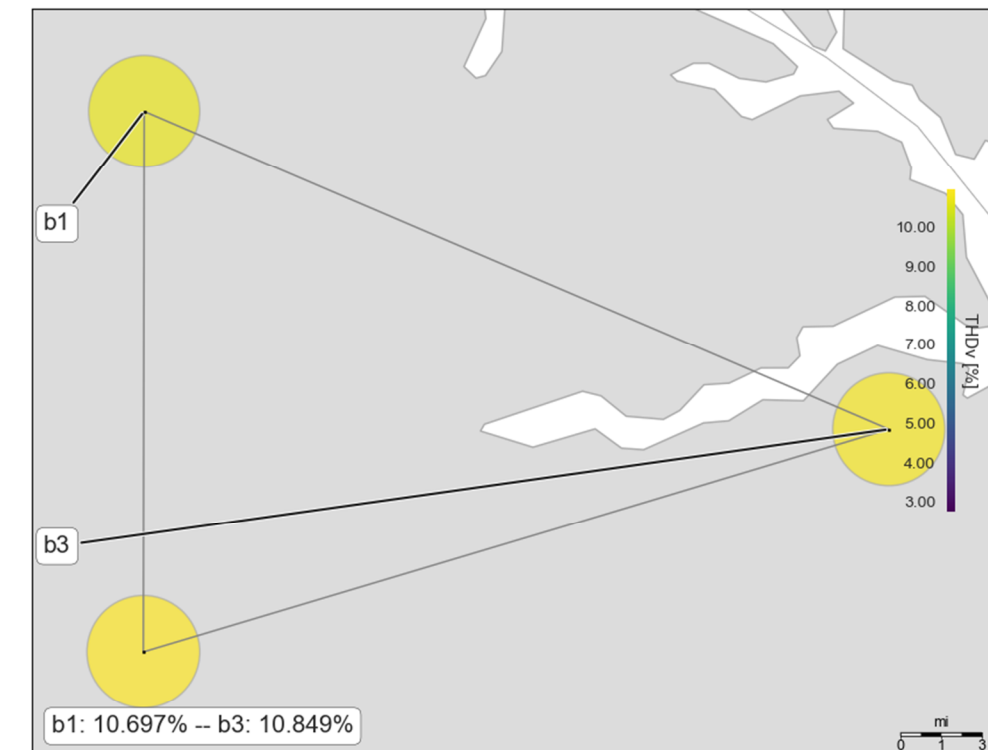
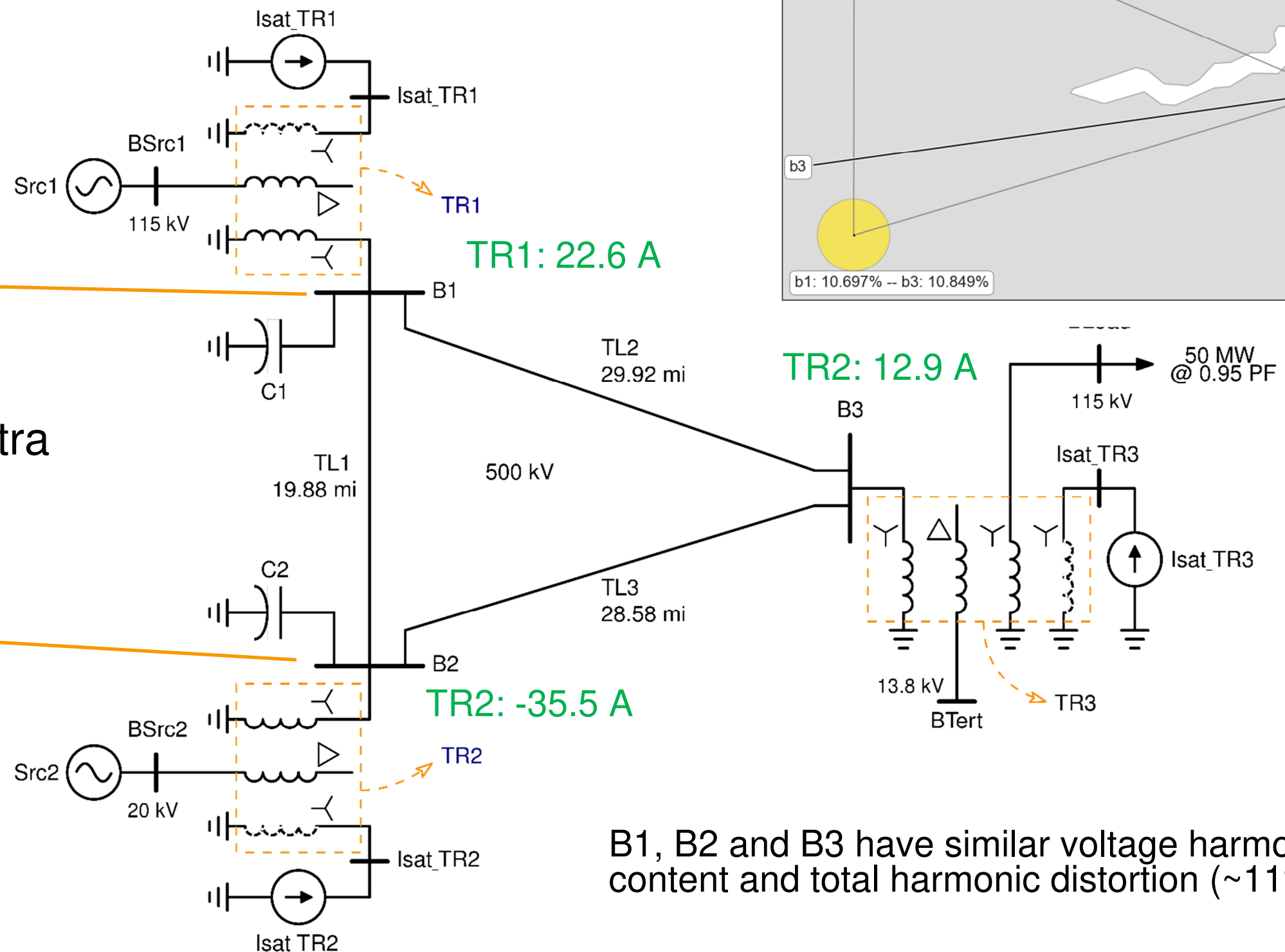
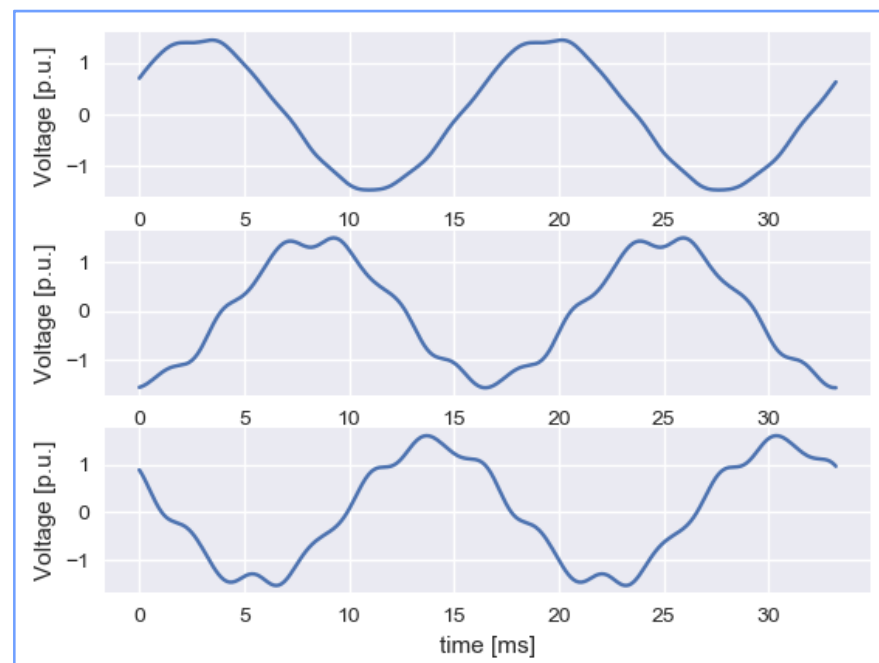
Transformer excitation currents



# Test Case for GIC harmonics analysis

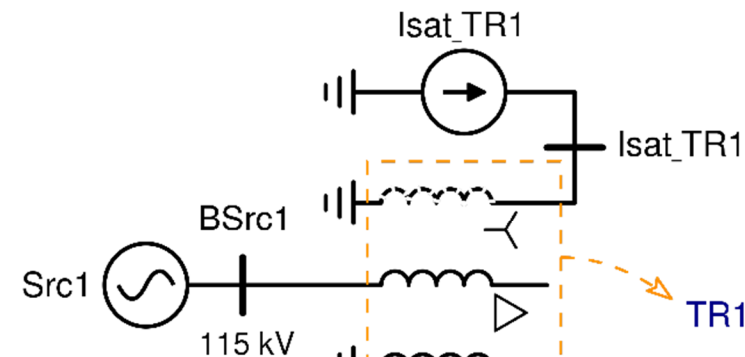
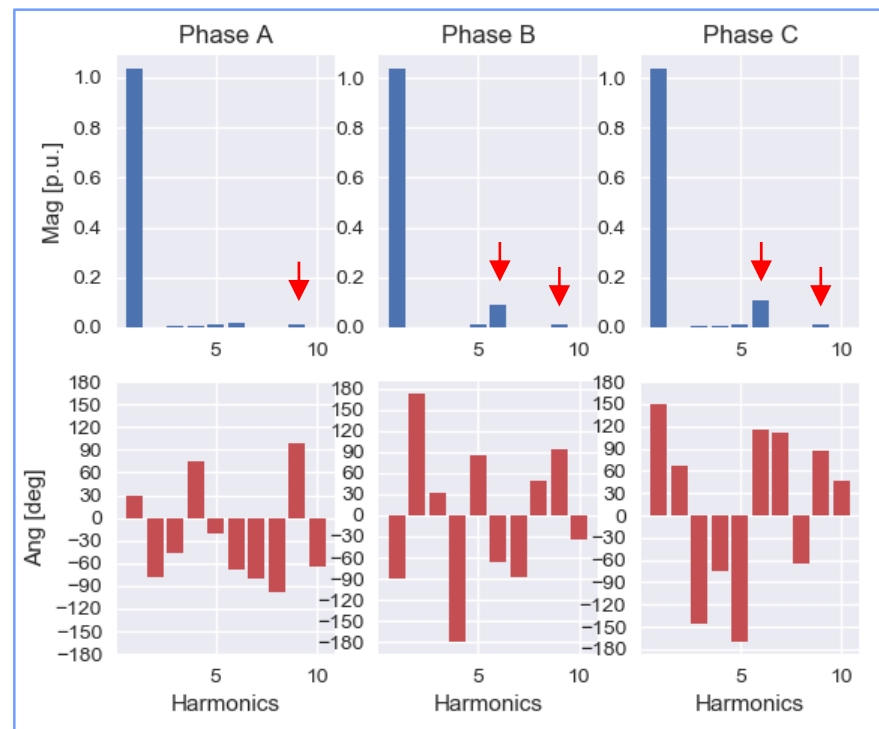


## Bus voltages waveforms and spectra

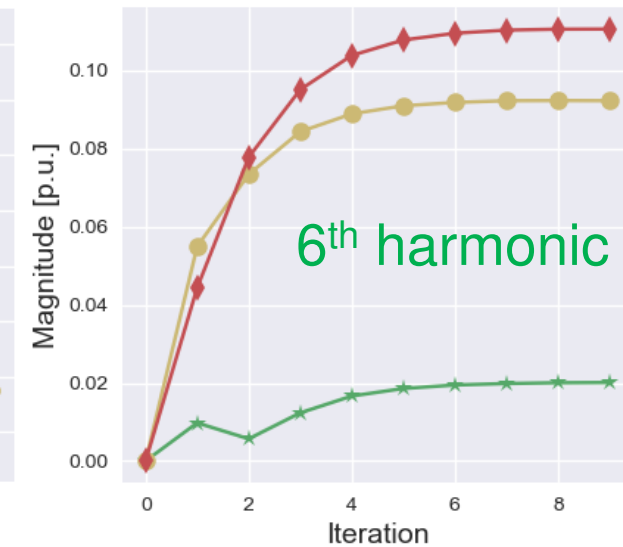
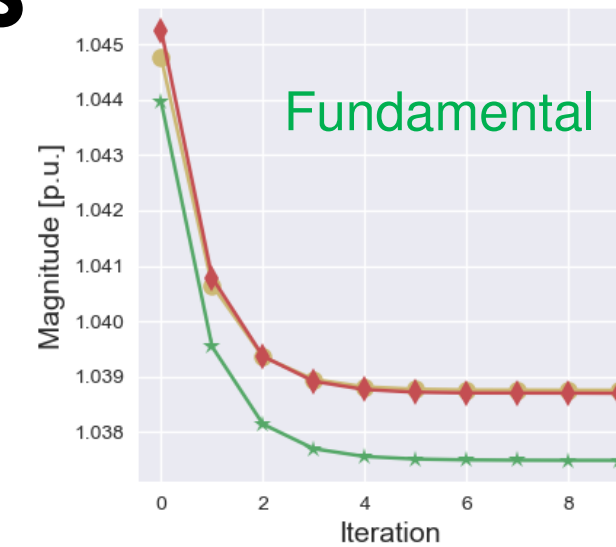




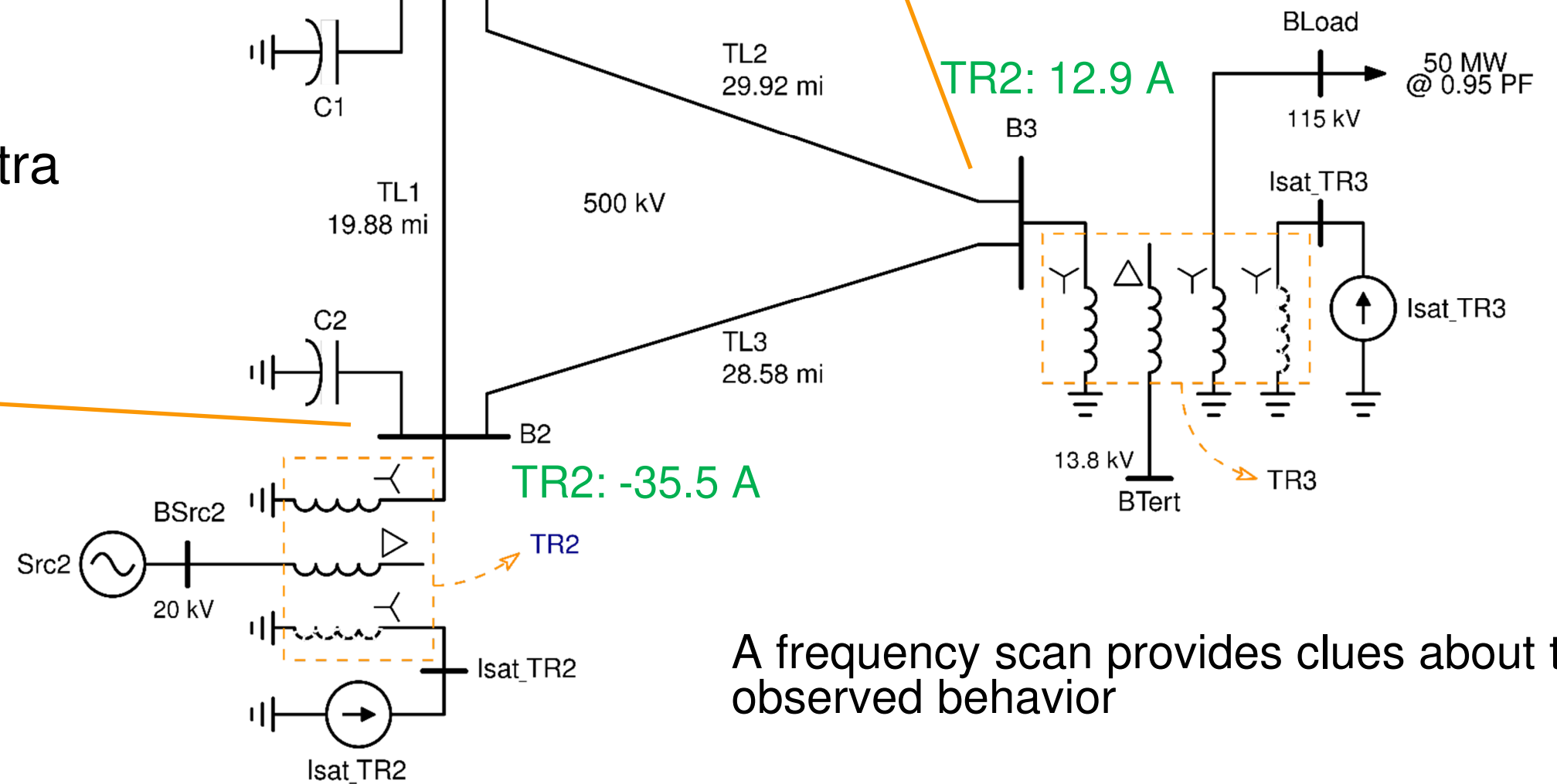
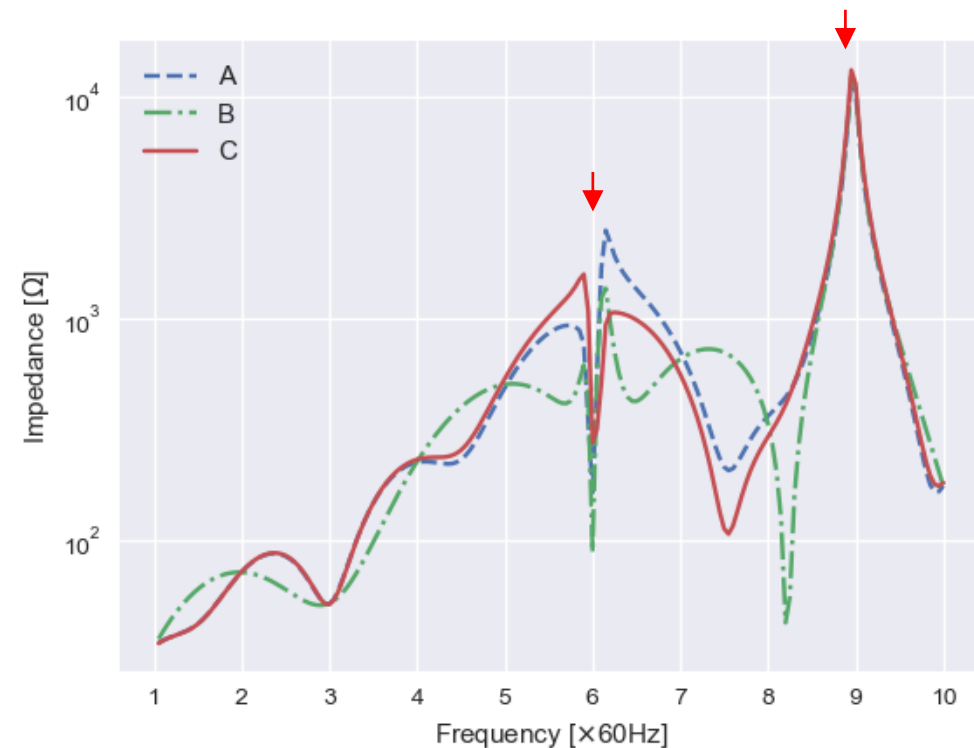
# Test Case for GIC harmonics analysis



TR1: 22.6 A



## Bus voltages waveforms and spectra



TR2: -35.5 A

TR2: 12.9 A

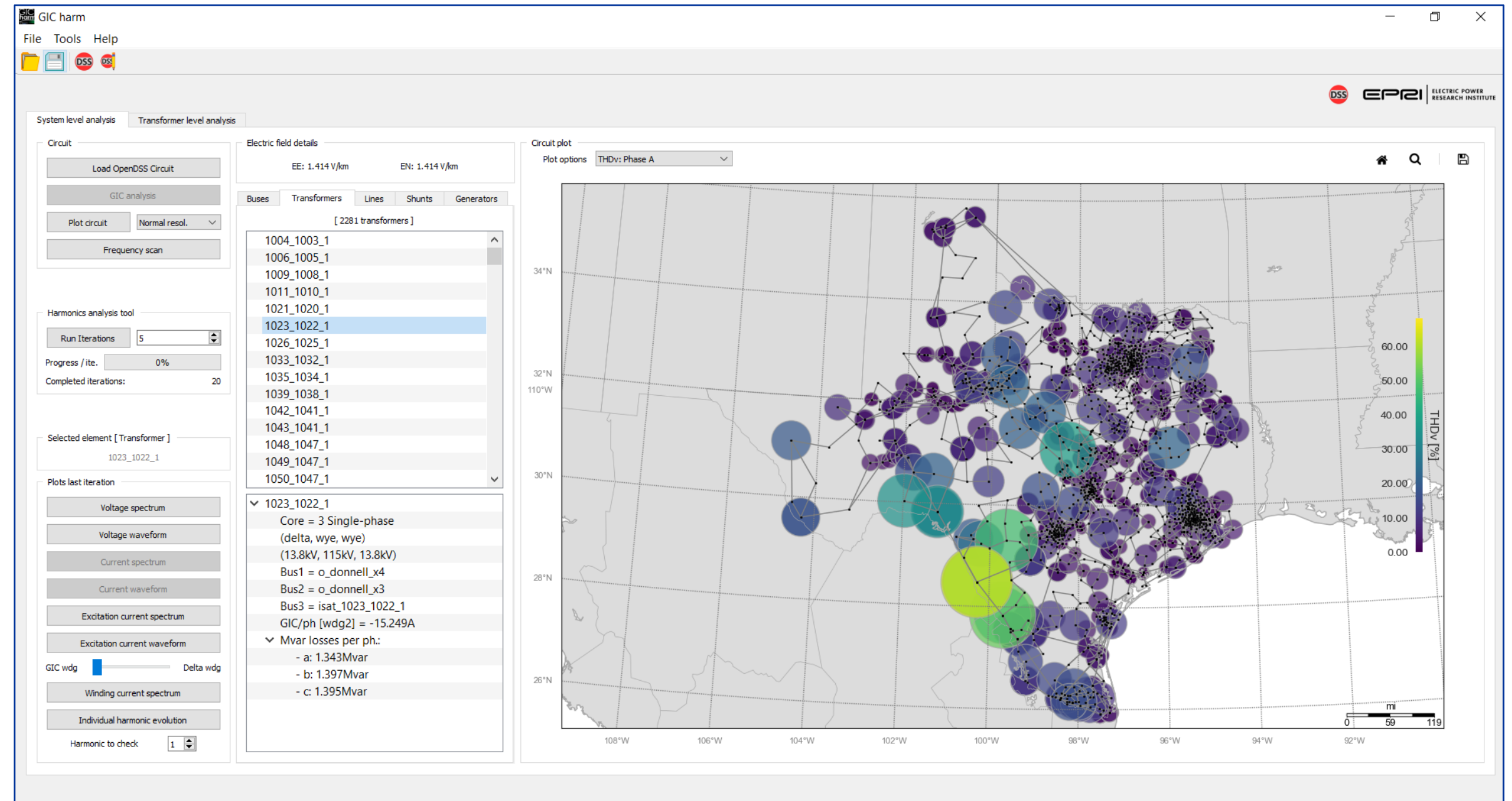
A frequency scan provides clues about the observed behavior

# Other test cases to explore

# Other test cases to explore

ERCOT synthetic case  
from Texas A&M  
University - Electric  
Grid Test Case  
Repository

- 2k buses
- 861 Transformers
- 2,281 Transformers including added load transformers and GSUs



[4] A. B. Birchfield, T. Xu, and T. J. Overbye, "Power flow convergence and reactive power planning in the creation of large synthetic grids," in IEEE Transactions on Power Systems, 2018.

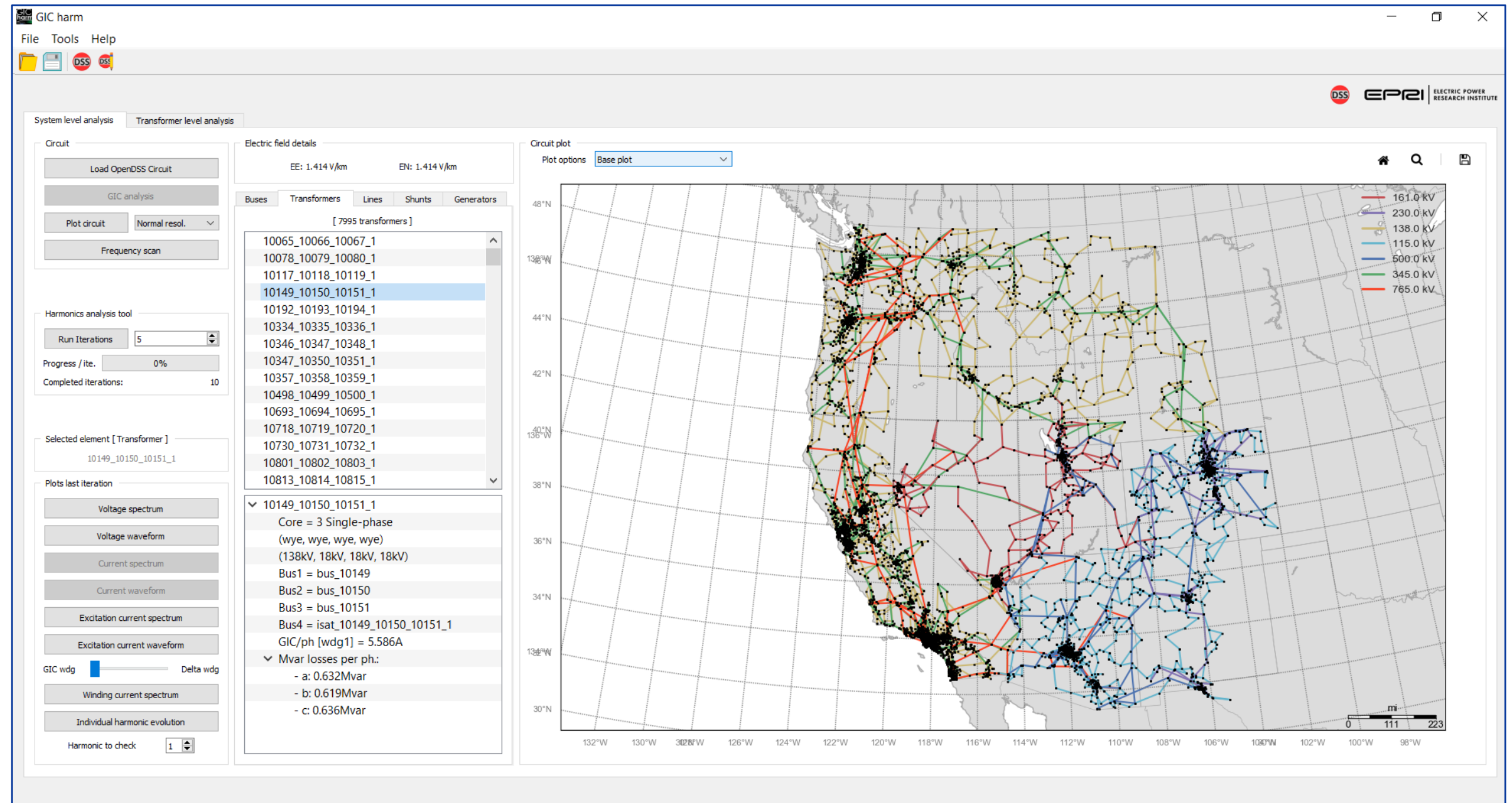
# Other test cases to explore

Western Interconnect  
synthetic case from  
Texas A&M University  
- Electric Grid Test  
Case Repository

10k buses

2,380 Transformers

7,995 Transformers  
including added load  
transformers and  
GSUs



[4] A. B. Birchfield, T. Xu, and T. J. Overbye, "Power flow convergence and reactive power planning in the creation of large synthetic grids," in IEEE Transactions on Power Systems, 2018.



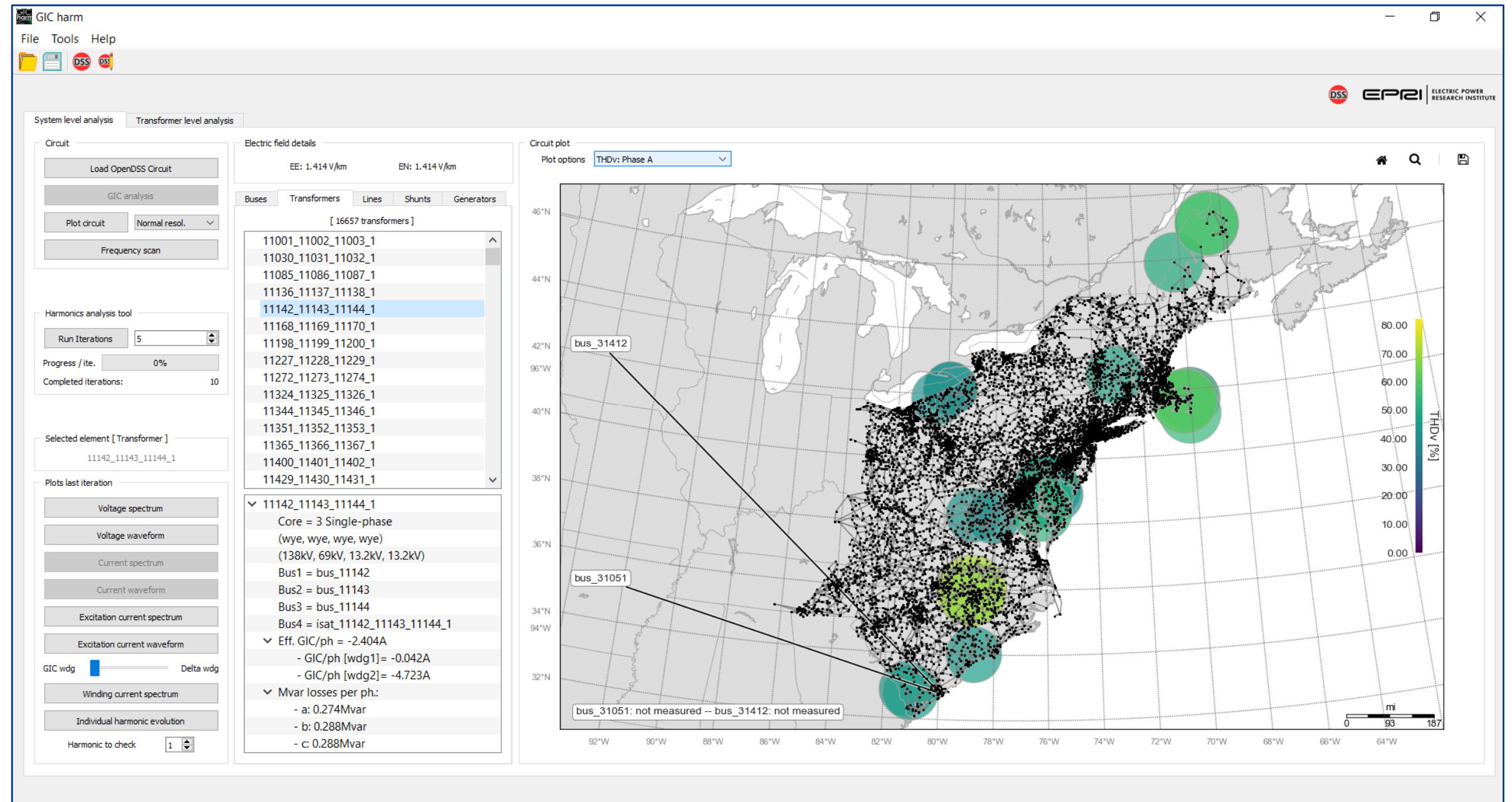
# Other test cases to explore

Eastern Interconnect  
synthetic case from  
Texas A&M University  
- Electric Grid Test  
Case Repository

25k buses

6,030 Transformers

16,657 Transformers  
including added load  
transformers and  
GSUs



[4] A. B. Birchfield, T. Xu, and T. J. Overbye, "Power flow convergence and reactive power planning in the creation of large synthetic grids," in IEEE Transactions on Power Systems, 2018.



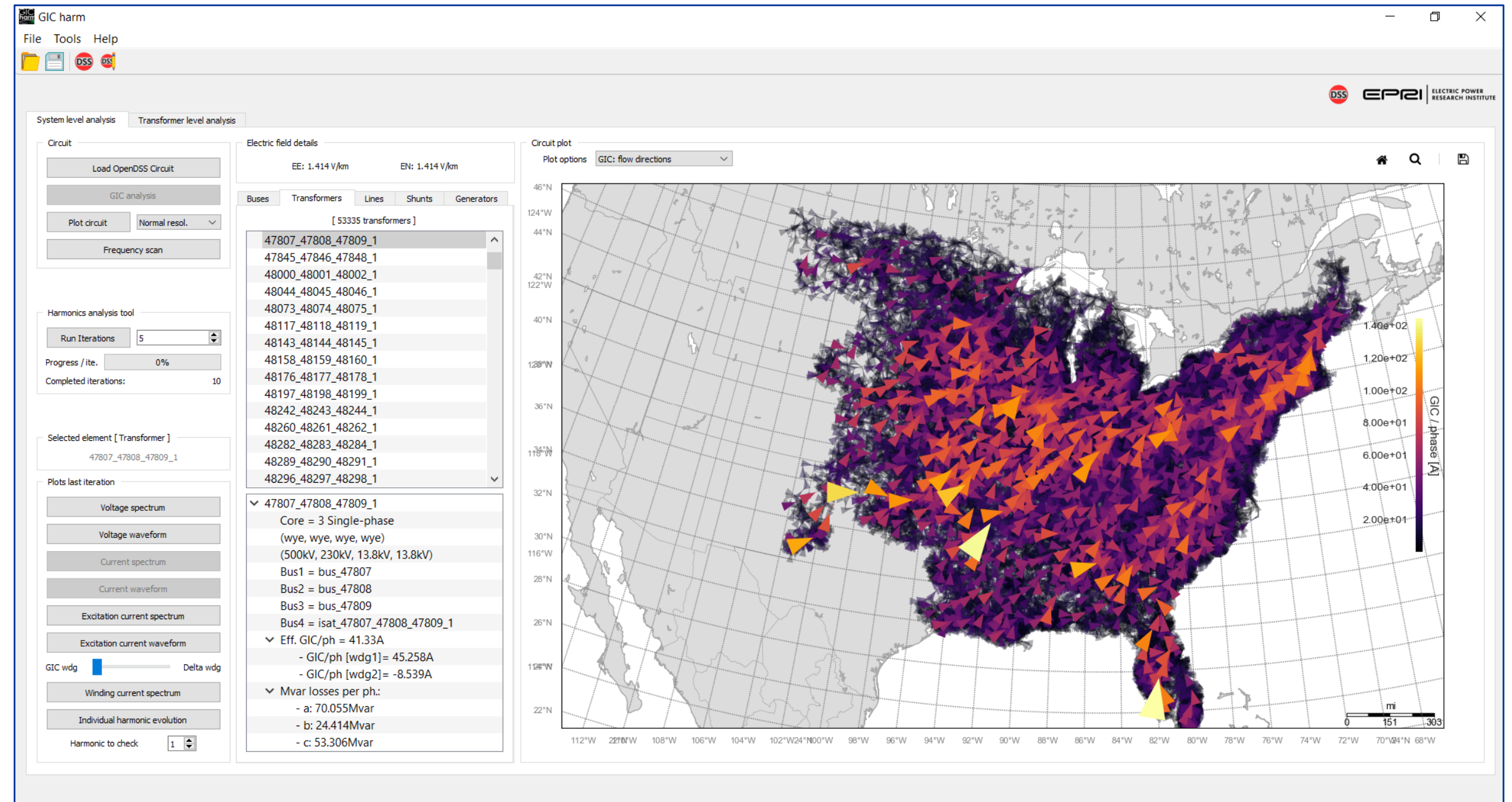
# Other test cases to explore

East and Mid West  
United States  
synthetic case from  
Texas A&M University  
- Electric Grid Test  
Case Repository

70k buses

12,655 Transformers

53,335 Transformers  
including added load  
transformers and  
GSUs



[4] A. B. Birchfield, T. Xu, and T. J. Overbye, "Power flow convergence and reactive power planning in the creation of large synthetic grids," in IEEE Transactions on Power Systems, 2018.

# Thank you! Questions?

# Together...Shaping the Future of Electricity