Documentation for SymPyCAP

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2 License

3 Acknowledgment

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4 About SymPyCAP

SymPyCAP is program for solving linear, time-invariant electric circuits. This program is Python-based (It's written entirely in Python) and uses SymPy, a Python library for symbolic mathematics. SymPyCAP uses MNA (Modified Nodal Analysis) to formulate and solve equations.

5 Why SymPy?

- SymPy is completely free, open source and licensed under the BSD license. So, you can modify the source code end sell it if you want to.
- SymPy uses Python as its language. This means that if you know Python, it is much easier to get started with SymPy (because you already knows the syntax). And if you don't know Python, it is really easy to learn.
- Third advantage of SymPy is that it is lightweight program. It has no dependencies other than Python, so it can be used almost anywhere easily.
- And finally, it can be used as a library. You can just import it in your own Python application.

Anaconda

- For monitoring this work we recommend Anaconda, free open-source Python distribution. Within it, the environment we recommend is *Jupyter Notebook*.

6 Algorithm

Nodes:

- Reference node - one node, labeled by zero, 0 (default node). The node voltage of this node (reference node) is set to zero, 0.
- Other nodes - labeled by consecutive integers, starting from one, 1.

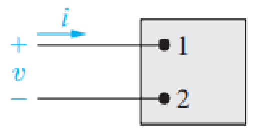
The Kirchhoff's current law equations (KCL)

- SymPyCAP formulates the KCL equations for all nodes, except reference node (for *other nodes*).

Passive sign convention

- Whenever the reference direction for the current in an element is in the direction of the reference voltage drop across the element (as in this picture), use a positive sign in any expression that relates the voltage to the current. Otherwise, use a negative sign.

- We apply this sign convention.



An ideal basic circuit element.

Modified Nodal Analysis

- ***MNA variables:*** node voltages and currents which cannot be expressed in terms of node voltages.
- Node voltages are labeled by V_1, V_2, V_3...
- V_0 = 0, by default
- Currents are labeled by I“id” (“id” specifies a circuit element).

Reserved symbols

- *I* - MNA current variables (I[id])
- *V* - MNA voltage variables (V_0, V_1, V_2...)
- *r* - dictionary of replacements in the form:
  {..., “id” : symbolic_value, ...}
- *replacement* - another name for r
- *w* - symbol/symbolic expression of frequency for time-invariant analysis
- *omega* - another name for w

7 Electric Circuit

Input to SymPyCAP (the circuit to be analyzed) is specified as a list of circuit elements (list of lists):

```
[list_1, list_2, list_3, ... list_N]
```

A circuit element (list$_i$) is specified as a list:

- for one-port element:
  ```
  [type, id, a, b]
  ```
  ```
  [type, id, a, b, IC]
  ```
- for two-port element:
  ```
  [type, id, [a1,a2], [b1,b2], p]
  ```
  ```
  [type, id, [a1,a2], b]
  ```
  (b = b1 when b2 is ground node)

type - string that specifies type of element (“R”, “L”, “C”, “Z”, “Y”, “I”, “V”, “OpAmp”, “IdealT”, “InductiveT”, “VCVS”, “VCCS”, “CCCS”, “CCVS”, “T”)

id - string that identifies circuit element (“R1”, “L1”, “C1”, “Ug”, “OpAmp1”, “I1”, “VCVS1”, etc.)

a - integer, positive terminal

b - integer, negative terminal

IC - initial conditions at $t_{[0]}$- (V0 for capacitors, I0 for inductors, [I_01,I_02] for linear inductive transformers)

a1 - integer, positive terminal of the 1st port

a2 - integer, negative terminal of the 1st port

b1 - integer, positive terminal of the 2nd port

b2 - integer, negative terminal of the 2nd port

p - parameter of parameters

One-port elements:

- **Resistor**
  ```
  ["R", "id", plusTerm, minusTerm]
  ```
- **Capacitor**
  ```
  ["C", "id", plusTerm, minusTerm, "U0"]
  ```
  ```
  ["C", "id", plusTerm, minusTerm]
  ```
  U_0 is here 0, by default.

- **Inductor**

  `["L", "id", plusTerm, minusTerm, "I0"]`
  `["L", "id", plusTerm, minusTerm]`

  I_0 is here 0, by default.

- **Impedance**

  `["Z", "id", plusTerm, minusTerm]`

- **Admitance**

  `["Y", "id", plusTerm, minusTerm]`

- **Current source - ideal current generator**

  `["I", "id", plusTerm, minusTerm]`

- **Voltage source - ideal voltage generator**

  `["V", "id", plusTerm, minusTerm]` (V = V [plusTerm] - V [minusTerm])

Two-port elements:

- **Operational Amplifier - Ideal OpAmp**

  `["OpAmp", "id", [nonInvertingTerm, invertingTerm], 2ndTerm]`

- **4-A two-port**

  `["4-A", "id", [plusPrimaryTerm, minusPrimaryTerm],`
  `[plusSecondaryTerm, minusSecondaryTerm], [["A", "B", "C", "D"]]]`

Controlled Sources:

- **VCVS - Voltage Controlled Voltage Source**

  `["VCVS", "id", [plusControllingTerm, minusControllingTerm],`
  `[plusControlledTerm, minusControlledTerm], "voltageGain"]`

- **VCCS - Voltage Controlled Current Source**

  `["VCCS", "id", [plusControllingTerm, minusControllingTerm],`
  `[plusControlledTerm, minusControlledTerm], "transconductance"]`

- **CCCS - Current Controlled Current Source**

  `["CCCS", "id", [plusControllingTerm, minusControllingTerm],`
  `[plusControlledTerm,  minusControlledTerm], "currentGain"]`

- **CCVS - Current Controlled Voltage Source**

  `["CCVS", "id", [plusControllingTerm, minusControllingTerm],`
  `[plusControlledTerm, minusControlledTerm], "transresistance"]`

Transformers:

- **Ideal Transformer**

```
["IdealT", "id", [plusPrimaryTerm, minusPrimaryTerm],
[plusSecondaryTerm, minusSecondaryTerm], turnsRatio]
```

- **Inductive Transformer**

```
["InductiveT", "id", [plusPrimaryTerm, minusPrimaryTerm],
[plusSecondaryTerm, minusSecondaryTerm], [L1, L2, L12]]
```

```
["InductiveT", "id", [plusPrimaryTerm, minusPrimaryTerm],
[plusSecondaryTerm, minusSecondaryTerm, [L1, L2, L12], [I_01,I_02]]
```

Transmission lines

- **Transmission line, Phasor Transform**

```
["T", "id", [plusSendingTerm, minusSendingTerm],
[plusReceivingTerm, minusReceivingTerm], [Zc, theta]]
```

Zc - symbolic expression
theta [radian] - symbolic expression, electrical length (real number)
I[“id”,plusSendingTerm] current **into** plusSendingTerm
I[“id”,plusReceivingTerm] current **out of** plusReceivingTerm

- **Transmission line, Laplace Transform**

```
["T", "id", [plusSendingTerm, minusSendingTerm],
[plusReceivingTerm, minusReceivingTerm], [Zc, tau]]
```

Zc - symbolic expression
tau [second] - symbolic expression, delay
I[“id”,plusSendingTerm] current **into** plusSendingTerm
I[“id”,plusReceivingTerm] current **into** plusReceivingTerm

8 Calling SymPyCAP

8.1 Importing symbols:

```
from symPyCAP import Circuit
from sympy import symbols
S = sympy.Symbol('S')
S1,S2,.. = sympy.symbols('S1,S2')
```

-SymPy’s Symbol() function’s argument is a string containing symbol which can be assigned to a variable.
-SymPy’s symbols() function returns a *sequence of symbols* with names taken from names argument,

which can be a comma or whitespace delimited string, or a sequence of strings.
-*S1,S2* - symbols that will be used for circuit analysis (for example: E, R, L, W..). In this sequence can't be reserved symbols.
-It is very important to define symbols which will be used in the program.

```
from symPyCAP import Circuit
 from sympy import symbols
S = sympy.Symbol('S', real=True, positive=True)
```

-Parameters *real* and *positive* are optional, which introduce assumptions about the properties of symbols used in the symbolic calculation. Without these parameters, S represents a complex number, by default.

- **For time-invariant analysis:**

```
from symPyCAP import Circuit
import sympy
system = Circuit(elements)
system.symPyCAP()
```

-*elements* - arbitrary name for list of circuit elements (it can be any other word..)
-*system* - instance of class Circuit (main class of the program)
- `symPyCAP()` - this method initializes V (to V_i), user defined symbols, creates MNA equations, for every element in circuit, solves linear system of equations by variables, checks validity of every element
-also, it can read replacement list for user symbols, for example:
-> `system.symPyCAP(replacement = ["R1 : R", "R2 : R"])`
-> `system.symPyCAP(r = ["R1 : R", "R2 : R"])`

- **For time varying excitations:**

```
from symPyCAP import Circuit
import sympy
system = Circuit(elements)
system.symPyCAP(w=W)
```

W - angular frequency [rad/s]

It can be replaced with:

-> " " `system.symPyCAP()`
this means that frequency is not specified - by default, it will be marked as "s" in the solution
-> w =W `system.symPyCAP( w = "W")`
-> omega = "W" `system.symPyCAP( omega = "W")`
-in this version, also, method can read replacement list, for example:
`system.symPyCAP( w=W, replacement = {"R1" : R, "R2" : R})` etc.

- **Outputs**

1) circuit specifications

```
from symPyCAP import Circuit
from sympy import symbols
system = Circuit(elements)
system.symPyCAP()
```

`system.electric_circuit_specifications()` - this function returns:

1.1) for time-invariant analysis

Circuit specifications:
Number of nodes: <"positive_integer">
Input elements: <"list of elements">
Replacement rule: { <"element_values"> }
Equations: [. . .]* PITATI!!!!!!
Variables: [V1, . . . Vn, I["id"]. . .]*

1.2) for time varying excitations *Circuit specifications:*
Number of nodes: <"positive_integer">
Input elements: <"list of elements">
Replacement rule: { <"element_values"> }
Equations: [list of equations]
Variables: [V1, . . . Vn, I["id"]. . .]
Frequency: jw

`Equations` are automatically equal to 0.

2) `system.print_solutions()` - returns -solution in form:
variable1: solution(variable1)
variable2: solution(variable2)
. . .

3) `system.print_specific_solutions()` - returns the solution in the same form as 2), but with applied replacement rules ("R1" : R, "C2" : C,. . .)
-Replacement rule physically changes id with symbols, so this function can return the solution in the form $\frac{1}{0}$.

- **Getters**

1) `get_solutions()` - gets dictionary of solutions.

2) `get_specific_solutions()` - gets dictionary of specific solutions (with applied replacement rules).

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