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# **CyDER Master Algorithm**

***Release 1.0.0***

**LBL - Building Technology and Urban Systems Division**

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## INTRODUCTION

This user manual explains how to install and use PyFMI to couple the CYMDISTToFMU with other FMUs such as a GridDyn FMU.



## INSTALLATION AND CONFIGURATION

This chapter describes how to install PyFMI on Windows.

### Running PyFMI with Python 3.4 on Windows 32 bit

*PyFMI* is a python package which can be used to import and run a CYMDIST FMU. In *PyFMI* version 2.3.1, a master algorithm was added to import and link multiple FMUs for co-simulation. At time of writing, there was no *PyFMI* 2.3.1 executable available for Python 3.4 for Windows 32bit (See [PyPyi](#)). The next steps describe requirements and steps to perform to compile *PyFMI* version 2.3.1 from source.

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**Note:** To avoid having to recompile *PyFMI* dependent libraries from source, we recommend to use pre-compiled Windows binaries whenever available.

---

### Requirements

The next table shows the list of Python modules and softwares used to compile version 2.3.1 of PyFMI from source so it can run with Python 3.4 on Windows 32 bit.

Install PyFMI dependencies with

```
pip install -r dev/master/bin/pyfmi-dependencies.txt
```

Below is a table with dependencies which fail to install using pip. For those, we recommend to use the MS Windows installer directly.

Modules	Version	Link
FMI Library	2.0.2 (source)	<a href="http://www.jmodelica.org/FMILibrary">http://www.jmodelica.org/FMILibrary</a>
Scipy	0.16.1	<a href="https://sourceforge.net/projects/scipy/files/scipy/0.16.1">https://sourceforge.net/projects/scipy/files/scipy/0.16.1</a>
lxml	3.4.4	<a href="https://pypi.python.org/pypi/lxml/3.4.4">https://pypi.python.org/pypi/lxml/3.4.4</a>
Assimulo	2.7b1	<a href="https://pypi.python.org/pypi/Assimulo/2.7b1">https://pypi.python.org/pypi/Assimulo/2.7b1</a>
PyFMI	2.3.1 (source)	<a href="https://pypi.python.org/pypi/PyFMI">https://pypi.python.org/pypi/PyFMI</a>

---

**Note:** *PyFMI* needs a C-compiler to compile the source codes. We used the Microsoft Visual Studio 10 Professional.

---

### Compilation

To compile *PyFMI* from source, run

```
python setup.py install --fmi-home=path_to_FMI_Library\
```

where `path_to_FMI_Library\` is the path to the FMI library.



## CO-SIMULATION

This section explains how to link a CYMDIST FMU with another FMU for co-simulation. We used the GridDyn FMU for the simulation coupling and explain the problematic caused by coupling the two tools with the solution implemented in CyDER.

Coupling GridDyn FMU to CYMDIST creates an algebraic loop that requires an iterative solution. Solving this nonlinear system of equations is not likely to be robust, because GridDyn and CYMDIST both contain iterative solvers. Therefore, the residual function of this algebraic loop will have numerical noise which is caused by the embedded iterative solvers. To avoid this problem, LLNL proposes to approximate CYMDIST by a polynomial and then solve the coupled system of equations that is formed by this polynomial and GridDyn. Details about approximating CYMDIST with a polynomial are discussed in the next sections. On occasion, this will require that CYMDIST to be called multiple times with varying input, but the same state variables, in order to compute its polynomial approximation.

Next, we describe how the system model needs to be configured to allow GridDyn to approximate CYMDIST as a polynomial. We consider the case where CYMDIST is coupled to GridDyn. For the discussion, we use  $p$  for parameters (which do not change in time),  $u$  for inputs, which may change in time,  $y$  for outputs and  $t$  for time. We will denote with subscript  $g$  quantities of GridDyn, and with subscript  $c$  quantities of CYMDIST. We will use  $f()$  to denote a function with unassigned variables.

Hence, the GridDyn model is of the form

$$y_g = f_g(p_g, u_g, t),$$

while the CYMDIST model is of the form

$$y_c = f_c(p_c, u_c, t).$$

Note that we make the assumption that both models only take voltage or current as inputs, that is, we assume  $u_g = y_c$  and  $u_c = y_g$ , and the CYMDIST model has no state. These models are connected as shown in **Figure #fig-couplingwloop**.

To implement the computation, these models are encapsulated as FMUs. To approximate CYMDIST as a polynomial, we will need to also propagate parameters  $p_g$  and a connection list that declares the connection between  $y_g$  and  $u_c$  and between  $y_c$  and  $u_g$ . We will call this connection list  $p_l$ . Hence, the CYMDIST FMU needs to be a function of the form

$$y_c = f_c(p_c, u_c, t),$$

while the GridDyn FMU is of the form

$$y_g = f_g(p_g, p_c, p_l, u_g, t).$$

Hence, the GridDyn model needs to take additional parameters the parameters  $p_c$  to parameterize the CYMDIST model, and  $p_l$  to connect the outputs to the inputs. The CYMDIST FMU is an FMU-ME 2.0, because it needs to be evaluated by GridDyn without advancing time when approximating it as a polynomial, which is not allowed for FMI-CS 2.0.

As CYMDIST obtains from GridDyn the input  $u_c$  that corresponds to the solution of the closed loop, the FMUs are connected as in **Figure #fig-couplingwloop**.

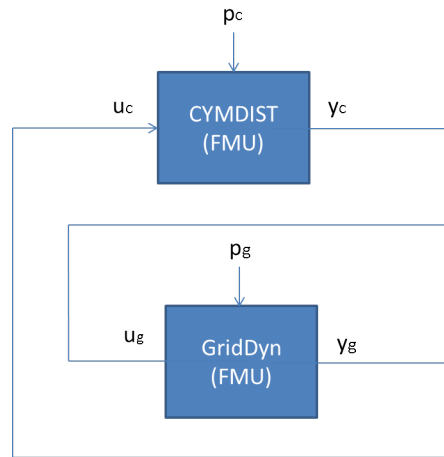


Fig. 3.1: Coupling of CYMDIST with GridDyn with algebraic loop.

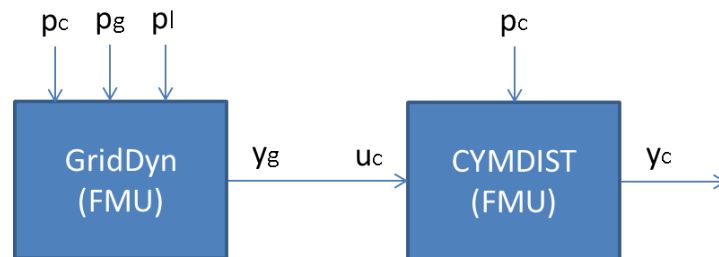


Fig. 3.2: Coupling of CYMDIST with GridDyn without algebraic loop.

The sequence of evaluations will be as follows: During instantiation, both FMUs get their parameters assigned. The GridDyn parameters include the parameters for CYMDIST  $p_c$  and the output-input connection list  $p_l$ . Then, GridDyn will instantiate a CYMDIST FMU, and connect  $u_c$  to  $y_g$ . This CYMDIST FMU, which we call  $f_c^*(, ,)$ , will not be visible to the outside. When GridDyn is invoked, it will approximate  $f_c^*(, ,)$ , compute a converged solution using this approximation, and compute the output  $y_g$ . The master algorithm will then assign  $u_g := y_c$  and evaluate the FMU  $f_g(p_g, p_c, p_l, u_g, t)$ , which completes the time step.

Next, we showed a snippet of the master algorithm which is used to couple a CYMDIST FMU (CYMDIST.FMU) with a GridDyn FMU (GridDyn.fmu).

Line imports the *PyFMI* modules which is needed for the coupling.

Line 25 loads the CYMDIST FMU

Line 26 loads the GridDyn FMU. We used in this example a GridDyn FMU which models the IEEE 14-Bus System.

Line 28 and 29 set-up the parameters for the simulation.

Line 32 - 37 create the vector of input and output names for both FMUs.

Line 45 - 53 get the value references of the CYMDIST and GridDyn variables

Line 69 and 70 initialize the FMUs.

Line 73 calls event update for the CYMDIST FMU. This is required by CYMDIST which is a model exchange FMU and hence needs to call this function prior to entering the continuous time mode.

Line 74 CYMDIST enters in continuous time mode.

Line 77 In the loop, CYMDIST and GridDyn are evaluated.

First, The outputs of GridDyn are retrieved. these outputs must be the covered solution between CYMDIST and GridDyn at the time when GridDyn is invoked.

Second, The outputs of GridDyn are set as inputs of CYMDIST at the same time instant. CYMDIST computes the outputs at that time instant and send the updated outputs.

Line 88 and 89 complete the simulation and terminate both FMUs.

```

1  from pyfmi import load_fmu
2
3  def simulate_cymdist_griddyn14bus_fmus():
4      """Simulate coupled GridDyn and CYMDIST FMUs.
5
6          """
7      # Simulation parameters
8      start_time = 0.0
9      stop_time  = 300
10     step_size   = 300
11
12     # Path to the CYMDIST configuration file
13     path_config=os.path.abspath("config.json")
14     # Conversion to byte for PyFMI
15     cymdist_con_val_str = bytes(path_config, 'utf-8')
16
17     griddyn_input_valref=[]
18     griddyn_output_valref=[]
19     griddyn_output_values=[]
20
21     cymdist_input_valref=[]
22     cymdist_output_valref=[]
23     cymdist_output_values=[]
24

```

```

25 cymdist = load_fmu("../fmus/CYMDIST/CYMDIST.fmu", log_level=7)
26 griddyn=load_fmu("../fmus/griddyn/griddyn14bus.fmu", log_level=7)
27
28 cymdist.setup_experiment(start_time=start_time, stop_time=stop_time)
29 griddyn.setup_experiment(start_time=start_time, stop_time=stop_time)
30
31 # Define the inputs
32 cymdist_input_names = ['VMAG_A', 'VMAG_B', 'VMAG_C', 'VANG_A', 'VANG_B', 'VANG_C']
33 cymdist_output_names = ['IA', 'IB', 'IC', 'IAngleA', 'IAngleB', 'IAngleC']
34
35 griddyn_input_names = ['Bus11_IA', 'Bus11_IB', 'Bus11_IC',
36                        'Bus11_IAngleA', 'Bus11_IAngleB', 'Bus11_IAngleC']
37 griddyn_output_names = ['Bus11_VA', 'Bus11_VB', 'Bus11_VC',
38                        'Bus11_VAngleA', 'Bus11_VAngleB', 'Bus11_VAngleC']
39
40 # Get the value references of griddyn inputs
41 for elem in griddyn_input_names:
42     griddyn_input_valref.append(griddyn.get_variable_valueref(elem))
43
44 # Get the value references of griddyn outputs
45 for elem in griddyn_output_names:
46     griddyn_output_valref.append(griddyn.get_variable_valueref(elem))
47
48 # Get the value references of cymdist inputs
49 for elem in cymdist_input_names:
50     cymdist_input_valref.append(cymdist.get_variable_valueref(elem))
51
52 # Get the value references of cymdist outputs
53 for elem in cymdist_output_names:
54     cymdist_output_valref.append(cymdist.get_variable_valueref(elem))
55
56 # Set the flag to save the results
57 cymdist.set("_saveToFile", 0)
58 # Get the initial outputs from griddyn
59 # Get value reference of the configuration file
60 cymdist_con_val_ref = cymdist.get_variable_valueref("_configurationFileName")
61
62 # Set the configuration file
63 cymdist.set_string([cymdist_con_val_ref], [cymdist_con_val_str])
64
65 # Set the value of the multiplier
66 griddyn.set('multiplier', 3.0)
67
68 # Initialize the FMUs
69 cymdist.initialize()
70 griddyn.initialize()
71
72 # Call event update prior to entering continuous mode.
73 cymdist.event_update()
74 cymdist.enter_continuous_time_mode()
75
76 # Co-simulation loop
77 for tim in np.arange(start_time, stop_time, step_size):
78     cnt+=1
79     # Get the outputs from griddyn
80     griddyn_output_values = (griddyn.get_real(griddyn_output_valref))
81     # set the time in cymdist
82     cymdist.time = tim

```

```
83     # Set the inputs of cymdist
84     cymdist.set_real(cymdist_input_valref, griddyn_output_values)
85     # Get the outputs of cymdist
86     cymdist_output_values = (cymdist.get_real(cymdist_output_valref))
87     # Terminate FMUs
88     cymdist.terminate()
89     griddyn.terminate()
90
91 if __name__ == '__main__':
92     simulate_cymdist_griddyn14bus_fmus()
```



## NOTATION

This chapter shows the formatting conventions used throughout the User Guide.

The command-line is an interactive session for issuing commands to the operating system. Examples include a DOS prompt on Windows, a command shell on Linux, and a Terminal window on MacOS.

The User Guide represents a command window like this:

```
# This is a comment.  
> (This is the command prompt, where you enter a command)  
(If shown, this is sample output in response to the command)
```

Note that your system may use a different symbol than “>” as the command prompt (for example, “\$”). Furthermore, the prompt may include information such as the name of your system, or the name of the current subdirectory.





## GLOSSARY

**Dymola** Dymola, Dynamic Modeling Laboratory, is a modeling and simulation environment for the Modelica language.

**Functional Mock-up Interface** The Functional Mock-up Interface (FMI) is the result of the Information Technology for European Advancement (ITEA2) project *MODELISAR*. The FMI standard is a tool independent standard to support both model exchange and co-simulation of dynamic models using a combination of XML-files, C-header files, C-code or binaries.

**Functional Mock-up Unit** A simulation model or program which implements the FMI standard is called Functional Mock-up Unit (FMU). An FMU comes along with a small set of C-functions (FMI functions) whose input and return arguments are defined by the FMI standard. These C-functions can be provided in source and/or binary form. The FMI functions are called by a simulator to create one or more instances of the FMU. The functions are also used to run the FMUs, typically together with other models. An FMU may either require the importing tool to perform numerical integration (model-exchange) or be self-integrating (co-simulation). An FMU is distributed in the form of a zip-file that contains shared libraries, which contain the implementation of the FMI functions and/or source code of the FMI functions, an XML-file, also called the model description file, which contains the variable definitions as well as meta-information of the model, additional files such as tables, images or documentation that might be relevant for the model.

**Modelica** Modelica is a non-proprietary, object-oriented, equation-based language to conveniently model complex physical systems containing, e.g., mechanical, electrical, electronic, hydraulic, thermal, control, electric power or process-oriented subcomponents.

**MODELISAR** MODELISAR is an ITEA 2 (Information Technology for European Advancement) European project aiming to improve the design of systems and of embedded software in vehicles.

**PyFMI** PyFMI is a package for loading and interacting with Functional Mock-Up Units (FMUs), which are compiled dynamic models compliant with the Functional Mock-Up Interface (FMI).

**Python** Python is a dynamic programming language that is used in a wide variety of application domains.



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