Oxtimal:
Optimal Control of Networked Microgrids

Joseph Young
David Wilson
Marvin Cook

www.optimojoe.com

Version: 1.0.0
Release Date: September 19, 2018

Contents

Chapter 1

Introduction

Oxtimal [oks-*tuh*-m*uh*l] is an open source research code designed for the optimal control of networked microgrids. It features

- **Flexible construction of microgrids**

    - Supports a combination of DC and AC components
    - Quickly combine new grids through a well-defined API

- **Open source**

    - Released under the MPL 2.0 license
    - Free and ready to use with both open and closed sourced codes

- **Robust computations and repeatability**

    - Built-in archiving of solutions
    - Archives assist in debugging the design of grid components

1.1   Licensing

Oxtimal is copyrighted by OptimoJoe and licensed under the MPL 2.0 License:

```
Copyright 2018 OptimoJoe.

Copyright 2018 National Technology & Engineering Solutions of Sandia, LLC
(NTESS). Under the terms of Contract DE-NA0003525 with NTESS, the U.S.
Government retains certain rights in this software.

Mozilla Public License Version 2.0
==================================

1. Definitions
--------------

1.1. "Contributor"
    means each individual or legal entity that creates, contributes to
    the creation of, or owns Covered Software.

1.2. "Contributor Version"
    means the combination of the Contributions of others (if any) used
```

by a Contributor and that particular Contributor's Contribution.

1.3. "Contribution"
    means Covered Software of a particular Contributor.

1.4. "Covered Software"
    means Source Code Form to which the initial Contributor has attached
    the notice in Exhibit A, the Executable Form of such Source Code
    Form, and Modifications of such Source Code Form, in each case
    including portions thereof.

1.5. "Incompatible With Secondary Licenses"
    means

    (a) that the initial Contributor has attached the notice described
        in Exhibit B to the Covered Software; or

    (b) that the Covered Software was made available under the terms of
        version 1.1 or earlier of the License, but not also under the
        terms of a Secondary License.

1.6. "Executable Form"
    means any form of the work other than Source Code Form.

1.7. "Larger Work"
    means a work that combines Covered Software with other material, in
    a separate file or files, that is not Covered Software.

1.8. "License"
    means this document.

1.9. "Licensable"
    means having the right to grant, to the maximum extent possible,
    whether at the time of the initial grant or subsequently, any and
    all of the rights conveyed by this License.

1.10. "Modifications"
    means any of the following:

    (a) any file in Source Code Form that results from an addition to,
        deletion from, or modification of the contents of Covered
        Software; or

    (b) any new file in Source Code Form that contains any Covered
        Software.

1.11. "Patent Claims" of a Contributor
    means any patent claim(s), including without limitation, method,
    process, and apparatus claims, in any patent Licensable by such
    Contributor that would be infringed, but for the grant of the
    License, by the making, using, selling, offering for sale, having
    made, import, or transfer of either its Contributions or its
    Contributor Version.

1.12. "Secondary License"
    means either the GNU General Public License, Version 2.0, the GNU
    Lesser General Public License, Version 2.1, the GNU Affero General
    Public License, Version 3.0, or any later versions of those
    licenses.

1.13. "Source Code Form"
    means the form of the work preferred for making modifications.

1.14. "You" (or "Your")
    means an individual or a legal entity exercising rights under this
    License. For legal entities, "You" includes any entity that
    controls, is controlled by, or is under common control with You. For
    purposes of this definition, "control" means (a) the power, direct
    or indirect, to cause the direction or management of such entity,
    whether by contract or otherwise, or (b) ownership of more than
    fifty percent (50%) of the outstanding shares or beneficial
    ownership of such entity.

2. License Grants and Conditions

2.1. Grants

Each Contributor hereby grants You a world-wide, royalty-free,
non-exclusive license:

(a) under intellectual property rights (other than patent or trademark)
    Licensable by such Contributor to use, reproduce, make available,
    modify, display, perform, distribute, and otherwise exploit its
    Contributions, either on an unmodified basis, with Modifications, or
    as part of a Larger Work; and

(b) under Patent Claims of such Contributor to make, use, sell, offer
    for sale, have made, import, and otherwise transfer either its
    Contributions or its Contributor Version.

2.2. Effective Date

The licenses granted in Section 2.1 with respect to any Contribution
become effective for each Contribution on the date the Contributor first
distributes such Contribution.

2.3. Limitations on Grant Scope

The licenses granted in this Section 2 are the only rights granted under
this License. No additional rights or licenses will be implied from the
distribution or licensing of Covered Software under this License.
Notwithstanding Section 2.1(b) above, no patent license is granted by a
Contributor:

(a) for any code that a Contributor has removed from Covered Software;
    or

(b) for infringements caused by: (i) Your and any other third party's
    modifications of Covered Software, or (ii) the combination of its
    Contributions with other software (except as part of its Contributor
    Version); or

(c) under Patent Claims infringed by Covered Software in the absence of
    its Contributions.

This License does not grant any rights in the trademarks, service marks,
or logos of any Contributor (except as may be necessary to comply with
the notice requirements in Section 3.4).

2.4. Subsequent Licenses

No Contributor makes additional grants as a result of Your choice to
distribute the Covered Software under a subsequent version of this
License (see Section 10.2) or under the terms of a Secondary License (if
permitted under the terms of Section 3.3).

2.5. Representation

Each Contributor represents that the Contributor believes its
Contributions are its original creation(s) or it has sufficient rights
to grant the rights to its Contributions conveyed by this License.

2.6. Fair Use

This License is not intended to limit any rights You have under
applicable copyright doctrines of fair use, fair dealing, or other
equivalents.

2.7. Conditions

Sections 3.1, 3.2, 3.3, and 3.4 are conditions of the licenses granted
in Section 2.1.

3. Responsibilities

3.1. Distribution of Source Form

All distribution of Covered Software in Source Code Form, including any
Modifications that You create or to which You contribute, must be under
the terms of this License. You must inform recipients that the Source
Code Form of the Covered Software is governed by the terms of this
License, and how they can obtain a copy of this License. You may not
attempt to alter or restrict the recipients' rights in the Source Code
Form.

3.2. Distribution of Executable Form

If You distribute Covered Software in Executable Form then:

(a) such Covered Software must also be made available in Source Code

Form, as described in Section 3.1, and You must inform recipients of
the Executable Form how they can obtain a copy of such Source Code
Form by reasonable means in a timely manner, at a charge no more
than the cost of distribution to the recipient; and

(b) You may distribute such Executable Form under the terms of this
    License, or sublicense it under different terms, provided that the
    license for the Executable Form does not attempt to limit or alter
    the recipients' rights in the Source Code Form under this License.

3.3. Distribution of a Larger Work

You may create and distribute a Larger Work under terms of Your choice,
provided that You also comply with the requirements of this License for
the Covered Software. If the Larger Work is a combination of Covered
Software with a work governed by one or more Secondary Licenses, and the
Covered Software is not Incompatible With Secondary Licenses, this
License permits You to additionally distribute such Covered Software
under the terms of such Secondary License(s), so that the recipient of
the Larger Work may, at their option, further distribute the Covered
Software under the terms of either this License or such Secondary
License(s).

3.4. Notices

You may not remove or alter the substance of any license notices
(including copyright notices, patent notices, disclaimers of warranty,
or limitations of liability) contained within the Source Code Form of
the Covered Software, except that You may alter any license notices to
the extent required to remedy known factual inaccuracies.

3.5. Application of Additional Terms

You may choose to offer, and to charge a fee for, warranty, support,
indemnity or liability obligations to one or more recipients of Covered
Software. However, You may do so only on Your own behalf, and not on
behalf of any Contributor. You must make it absolutely clear that any
such warranty, support, indemnity, or liability obligation is offered by
You alone, and You hereby agree to indemnify every Contributor for any
liability incurred by such Contributor as a result of warranty, support,
indemnity or liability terms You offer. You may include additional
disclaimers of warranty and limitations of liability specific to any
jurisdiction.

4. Inability to Comply Due to Statute or Regulation

If it is impossible for You to comply with any of the terms of this
License with respect to some or all of the Covered Software due to
statute, judicial order, or regulation then You must: (a) comply with
the terms of this License to the maximum extent possible; and (b)
describe the limitations and the code they affect. Such description must
be placed in a text file included with all distributions of the Covered
Software under this License. Except to the extent prohibited by statute

or regulation, such description must be sufficiently detailed for a
recipient of ordinary skill to be able to understand it.

5. Termination

5.1. The rights granted under this License will terminate automatically
if You fail to comply with any of its terms. However, if You become
compliant, then the rights granted under this License from a particular
Contributor are reinstated (a) provisionally, unless and until such
Contributor explicitly and finally terminates Your grants, and (b) on an
ongoing basis, if such Contributor fails to notify You of the
non-compliance by some reasonable means prior to 60 days after You have
come back into compliance. Moreover, Your grants from a particular
Contributor are reinstated on an ongoing basis if such Contributor
notifies You of the non-compliance by some reasonable means, this is the
first time You have received notice of non-compliance with this License
from such Contributor, and You become compliant prior to 30 days after
Your receipt of the notice.

5.2. If You initiate litigation against any entity by asserting a patent
infringement claim (excluding declaratory judgment actions,
counter-claims, and cross-claims) alleging that a Contributor Version
directly or indirectly infringes any patent, then the rights granted to
You by any and all Contributors for the Covered Software under Section
2.1 of this License shall terminate.

5.3. In the event of termination under Sections 5.1 or 5.2 above, all
end user license agreements (excluding distributors and resellers) which
have been validly granted by You or Your distributors under this License
prior to termination shall survive termination.

```
************************************************************************
*                                                                      *
*  6. Disclaimer of Warranty                                           *
*  -------------------------                                           *
*                                                                      *
*  Covered Software is provided under this License on an "as is"       *
*  basis, without warranty of any kind, either expressed, implied, or  *
*  statutory, including, without limitation, warranties that the       *
*  Covered Software is free of defects, merchantable, fit for a        *
*  particular purpose or non-infringing. The entire risk as to the     *
*  quality and performance of the Covered Software is with You.        *
*  Should any Covered Software prove defective in any respect, You     *
*  (not any Contributor) assume the cost of any necessary servicing,   *
*  repair, or correction. This disclaimer of warranty constitutes an   *
*  essential part of this License. No use of any Covered Software is    *
*  authorized under this License except under this disclaimer.         *
*                                                                      *
************************************************************************

************************************************************************
*                                                                      *
*  7. Limitation of Liability                                          *
```

```
*  -------------------------                                        *
*                                                                   *
*  Under no circumstances and under no legal theory, whether tort   *
*  (including negligence), contract, or otherwise, shall any        *
*  Contributor, or anyone who distributes Covered Software as       *
*  permitted above, be liable to You for any direct, indirect,      *
*  special, incidental, or consequential damages of any character   *
*  including, without limitation, damages for lost profits, loss of *
*  goodwill, work stoppage, computer failure or malfunction, or any *
*  and all other commercial damages or losses, even if such party   *
*  shall have been informed of the possibility of such damages. This*
*  limitation of liability shall not apply to liability for death or *
*  personal injury resulting from such party's negligence to the    *
*  extent applicable law prohibits such limitation. Some            *
*  jurisdictions do not allow the exclusion or limitation of        *
*  incidental or consequential damages, so this exclusion and       *
*  limitation may not apply to You.                                 *
*                                                                   *
*********************************************************************
```

8. Litigation

Any litigation relating to this License may be brought only in the
courts of a jurisdiction where the defendant maintains its principal
place of business and such litigation shall be governed by laws of that
jurisdiction, without reference to its conflict-of-law provisions.
Nothing in this Section shall prevent a party's ability to bring
cross-claims or counter-claims.

9. Miscellaneous

This License represents the complete agreement concerning the subject
matter hereof. If any provision of this License is held to be
unenforceable, such provision shall be reformed only to the extent
necessary to make it enforceable. Any law or regulation which provides
that the language of a contract shall be construed against the drafter
shall not be used to construe this License against a Contributor.

10. Versions of the License

10.1. New Versions

Mozilla Foundation is the license steward. Except as provided in Section
10.3, no one other than the license steward has the right to modify or
publish new versions of this License. Each version will be given a
distinguishing version number.

10.2. Effect of New Versions

You may distribute the Covered Software under the terms of the version
of the License under which You originally received the Covered Software,

or under the terms of any subsequent version published by the license
steward.

10.3. Modified Versions

If you create software not governed by this License, and you want to
create a new license for such software, you may create and use a
modified version of this License if you rename the license and remove
any references to the name of the license steward (except to note that
such modified license differs from this License).

10.4. Distributing Source Code Form that is Incompatible With Secondary
Licenses

If You choose to distribute Source Code Form that is Incompatible With
Secondary Licenses under the terms of this version of the License, the
notice described in Exhibit B of this License must be attached.

Exhibit A - Source Code Form License Notice

  This Source Code Form is subject to the terms of the Mozilla Public
  License, v. 2.0. If a copy of the MPL was not distributed with this
  file, You can obtain one at http://mozilla.org/MPL/2.0/.

If it is not possible or desirable to put the notice in a particular
file, then You may include the notice in a location (such as a LICENSE
file in a relevant directory) where a recipient would be likely to look
for such a notice.

You may add additional accurate notices of copyright ownership.

Exhibit B - "Incompatible With Secondary Licenses" Notice

  This Source Code Form is "Incompatible With Secondary Licenses", as
  defined by the Mozilla Public License, v. 2.0.

In short, Oxtimal is free to use in both open and closed sourced codes, but modifications to Oxtimal itself must be shared. If you use it, we ask that you provide a citation or link to http://www.optimojoe.com.

1.2 Support

News, updates, and download information for Oxtimal can be found at

$$\text{http://www.optimojoe.com}$$

Our user forum can be found at

$$\text{http://forum.optimojoe.com}$$

Finally, if you are interested in paid support and consulting, please contact us at contact@optimojoe.com.

1.3 Referencing

We have published several papers that describe the algorithms behind Oximal. In order to cite Oximal, please reference one of the following:

- D. G. Wilson, W. W. Weaver, R. D. Robinett Iii, J. Young, S. F. Glover, M. A. Cook, S. Markle, T. J. McCoy. **Nonlinear Power Flow Control Design Methodology for Navy Electric Ship Microgrid Energy Storage Requirements**. INEC/iSCSS 2018: *To appear*. 2018.

- Joseph Young, Marvin A. Cook, David G. Wilson. **A Predictive Engine for On-Line Optimal Microgrid Control**. 2017 IEEE Electric Ship Technologies Symposium (ESTS): 564 - 571. 2017.

- D. G. Wilson, R. D. Robinett, W. W. Weaver, R. H. Byrne and J. Young. **Nonlinear Power Flow Control Design of High Penetration Renewable Sources for AC Inverter Based Microgrids**. 2016 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM): 701 - 708, 2016.

- David G. Wilson, Jason C. Neely, Marvin A. Cook, Steven F. Glover, Joseph Young, and Rush D. Robinett. **Hamiltonian control design for DC microgrids with stochastic sources and loads with applications**. 2014 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM): 1264 - 1271, 2014.

Chapter 2

Installation

Oxtimal can be downloaded from

as a zipped archive. We also give direct access to our code repository at

https://github.com/optimojoe/oxtimal

In order to install Oxtimal

1. Unzip the archive

2. Add the directory `code` to the MATLAB/Octave path

2.1 Dependencies

Oxtimal uses the following software packages

Package	Version	License
Oxtimal	1.2	MPL-2.0
Optizelle	1.2	BSD-2-Clause
MATLAB	R2018	Custom
Octave	4.4	GPL-3.0

Chapter 3

Usage

Oximal can be run in two different modes: direct or by scenario. We address each of these cases in their own section.

3.1 Direct

In direct mode, Oximal is run with the command

```
solution = runDirect(params);
```

Here we have

Name   `params`

Type   Structure array

Description   Parameters that describe the optimization and microgrid setup. It requires two variables `Optizelle` and `microgrid`. The variable `Optizelle` may be empty or contain optimization parameters that are sent directly to Optizelle. For a description of these parameters, please see the Optizelle manual. The variable `microgrid` contains the microgrid parameters, which are discussed in Chapter 4.

Name   `solution`

Type   Structure array

Description   Optimal control found by Optizelle. A complete description of these parameters is discussed in Chapter 4.

3.2 Scenario

In scenario mode, Oximal is run with the command

```
solution = runScenario(scenario,variant)
```

Here we have

Name   `scenario`

Type   String

Description Name of a scenario found in the `data` directory. In order to create a new scenario, create a folder in this directory named `myscenario`, which contains a single file named `microgrid.json`. This is a json formatted file that contains two sections: `Oxtimal` and `microgrid`. The section `Optizelle` may be empty or contain optimization parameters that are sent directly to Optizelle. For a description of these parameters, please see the Optizelle manual. The section `microgrid` contains the microgrid parameters, which are discussed in Chapter 4.

Name `variant`

Type String

Description Optional argument that refers to a section in the `microgrid.json` file. The parameters in this section overwrite the parameters in the `microgrid` section. In addition, the solution for this scenario will be written to the `solution.json` file in the `results/scenario` directory under the specified variant. This is useful for archiving runs for later study. If this archiving feature is desired without overwriting any parameters, simply make an empty section in the `microgrid.json` file.

Name `solution`

Type Structure array

Description Optimal control found by Optizelle. A complete description of these parameters is discussed in Chapter 4.

In addition, the last control produced is written to the file `results/scenario/last_solution.json` file. The last output created by Optizelle is written to the file `results/scenario/last_output.txt`.

Chapter 4

Parameters

In the following chapter, we discuss the parameters required to construct a microgrid. We use these parameters when running the optimal controller as described in Chapter 3.

4.1 Models

Within Oximal, we construct a microgrid from the components A-F found in Figures 4.1, 4.2, 4.3, 4.4, 4.5, and 4.6. More simply, component A represents a boost converter, B a DC bus, C a connector between DC buses, E a connector between a DC bus and an AC bus, F an AC bus, and G a three-phase inverter. In our notation, the numbers indicate how each of these components connects to each other. For example, we represent a single DC microgrid with two boost converters in Figure 4.7. For a single AC microgrid, we can see the setup in Figure 4.8.
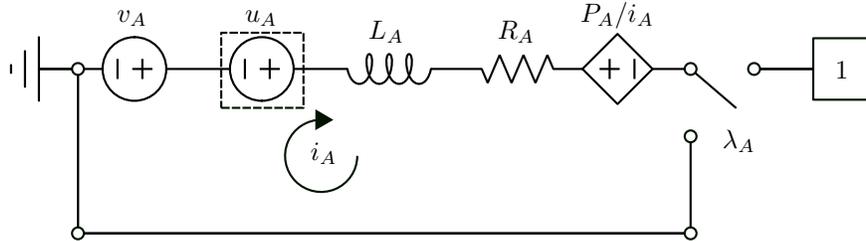

Figure 4.1: (A) Boost Converter

4.2 Optimization Formulation

Based on the grid components from Section 4.1, Oximal finds an optimal control for the grid by solving the optimization problem

Minimize

Objective Function

$$\frac{1}{2}\left(\|w_{A_{duty}}\dot{\lambda_A}\|^2 + \|w_{C_{duty}}\dot{\lambda_C}\|^2 + \|w_{E_{duty}}\dot{\lambda_E}\|^2 + \|w_{G_{duty}}\dot{\lambda_G}\|^2\right) +$$

$$\frac{1}{2}\left(\|w_{A_{control}}u_A u_{A\,switch}\|^2 + \|w_{B_{control}}u_B u_{B\,switch}\|^2 + \|w_{C_{control}}u_C u_{C\,switch}\|^2\right.$$
$$\left. + \|w_{F_{control}}u_{F_d}u_{F\,switch}\|^2 + \|w_{F_{control}}u_{F_q}u_{F\,switch}\|^2 + \|w_{G_{control}}u_G u_{G\,switch}\|^2\right) +$$

$$\frac{1}{2}\left(\langle w_{A_{loss}}R_A i_A, i_A\rangle + \langle w_{C_{loss}}R_C i_C, i_C\rangle + \langle w_{E_{loss}}R_E i_{E_d}, i_{E_d}\rangle + \langle w_{E_{loss}}R_E i_{E_q}, i_{E_q}\rangle + \langle w_{G_{loss}}R_G i_G, i_G\rangle\right) +$$

$$\frac{1}{2}\left(\|w_{A_{power}}p_A u_{switch}\|^2 + \|w_{B_{power}}p_B u_{B\,switch}\|^2 + \|w_{C_{power}}p_C u_{C\,switch}\|^2\right.$$

15

$$+\|w_{F_{power}} p_F u_{F\,switch}\|^2 + \|w_{G_{power}} p_G u_{G\,switch}\|^2)$$

Subject to

Boost Converters
$$L_A \dot{i}_A = -R_A i_A - \frac{P_A}{i_A} + v_A + u_A u_{A_{switch}} - \lambda_A(\Phi_1 v_B)$$

DC buses
$$C_B \dot{v}_B = -\frac{v_B}{R_B} - \frac{P_B}{v_B} + u_B u_{B\,switch} + \Phi_1^T(\lambda_A i_A) - \Phi_2^T i_C + \Phi_3^T(\lambda_C i_C) - \Phi_5^T\left(\Xi\lambda_E(\xi_{E_c} i_{E_d} + \xi_{E_s} i_{E_q})\right)$$

DC to DC Connectors
$$L_C \dot{i}_C = -R_C i_C + u_C u_{C\,switch} + \Phi_2 v_B - \lambda_C(\Phi_3 v_B)$$

AC to DC Connectors
$$L_E \dot{i}_{E_d} = -R_E i_{E_d} + \Xi\lambda_E\xi_{E_c}\Phi_5 v_B + L_E i_{E_q}\Phi_6\omega_F - \Phi_6 v_{F_d}$$
$$L_E \dot{i}_{E_q} = -R_E i_{E_q} + \Xi\lambda_E\xi_{E_s}\Phi_5 v_B - L_E i_{E_d}\Phi_6\omega_F - \Phi_6 v_{F_q}$$

AC buses
$$C_F \dot{v}_{F_d} = -\frac{v_{F_d}}{R_F} - \frac{P_{F_d}}{v_{F_d}} + \omega_F C_F v_{F_q} + u_{F_d} u_{F\,switch} + \Phi_6^T i_{E_d} + \Phi_7^T i_{G_d}$$
$$C_F \dot{v}_{F_q} = -\frac{v_{F_q}}{R_F} - \frac{P_{F_q}}{v_{F_q}} - \omega_F C_F v_{F_d} + u_{F_q} u_{F\,switch} + \Phi_6^T i_{E_q} + \Phi_7^T i_{G_q}$$

Inverters
$$R_{G_{dc}} i_G = v_G + u_G u_{G\,switch} - v_{G_{dc}}$$
$$C_{G_{dc}} \dot{v}_{G_{dc}} = i_G - \Xi\lambda_G(\xi_{G_c} i_{G_d} + \xi_{G_s} i_{G_q})$$
$$L_G \dot{i}_{G_d} = -R_G i_{G_d} + \Xi\lambda_G\xi_{G_c} v_{G_{dc}} + L_G i_{G_q}\Phi_7\omega_F - \Phi_7 v_{F_d}$$
$$L_G \dot{i}_{G_q} = -R_G i_{G_q} + \Xi\lambda_G\xi_{G_s} v_{G_{dc}} - L_G i_{G_d}\Phi_7\omega_F - \Phi_7 v_{F_q}$$

Trigonometric
$$\xi_{E_s}^2 + \xi_{E_c}^2 = e$$
$$\xi_{G_s}^2 + \xi_{G_c}^2 = e$$

Power
$$p_A = u_A i_A$$
$$p_B = v_B u_B$$
$$p_C = u_C i_C$$
$$p_F = v_{F_d} u_{F_d} + v_{F_q} u_{F_q}$$
$$p_G = u_G i_G$$

Discretization
$$i_{A\,k+1} = i_{A\,k} + \Delta t \dot{i}_{A\,k+1}, \qquad\qquad k = 0, \ldots, n_{time} - 1$$
$$e_{A\,k+1} = e_{A\,k} - \Delta t p_{A\,k+1}$$
$$\lambda_{A\,k+1} = \lambda_{A\,k} + \Delta t \dot{\lambda}_{A\,k+1}$$

$$v_{B\,k+1} = v_{B\,k} + \Delta t \dot{v}_{B\,k+1}$$
$$e_{B\,k+1} = e_{B\,k} - \Delta t p_{B\,k+1}$$

$$i_{C\,k+1} = i_{C\,k} + \Delta t \dot{i}_{C\,k+1}$$
$$\lambda_{C\,k+1} = \lambda_{C\,k} + \Delta t \dot{\lambda}_{C\,k+1}$$
$$e_{C\,k+1} = e_{C\,k} - \Delta t p_{C\,k+1}$$

$$i_{E_d\,k+1} = i_{E_d\,k} + \Delta t \dot{i}_{E_d\,k+1}$$
$$i_{E_q\,k+1} = i_{E_q\,k} + \Delta t \dot{i}_{E_q\,k+1}$$

$$\lambda_{E\,k+1} = \lambda_{E\,k} + \Delta t \dot{\lambda}_{E\,k+1}$$

$$v_{F_d\,k+1} = v_{F_d\,k} + \Delta t \dot{v}_{F_d\,k+1}$$
$$v_{F_q\,k+1} = v_{F_q\,k} + \Delta t \dot{v}_{F_q\,k+1}$$
$$e_{F\,k+1} = e_{F\,k} - \Delta t p_{F\,k+1}$$
$$i_{G_d\,k+1} = i_{G_d\,k} + \Delta t \dot{i}_{G_d\,k+1}$$
$$i_{G_q\,k+1} = i_{G_q\,k} + \Delta t \dot{i}_{G_q\,k+1}$$
$$v_{G_{dc}\,k+1} = v_{G_{dc}\,k} + \Delta t \dot{v}_{G_{dc}\,k+1}$$
$$\lambda_{G\,k+1} = \lambda_{G\,k} + \Delta t \dot{\lambda}_{G\,k+1}$$
$$e_{G\,k+1} = e_{G\,k} - \Delta t p_{G\,k+1}$$

Bounds

$$i_{A\min} \le i_A \le i_{A\max}$$
$$u_{A\min} \le u_A \le u_{A\max}$$
$$\lambda_{A\min} \le \lambda_A \le \lambda_{A\max}$$
$$e_{A\min} \le e_A \le e_{A\max}$$

$$v_{B\min} \le v_B \le v_{B\max}$$
$$u_{B\min} \le u_B \le u_{B\max}$$
$$e_{B\min} \le e_B \le e_{B\max}$$

$$i_{C\min} \le i_C \le i_{C\max}$$
$$u_{C\min} \le u_C \le u_{C\max}$$
$$\lambda_{C\min} \le \lambda_C \le \lambda_{C\max}$$
$$e_{C\min} \le e_C \le e_{C\max}$$

$$i_{E_d\min} \le i_{E_d} \le i_{E_d\max}$$
$$i_{E_q\min} \le i_{E_q} \le i_{E_q\max}$$
$$\lambda_{E\min} \le \lambda_E \le \lambda_{E\max}$$

$$v_{F_d\min} \le v_{F_d} \le v_{V_d\max}$$
$$v_{F_q\min} \le v_{F_q} \le v_{V_q\max}$$
$$u_{F_d\min} \le u_{F_d} \le u_{F_d\max}$$
$$u_{F_q\min} \le u_{F_q} \le u_{F_q\max}$$
$$e_{F\min} \le e_F \le e_{F\max}$$
$$i_{G\min} \le i_G \le i_{G\max}$$
$$v_{G_{dc}\min} \le v_{G_{dc}} \le v_{G_{dc}\max}$$
$$i_{G_d\min} \le i_{G_d} \le i_{G_d\max}$$
$$i_{G_q\min} \le i_{G_q} \le i_{G_q\max}$$
$$u_{G\min} \le u_G \le u_{G\max}$$
$$\lambda_{G\min} \le \lambda_G \le \lambda_{G\max}$$
$$e_{G\min} \le e_G \le e_{G\max}$$

4.3 Parameters

In order to specify the microgrid, we require several parameters. In the following specification, we use the following schema

Name *Mathematical name*

Domain *Code name*

Type *Mathematical domain*

Description *Programming type*
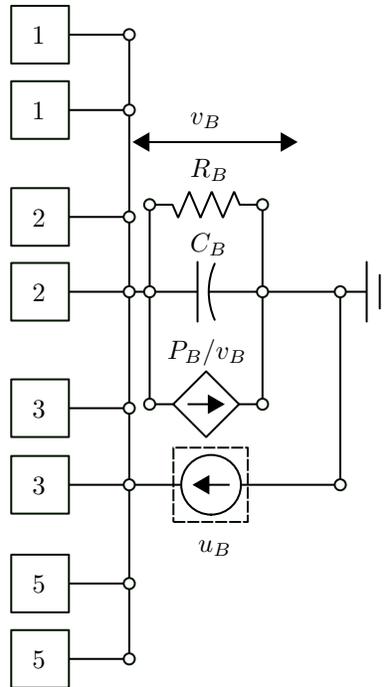
Figure 4.2: (B) DC Bus
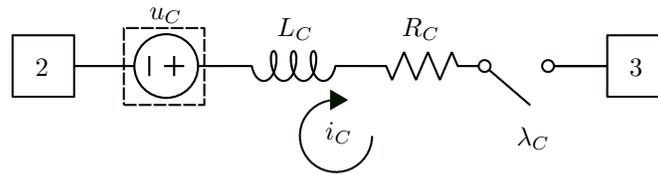
Figure 4.3: (C) DC to DC Bus Connector

Input/output Requirements for specification Description of parameter

In order to specify a matrix parameter, $x \in \mathbb{R}^{m \times n}$, we use a MATLAB/Octave matrix with m rows and n columns. In the json formatted parameter files, this becomes an array of arrays that specify the matrix in row-major format. For example, the matrix

$$x = \begin{bmatrix} 1 & 2 \\ 3 & 4 \end{bmatrix}$$

becomes

```
"x" : [[1.0 2.0],[3.0 4.0]]
```

in json format.

Finally, for parameters whose size is dependent on time, n_{time}, if the number of columns is 1, then the same parameter is repeated for all time steps. For example, both

```
"x" : [1.0,1.0,1.0,1.0]
```

and

```
"x" : [1.0]
```

18
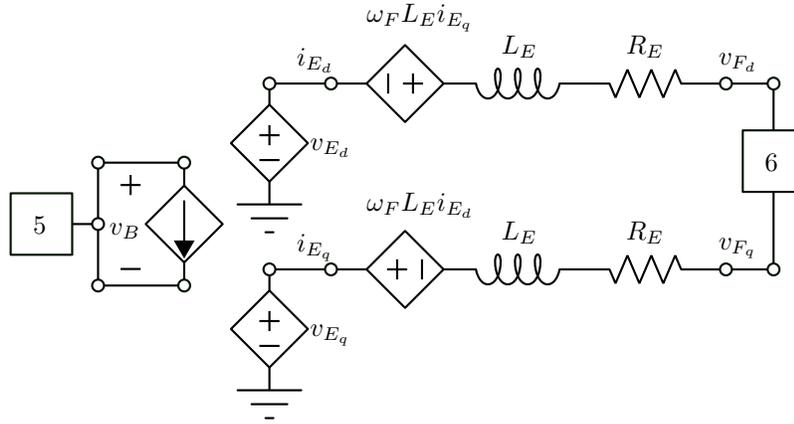
Figure 4.4: (E) AC to DC Bus Connector

are equivalent. If there is a matrix parameter, all rows must have the same number of columns. Hence, we disallow

```
"x" : [[1.0,2.0,3.0,4.0],
       [2.0]]
```

and instead require

```
"x" : [[1.0,2.0,3.0,4.0],
       [2.0,2.0,2.0,2.0]]
```

As for the parameters themselves, we specify that

Topology

Name n_{boost}

API Name nboost

Domain $\mathbb{N}$

Type Integer

I/O Input

Requirement None

Description Number of boost converters, A

Name n_{dc}

API Name ndc

Domain $\mathbb{N}$

Type Integer

I/O Input

Requirement None

Description Number of DC buses, B

Name n_{dcdc}

API Name ndcdc

Domain $\mathbb{N}$

Type Integer

I/O Input

Requirement None

Description Number of connections between DC buses, C

Name n_{load}

API Name nload

Domain $\mathbb{N}$

19

Figure 4.5: (F) AC Bus

Type Integer

I/O Input

Requirement None

Description Number of additional loads, D

Name n_{acdc}

API Name nacdc

Domain $\mathbb{N}$

Type Integer

I/O Input

Requirement None

Description Number of connections between AC and DC buses, E

Name n_{ac}

API Name nac

Domain $\mathbb{N}$

Type Integer

I/O Input

Requirement None

Description Number of AC buses, F

Name n_{inv}

API Name ninv

Domain $\mathbb{N}$

Type Integer

I/O Input

Requirement None

Description Number of three-phase inverters, G

Name n_{time}

API Name ntime

Domain $\mathbb{N}$

Type Integer

I/O Input

Requirement None

Description Number of time steps
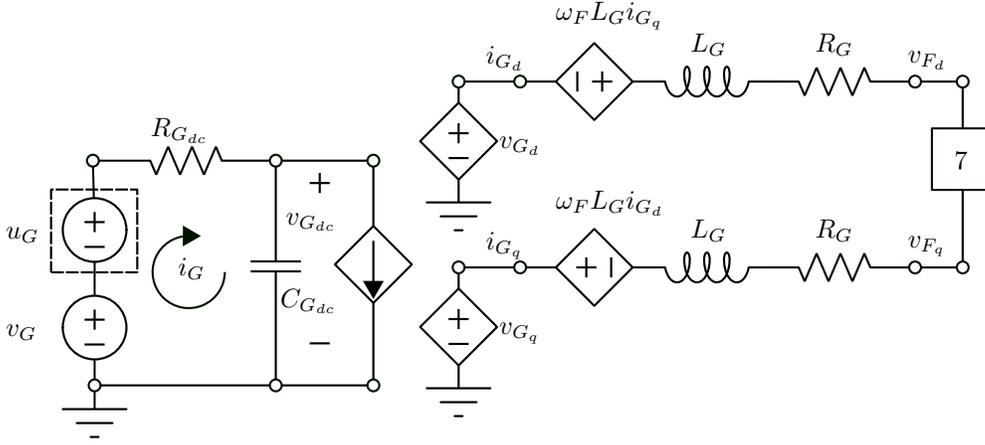
Figure 4.6: (G) Three-Phase Inverter
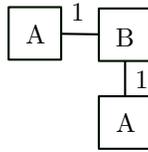
Figure 4.7: Single DC microgrid

Name	Δt		**Type**	Integer
API Name	Delta_t		**I/O**	Input
Domain	$\mathbb{R}$		**Requirement**	$n_{dc} > 0$, $n_{boost} > 0$

Name Δt

API Name Delta_t

Domain $\mathbb{R}$

Type Float

I/O Input

Requirement None

Description Time step for the discretization of the differential equations

Name Φ_1

API Name Phi_boost_dc_1

Domain $\{0,1\}^{n_{boost} \times n_{dc}}$

Type Integer

I/O Input

Requirement $n_{dc} > 0$, $n_{boost} > 0$

Description Boost converter/DC bus expansion operator, $\Phi_{1ij} = 1$ when boost converter i is connected to DC bus j over the connection labeled 1

Name Φ_2

API Name Phi_dcdc_dc_2

Domain $\{0,1\}^{n_{dcdc} \times n_{dc}}$

Type Integer

I/O Input

Figure 4.8: Single AC microgrid

Requirement $n_{dc} > 0, n_{dcdc} > 0$

Description DC-DC Connector/DC bus expansion operator, $\Phi_{2ij} = 1$ when connector i is connected to DC bus j over the connection labeled 2

Name Φ_3

API Name `Phi_dcdc_dc_3`

Domain $\{0,1\}^{n_{dcdc} \times n_{dc}}$

Type `Integer`

I/O Input

Requirement $n_{dc} > 0, n_{dcdc} > 0$

Description DC-DC Connector/DC bus expansion operator, $\Phi_{3ij} = 1$ when connector i is connected to DC bus j over the connection labeled 3

Name Φ_5

API Name `Phi_acdc_dc_5`

Domain $\{0,1\}^{n_{acdc} \times n_{dc}}$

Type `Integer`

I/O Input

Requirement $n_{dc} > 0, n_{acdc} > 0, n_{ac} > 0$

Description AC-DC Connector/DC bus expansion operator, $\Phi_{5ij} = 1$ when AC to DC connector i is connected to DC bus j over the connection labeled 5

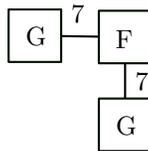**Name** Φ_6

API Name `Phi_acdc_ac_6`

Domain $\{0,1\}^{n_{acdc} \times n_{ac}}$

Type `Integer`

I/O Input

Requirement $n_{acdc} > 0, n_{ac} > 0$

Description AC-DC Connector/AC bus expansion operator, $\Phi_{6ij} = 1$ when AC to DC connector i is connected to AC bus j over the connection labeled 6

Name Φ_7

API Name `Phi_inv_ac_7`

Domain $\{0,1\}^{n_{inv} \times n_{ac}}$

Type `Integer`

I/O Input

Requirement $n_{ac} > 0, n_{inv} > 0$

Description Inverter/AC bus expansion operator, $\Phi_{7ij} = 1$ when three-phase inverter i is connected to AC bus j over the connection labeled 7

Boost Converter

Name u_A

API Name `u_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type `Float`

I/O Output

Requirement $n_{boost} > 0$

Description Controllable voltage source in the boost converters connected to the DC buses

Name $u_{A_{switch}}$

API Name `u_A_switch`

Domain $\{0,1\}^{n_{boost} \times n_{time}}$

Type `Integer`

I/O Input

Requirement $n_{boost} > 0$

Description Toggles whether the controllable voltage source is active

22

Name $u_{A\max}$

API Name `u_A_max`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Maximum voltage generated by the controllable source on the boost converter

Name $u_{A\min}$

API Name `u_A_min`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Minimum voltage generated by the controllable source on the boost converter

Name p_A

API Name `p_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Power at the controllable source u_A in the boost converter

Name e_A

API Name `e_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Energy in the controllable source u_A on the boost converter

Name e_{A0}

API Name `e_A_0`

Domain $\mathbb{R}^{n_{boost} \times 1}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Energy in the controllable source u_A on the boost converter at time 0

Name $e_{A\max}$

API Name `e_A_max`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Maximum energy allowed in the controllable source u_A on the boost converters

Name $e_{A\min}$

API Name `e_A_min`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Minimum energy allowed in the controllable source u_A on the boost converters

Name v_A

API Name `v_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Constant voltage source in the boost converters connected to the DC buses

Name L_A

API Name `L_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Inductance of the boost converters connected to the DC buses

Name R_A

API Name `R_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Resistance of the boost converters connected to the DC buses

Name P_A

API Name `P_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description General load on the boost converters

Name i_A

API Name `i_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Current of the boost converters connected to the DC buses

Name $\dot{i}_A$

API Name `i_A_dot`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Derivative of the current in boost converters connected to the DC buses

Name i_{A0}

API Name `i_A_0`

Domain $\mathbb{R}^{n_{boost} \times 1}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Current in the boost converters connected to the DC buses at time 0

Name $i_{A\max}$

API Name `i_A_max`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Maximum current on boost converters connected to the DC buses

Name $i_{A\min}$

API Name `i_A_min`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Minimum current on boost converters connected to the DC buses

Name λ_A

API Name `lambda_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Duty cycle in boost converters connected to the DC buses

Name $\dot{\lambda}_A$

API Name `lambda_A_dot`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Derivative of the duty cycle in the boost converters connected to the DC buses

Name λ_{A0}

API Name `lambda_A_0`

Domain $\mathbb{R}^{n_{boost} \times 1}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Initial duty cycle in the boost converters connected to the DC buses

Name $\lambda_{A\max}$

API Name `lambda_A_max`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Maximum duty cycle on the boost converters. Likely, 1.

Name $\lambda_{A\min}$

API Name `lambda_A_min`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Minimum duty cycle on the boost converters. Likely, 0.

Name $w_{A_{duty}}$

API Name `w_A_duty`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Duty cycle objective weighting for the boost converters connected to the DC buses

Name $w_{A_{control}}$

API Name `w_A_control`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Controllable source objective weighting for the boost converters connected to the DC buses

Name $w_{A_{loss}}$

API Name `w_A_loss`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Parasitic loss objective weighting for the boost converters connected to the DC buses

Name $w_{A_{power}}$

API Name `w_A_power`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{boost} > 0$

Description Controllable source power objective weighting for the boost converters connected to the DC buses

Name

API Name `derived.load_v_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Voltage across load terms L_A, R_A, and P_A, on the boost converters connected to the DC buses.

Name

API Name `derived.load_i_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Current on the boost converters connected to the DC bus

Name

API Name `derived.load_p_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Power consumed by the load terms on the boost converters connected to the DC bus

Name

API Name `derived.generation_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Power generated by the boost converters connected the DC bus

Name

API Name `derived.duty_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Duty cycle of the boost converters connected to the DC bus

Name

API Name `derived.storage_v_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Voltage of the storage on the boost converters connected to the DC bus

Name

API Name `derived.storage_i_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Current on the boost converters connected to the DC bus

Name

API Name `derived.storage_p_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Power consumed by the storage on boost converters connected to the DC bus

Name

API Name `derived.storage_e_A`

Domain $\mathbb{R}^{n_{boost} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{boost} > 0$

Description Energy within the storage on boost converters connected to the DC bus

DC Bus

Name u_B

API Name `u_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description $\mathbb{R}^{n_{dc} \times n_{time}}$

Float $n_{dc} > 0$ Controllable current source in the DC buses

Name $u_{B_{switch}}$

API Name `u_B_switch`

Domain $\{0,1\}^{n_{dc} \times n_{time}}$

Type Integer

I/O Input

Requirement $n_{dc} > 0$

Description Toggles whether the controllable current source in the DC buses is active

Name $u_{B\max}$

API Name `u_B_max`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Maximum current generated by the controllable source on the DC bus

Name $u_{B\min}$

API Name `u_B_min`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Minimum current generated by the controllable source on the DC bus

Name p_B

API Name `p_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Power at the controllable source u_B on the DC bus

Name e_B

API Name `e_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Energy in the controllable source u_B on the DC bus

Name e_{B0}

API Name `e_B_0`

Domain $\mathbb{R}^{n_{dc} \times 1}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Energy in the controllable source u_B on the DC bus at time 0

Name $e_{B\max}$

API Name `e_B_max`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Maximum energy allowed in the controllable source u_B on the DC bus

Name $e_{B\min}$

API Name `e_B_min`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Minimum energy allowed in the controllable source u_B on the DC bus

Name v_B

API Name `v_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Voltage in the DC buses

Name $\dot{v_B}$

API Name `v_B_dot`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Derivative of the voltage in the DC bus

Name v_{B0}

API Name v_B_0

Domain $\mathbb{R}^{n_{dc} \times 1}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Voltage in the DC bus at time 0

Name $v_{B\max}$

API Name v_B_max

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Maximum voltage on the DC buses

Name $v_{B\min}$

API Name v_B_min

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Minimum voltage on the DC buses

Name R_B

API Name R_B

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Resistance on the DC buses

Name C_B

API Name C_B

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Capacitance on the DC buses

Name P_B

API Name P_B

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description General load on the DC buses

Name $w_{B_{control}}$

API Name w_B_control

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Controllable source objective weighting for the DC buses

Name $w_{B_{power}}$

API Name w_B_power

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dc} > 0$

Description Controllable source power objective weighting for the DC buses

Name

API Name `derived.load_v_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Voltage on the DC bus

Name

API Name `derived.load_i_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Current consumed by the loads C_B, R_B, and P_B on the DC bus

Name

API Name `derived.load_p_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Power consumed by the load terms on the DC bus

Name

API Name `derived.generation_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Power generated by the DC bus

Name

API Name `derived.storage_v_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Voltage on the DC bus

Name

API Name `derived.storage_i_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Current of the storage on the DC bus

Name

API Name `derived.storage_p_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Power consumed by the storage on the DC bus

Name

API Name `derived.storage_e_B`

Domain $\mathbb{R}^{n_{dc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dc} > 0$

Description Energy within the storage on the DC bus

Name u_C

API Name u_C

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Controllable voltage source in the connections between the DC buses

Name $u_{C\max}$

API Name u_C_max

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Maximum voltage generated by the controllable source on the connections between DC buses

Name $u_{C\min}$

API Name u_C_min

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Minimum voltage generated by the controllable source on the connections between DC buses

Name $u_{C_{switch}}$

API Name u_C_switch

Domain $\{0,1\}^{n_{dcdc} \times n_{time}}$

Type Integer

I/O Input

Requirement $n_{dcdc} > 0$

Description Toggles whether the controllable voltage source in the connections between the DC buses is active

Name p_C

API Name p_C

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Power at the controllable source u_C on the connector between DC buses

Name e_C

API Name e_C

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Energy in the controllable source u_C on the connection between DC buses

Name e_{C0}

API Name e_C_0

Domain $\mathbb{R}^{n_{dcdc} \times 1}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Energy in the controllable source u_C on the connection between DC buses at time 0

Name $e_{C\max}$

API Name e_C_max

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type   Float

I/O   Input

Requirement $n_{dcdc} > 0$

Description Maximum energy allowed in the controllable source u_C on the connections between DC buses

Name $e_{C\min}$

API Name e_C_min

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type   Float

I/O   Input

Requirement $n_{dcdc} > 0$

Description Minimum energy allowed in the controllable source u_C on the connections between DC buses

Name L_C

API Name L_C

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type   Float

I/O   Input

Requirement $n_{dcdc} > 0$

Description Inductance in the connections between the DC buses

Name R_C

API Name R_C

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type   Float

I/O   Input

Requirement $n_{dcdc} > 0$

Description Resistance in the connections between the DC buses

Name i_C

API Name i_C

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type   Float

I/O   Output

Requirement $n_{dcdc} > 0$

Description Current in the connections between the DC buses

Name $\dot{i_C}$

API Name i_C_dot

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type   Float

I/O   Output

Requirement $n_{dcdc} > 0$

Description Derivative of the current in the connections between the DC buses

Name i_{C0}

API Name i_C_0

Domain $\mathbb{R}^{n_{dcdc} \times 1}$

Type   Float

I/O   Input

Requirement $n_{dcdc} > 0$

Description Current in the connections between the DC buses at time 0

Name $i_{C\max}$

API Name i_C_max

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type   Float

I/O   Input

Requirement $n_{dcdc} > 0$

Description $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Maximum current on the connections between the DC buses

Name $i_{C\min}$

API Name `i_C_min`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Minimum current on the connections between the DC buses

Name λ_C

API Name `lambda_C`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Duty cycle in the connections between the DC buses

Name $\dot{\lambda}_C$

API Name `lambda_C_dot`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Derivative of the duty cycle in the connection between the DC buses

Name λ_{C0}

API Name `lambda_C_0`

Domain $\mathbb{R}^{n_{dcdc} \times 1}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Initial duty cycle in the connection between the DC buses

Name $\lambda_{C\max}$

API Name `lambda_C_max`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Maximum duty cycle on the connections between DC buses

Name $\lambda_{C\min}$

API Name `lambda_C_min`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Minimum duty cycle on the connections between DC buses

Name $w_{C_{duty}}$

API Name `w_C_duty`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Duty cycle objective weighting for the for the connections between DC buses

Name $w_{C_{control}}$

API Name `w_C_control`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Controllable source objective weighting for the for the connections between DC buses

Name $w_{C_{loss}}$

API Name `w_C_loss`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Parasitic loss objective weighting for the for the connections between DC buses

Name $w_{C_{power}}$

API Name `w_C_power`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{dcdc} > 0$

Description Controllable source power objective weighting for the connections between DC buses

Name

API Name `derived.load_v_C`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Voltage across load terms L_C and R_C on the connections between DC buses

Name

API Name `derived.load_i_C`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Current on the connections between the DC buses

Name

API Name `derived.load_p_C`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Power consumed by the load terms on the connections between the DC buses

Name

API Name `derived.generation_C`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Power generated by the connections between the DC buses

Name

API Name `derived.duty_C`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Duty cycle of the connections between the DC buses

Name

API Name `derived.storage_v_C`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Voltage of the storage on the connections between the DC buses

Name

API Name `derived.storage_i_C`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Current on the connections between the DC buses

Name

API Name `derived.storage_p_C`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Power consumed by the storage on connections between the DC buses

Name

API Name `derived.storage_e_C`

Domain $\mathbb{R}^{n_{dcdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{dcdc} > 0$

Description Energy within the storage on connections between the DC buses

AC Components

Name Ξ

API Name `Xi`

Domain $\mathbb{R}$

Type Float

I/O Neither

Requirement None

Description Constant associated with the dq0 transformation, $\frac{1}{2}\sqrt{\frac{3}{2}}$

AC to DC connector

Name i_{E_q}

API Name `i_E_q`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Current associated with the quadrature axis in the connection

between AC and DC buses

Name $\dot{i_{E_q}}$

API Name `i_E_q_dot`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type `Float`

I/O Output

Requirement $n_{acdc} > 0$

Description Derivative of the current associated with the quadrature axis in the connector between AC and DC buses

Name $i_{E_q 0}$

API Name `i_E_q_0`

Domain $\mathbb{R}^{n_{acdc} \times 1}$

Type `Float`

I/O Input

Requirement $n_{acdc} > 0$

Description Current associated with the quadrature axis on the connection between AC and DC buses at time 0

Name $i_{E_q \max}$

API Name `i_E_q_max`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type `Float`

I/O Input

Requirement $n_{acdc} > 0$

Description Maximum current associated with the quadrature axis on the connections between the AC and DC buses

Name $i_{E_q \min}$

API Name `i_E_q_min`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type `Float`

I/O Input

Requirement $n_{acdc} > 0$

Description Minimum current associated with the quadrature axis on the connections between the AC and DC buses

Name i_{E_d}

API Name `i_E_d`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type `Float`

I/O Output

Requirement $n_{acdc} > 0$

Description Current associated with the direct axis in the connection between AC and DC buses

Name $\dot{i_{E_d}}$

API Name `i_E_d_dot`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type `Float`

I/O Output

Requirement $n_{acdc} > 0$

Description Derivative of the current associated with the direct axis in the connector between AC and DC buses

Name $i_{E_d 0}$

API Name `i_E_d_0`

Domain $\mathbb{R}^{n_{acdc} \times 1}$

Type `Float`

I/O Input

Requirement $n_{acdc} > 0$

Description Current associated with the direct axis on the connection between AC and DC buses at time 0

Name $i_{E_d \max}$

API Name `i_E_d_max`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{acdc} > 0$

Description Maximum current associated with the direct axis on the connections between the AC and DC buses

Name $i_{E_d \min}$

API Name `i_E_d_min`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{acdc} > 0$

Description Minimum current associated with the direct axis on the connections between the AC and DC buses

Name L_E

API Name `L_E`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{acdc} > 0$

Description Inductance on the AC side of the connector between AC and DC buses

Name R_E

API Name `R_E`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{acdc} > 0$

Description Resistance on the AC side of the connector between AC and DC buses

Name λ_E

API Name `lambda_E`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Duty cycle in the connector between AC and DC buses

Name $\dot{\lambda}_E$

API Name `lambda_E_dot`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Derivative of the duty cycle in the connection between the AC and DC buses

Name λ_{E0}

API Name `lambda_E_0`

Domain $\mathbb{R}^{n_{acdc} \times 1}$

Type Float

I/O Input

Requirement $n_{acdc} > 0$

Description Initial duty cycle in the connection between the AC and DC buses

Name $\lambda_{E \max}$

API Name `lambda_E_max`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{acdc} > 0$

Description Maximum duty cycle on the connections between AC and DC buses. Likely, 1.

Name $\lambda_{E\min}$

API Name lambda_E_min

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{acdc} > 0$

Description Minimum duty cycle on the connections between AC and DC buses. Likely, 0.

Name ξ_{E_s}

API Name xi_E_s

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Sine of angle associated with the dq0 transformation in the connection between AC and DC buses

Name ξ_{E_c}

API Name xi_E_c

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Cosine of angle associated with the dq0 transformation in the connection between AC and DC buses

Name $w_{E_{duty}}$

API Name w_E_duty

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{acdc} > 0$

Description Duty cycle objective weighting for the for the connections between AC and DC buses

Name $w_{E_{loss}}$

API Name w_E_loss

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{acdc} > 0$

Description Parasitic loss objective weighting for the for the connections between AC and DC buses

Name

API Name derived.load_v_E_d

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Voltage across load terms L_E and R_E on the direct axis on the connections between AC and DC buses

Name

API Name derived.load_i_E_d

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Current on the direct axis on connections between the AC and DC buses

Name

API Name `derived.load_v_E_q`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Voltage across load terms L_E and R_E on the quadrature axis on the connections between AC and DC buses

Name

API Name `derived.load_i_E_q`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Current on the quadrature axis on connections between the AC and DC buses

Name

API Name `derived.load_v_E`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Voltage across load terms L_E and R_E on the connections between AC and DC buses

Name

API Name `derived.load_i_E`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Current on the connections between the AC and DC buses

Name

API Name `derived.load_p_E`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Power consumed by the load terms on the connections between the DC buses

Name

API Name `derived.duty_E`

Domain $\mathbb{R}^{n_{acdc} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{acdc} > 0$

Description Duty cycle of the connections between the AC and DC buses

AC Bus

Name ω_F

API Name `omega_F`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Angular frequency of the AC bus

Name $u_{F_{switch}}$

API Name u_F_switch

Domain $\{0,1\}^{n_{ac} \times n_{time}}$

Type Integer

I/O Input

Requirement $n_{ac} > 0$

Description Toggles whether the controllable current source on the AC bus is active

Name u_{F_q}

API Name u_F_q

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Controllable current source associated with the quadrature axis on the AC bus

Name $u_{F_q \max}$

API Name u_F_q_max

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Maximum current generated by the controllable source associated with the quadrature axis on the AC bus

Name $u_{F_q \min}$

API Name u_F_q_min

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Minimum current generated by the controllable source associated with the quadrature axis on the AC bus

Name u_{F_d}

API Name u_F_d

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Controllable current source associated with the direct axis on the AC bus

Name $u_{F_d \max}$

API Name u_F_d_max

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Maximum current generated by the controllable source associated with the direct axis on the AC bus

Name $u_{F_d \min}$

API Name u_F_d_min

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Minimum current generated by the controllable source associated with the direct axis on the AC bus

Name p_F

API Name `p_F`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Power at the controllable source u_{F_d} and u_{F_q} on the AC bus

Name e_F

API Name `e_F`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Energy in the controllable source u_{F_d} and u_{F_q} on the AC bus

Name e_{F0}

API Name `e_F_0`

Domain $\mathbb{R}^{n_{ac} \times 1}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Energy in the controllable source u_{F_d} and u_{F_d} on the AC bus at time 0

Name $e_{F\max}$

API Name `e_F_max`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Maximum energy allowed in the controllable source u_{F_d} and u_{F_q} on the AC bus

Name $e_{F\min}$

API Name `e_F_min`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Minimum energy allowed in the controllable source u_{F_d} and u_{F_q} on the AC bus

Name v_{F_q}

API Name `v_F_q`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Voltage associated with the quadrature axis on the AC bus

Name $\dot{v_{F_q}}$

API Name `v_F_q_dot`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Derivative of the voltage associated with the quadrature axis on the AC bus

Name $v_{F_q 0}$

API Name `v_F_q_0`

Domain $\mathbb{R}^{n_{ac} \times 1}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Voltage associated with the quadrature axis on the AC bus at time 0

Name $v_{F_q \max}$

API Name `v_F_q_max`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Maximum voltage associated with the quadrature axis on the AC bus

Name $v_{F_q \min}$

API Name `v_F_q_min`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Minimum voltage associated with the quadrature axis on the AC bus

Name v_{F_d}

API Name `v_F_d`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Voltage associated with the direct axis on the AC bus

Name $\dot{v_{F_d}}$

API Name `v_F_d_dot`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Derivative of the voltage associated with the direct axis on the AC bus

Name $v_{F_d 0}$

API Name `v_F_d_0`

Domain $\mathbb{R}^{n_{ac} \times 1}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Voltage associated with the quadrature axis on the AC bus at time 0

Name $v_{F_d \max}$

API Name `v_F_d_max`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Maximum voltage associated with the direct axis on the AC bus

Name $v_{F_d \min}$

API Name `v_F_d_min`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Minimum voltage associated with the direct axis on the AC bus

Name R_F

API Name `R_F`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Resistance on the AC buses

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Controllable source power objective weighting for the AC buses

Name P_F

API Name P_F

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description General load on the AC buses

Name

API Name derived.load_v_F_d

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Voltage on the direct axis on the AC bus

Name C_F

API Name C_F

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Capacitance on the AC buses

Name

API Name derived.load_v_F_q

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Voltage on the quadrature axis on the AC bus

Name $w_{F_{control}}$

API Name w_F_control

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{ac} > 0$

Description Controllable source objective weighting for the AC buses

Name

API Name derived.load_v_F

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{ac} > 0$

Description Voltage on the AC bus

Name $w_{F_{power}}$

API Name w_F_power

Name

API Name derived.load_i_F_d

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type   Float

I/O   Output

Requirement $n_{ac} > 0$

Description Current consumed by the loads C_F, R_F, and P_{F_d} on the direct axis on the AC bus

Name

API Name `derived.load_i_F_q`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type   Float

I/O   Output

Requirement $n_{ac} > 0$

Description Current consumed by the loads C_F, R_F, and P_{F_q} on the quadrature axis on the AC bus

Name

API Name `derived.load_i_F`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type   Float

I/O   Output

Requirement $n_{ac} > 0$

Description Current consumed by the loads on the AC bus

Name

API Name `derived.load_p_F`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type   Float

I/O   Output

Requirement $n_{ac} > 0$

Description Power consumed by the load terms on the AC bus

Name

API Name `derived.generation_F`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type   Float

I/O   Output

Requirement $n_{ac} > 0$

Description Power generated by the AC bus

Name

API Name `derived.storage_v_F`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type   Float

I/O   Output

Requirement $n_{ac} > 0$

Description Voltage on the AC bus

Name

API Name `derived.storage_i_F`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type   Float

I/O   Output

Requirement $n_{ac} > 0$

Description Current of the storage on the AC bus

Name

API Name `derived.storage_p_F`

Domain $\mathbb{R}^{n_{ac} \times n_{time}}$

Type   Float

I/O   Output

Requirement $n_{ac} > 0$

Description Power consumed by the storage on the AC bus

Name

API Name `derived.storage_e_F`

Domain	$\mathbb{R}^{n_{ac} \times n_{time}}$
Type	Float
I/O	Output

Requirement	$n_{ac} > 0$
Description	Energy within the storage on the AC bus

Three-phase Inverter

Name	u_G
API Name	u_G
Domain	$\mathbb{R}^{n_{inv} \times n_{time}}$
Type	Float
I/O	Output
Requirement	$n_{inv} > 0$
Description	Controllable voltage source in the inverter connected to the AC bus

API Name	u_G_min
Domain	$\mathbb{R}^{n_{inv} \times n_{time}}$
Type	Float
I/O	Input
Requirement	$n_{inv} > 0$
Description	Minimum voltage generated by the controllable source on the inverter

Name	$u_{G_{switch}}$
API Name	u_G_switch
Domain	$\{0,1\}^{n_{inv} \times n_{time}}$
Type	Integer
I/O	Input
Requirement	$n_{inv} > 0$
Description	$\{0,1\}^{n_{inv} \times n_{time}}$

Toggles whether the controllable voltage source is active

Name	$u_{G\max}$
API Name	u_G_max
Domain	$\mathbb{R}^{n_{inv} \times n_{time}}$
Type	Float
I/O	Input
Requirement	$n_{inv} > 0$
Description	Maximum voltage generated by the controllable source on the inverter

Name	$u_{G\min}$

Name	p_G
API Name	p_G
Domain	$\mathbb{R}^{n_{inv} \times n_{time}}$
Type	Float
I/O	Output
Requirement	$n_{inv} > 0$
Description	Power at the controllable source u_G in the inverter

Name	e_G
API Name	e_G
Domain	$\mathbb{R}^{n_{inv} \times n_{time}}$
Type	Float
I/O	Output
Requirement	$n_{inv} > 0$
Description	Energy in the controllable source u_G on the inverter

Name	e_{G0}
API Name	e_G_0
Domain	$\mathbb{R}^{n_{inv} \times 1}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Energy in the controllable source u_G on the inverter at time 0

Name $e_{G\max}$

API Name e_G_max

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Maximum energy allowed in the controllable source u_G on the inverter

Name $e_{G\min}$

API Name e_G_min

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Minimum energy allowed in the controllable source u_G on the inverter

Name v_G

API Name v_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Renewable and/or fossil source voltage in the inverter connected to the AC bus

Name i_G

API Name i_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Current on the DC side of the inverter

Name $i_{G\max}$

API Name i_G_max

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Maximum current on the inverters

Name $i_{G\min}$

API Name i_G_min

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Minimum current on the inverters

Name $C_{G_{dc}}$

API Name C_G_dc

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Capacitance on the DC side of the inverter

Name $R_{G_{dc}}$

API Name `R_G_dc`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Resistance on the DC side of the inverter

Name $v_{G_{dc}}$

API Name `v_G_dc`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Voltage on the DC side of the inverter

Name $\dot{v_{G_{dc}}}$

API Name `v_G_dc_dot`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Derivative of the voltage in the inverter

Name $v_{G_{dc}0}$

API Name `v_G_dc_0`

Domain $\mathbb{R}^{n_{inv} \times 1}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Voltage in the inverter bus at time 0

Name $v_{G_{dc}\max}$

API Name `v_G_dc_max`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Maximum voltage on the inverters

Name $v_{G_{dc}\min}$

API Name `v_G_dc_min`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Minimum voltage on the inverters

Name i_{G_q}

API Name `i_G_q`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Current associated with the quadrature axis in the inverter

Name $\dot{i_{G_q}}$

API Name `i_G_q_dot`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Derivative of the current associated with the quadrature axis on the inverter

Name $i_{G_q 0}$

API Name `i_G_q_0`

Domain $\mathbb{R}^{n_{inv} \times 1}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Current associated with the quadrature axis on the inverter at time 0

Name $i_{G_q \max}$

API Name `i_G_q_max`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Maximum current associated with the quadrature axis on the inverters

Name $i_{G_q \min}$

API Name `i_G_q_min`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Minimum current associated with the quadrature axis on the inverters

Name i_{G_d}

API Name `i_G_d`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Current associated with the direct axis in the inverter

Name $\dot{i}_{G_d}$

API Name `i_G_d_dot`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Derivative of the current associated with the direct axis on the inverter

Name $i_{G_d 0}$

API Name `i_G_d_0`

Domain $\mathbb{R}^{n_{inv} \times 1}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Current associated with the quadrature axis on the inverter at time 0

Name $i_{G_d \max}$

API Name `i_G_d_max`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Maximum current associated with the direct axis on the inverters

Name $i_{G_d \min}$

API Name `i_G_d_min`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Minimum current associated with the direct axis on the inverters

Name L_G

API Name L_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Inductance on the AC side of the inverter

Name R_G

API Name R_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Resistance on the AC side of the inverter

Name λ_G

API Name lambda_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Duty cycle in inverters connected to the AC bus

Name $\dot{\lambda}_G$

API Name lambda_G_dot

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Derivative of the duty cycle in the inverter

Name λ_{G0}

API Name lambda_G_0

Domain $\mathbb{R}^{n_{inv} \times 1}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Initial duty cycle in the inverter

Name $\lambda_{G\max}$

API Name lambda_G_max

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Maximum duty cycle on the inverter. Likely, 1.

Name $\lambda_{G\min}$

API Name lambda_G_min

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Minimum duty cycle on the inverter Likely, 0.

Name ξ_{G_s}

API Name xi_G_s

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Sine of angle associated with the dq0 transformation in the inverter

Name ξ_{G_c}

API Name `xi_G_c`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Cosine of angle associated with the dq0 transformation in the inverter

Name $w_{G_{duty}}$

API Name `w_G_duty`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Duty cycle objective weighting for the inverter connected to the AC bus

Name $w_{G_{control}}$

API Name `w_G_control`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Controllable source objective weighting for the inverter connected to the AC bus

Name $w_{G_{loss}}$

API Name `w_G_loss`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Parasitic loss objective weighting for the inverter connected to the AC bus

Name $w_{G_{power}}$

API Name `w_G_power`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Input

Requirement $n_{inv} > 0$

Description Controllable source power objective weighting for the inverter connected to the AC bus

Name

API Name `derived.load_v_G_d`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Voltage across the load terms L_G and R_G on the direct axis on the AC side of the three-phase inverter

Name

API Name `derived.load_v_G_q`

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Voltage across the load terms L_G and R_G on the quadrature axis on the AC side of the three-phase inverter

Name

API Name derived.load_v_G_ac

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Voltage on the AC side of the three-phase inverter

Name

API Name derived.load_i_G_d

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Current on the direct axis on the AC side of the three-phase inverter

Name

API Name derived.load_i_G_q

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Current on the quadrature axis on the AC side of the three-phase inverter

Name

API Name derived.load_i_G_ac

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Current on the AC side of the three-phase inverter

Name

API Name derived.load_p_G_ac

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Power consumed by the load terms on the AC side of the three-phase inverter

Name

API Name derived.load_v_G_dc

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Voltage on the DC side of the three-phase inverter bus

Name

API Name derived.load_i_G_dc

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Current consumed by the loads $C_{G_{dc}}$ and $R_{G_{dc}}$ on the DC side of the three-phase inverter

Name

API Name derived.load_p_G_dc

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Power consumed by the load terms on the DC side of the three-phase inverter

Name

API Name derived.generation_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Power generated by the DC side of the three-phase inverter

Name

API Name derived.duty_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Duty cycle of the three-phase inverter

Name

API Name derived.storage_v_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Voltage of the storage on the three-phase inverter

Name

API Name derived.storage_i_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Current on the DC side of the three-phase inverter

Name

API Name derived.storage_p_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Power consumed by the storage on the three-phase inverter

Name

API Name derived.storage_e_G

Domain $\mathbb{R}^{n_{inv} \times n_{time}}$

Type Float

I/O Output

Requirement $n_{inv} > 0$

Description Energy within the storage on the three-phase inverter

Miscellaneous

Name

API Name `ineq_scaling`

Domain $\mathbb{R}$

Type   Float

I/O   Input

Requirement None

Description Scaling of the inequality constraints. This must be balanced against the rest of the objective.

Name

API Name `metrics.optimality`

Domain $\mathbb{R}$

Type   Float

I/O   Output

Requirement None

Description Norm of the optimality conditions. When this is small, the optimization problem is optimal.

Name

API Name `metrics.feasibility`

Domain $\mathbb{R}$

Type   Float

I/O   Output

Requirement None

Description Norm of the infeasibility. When this is small, the optimization problem satisfies the state conditions.

Name

API Name `metrics.barrier`

Domain $\mathbb{R}$

Type   Float

I/O   Output

Requirement None

Description Current barrier parameter. When this is small, the optimization problem satisfies the complementary slackness condition required for optimality.

Chapter 5

Examples

The following chapter presents two different simple examples of how to create and run an optimal control scenario for a given microgrid.

5.1   Single DC Microgrid

Recall, the single DC microgrid has a topology in Figure 4.7. We specify this with the parameter file

```json
{
    "Optizelle" : {
        "iter_max" : 300
    },
    "microgrid": {
        "Delta_t": 1.0,
        "ntime" : 1,
        "nboost" : 2,
        "ndc" : 1,
        "Phi_boost_dc_1" : [
            [1],
            [1]
        ],
        "w_A_duty": [
            [1],
            [1]
        ],
        "w_A_control": [
            [0],
            [0]
        ],
        "w_A_loss": [
            [0],
            [0]
        ],
        "w_A_power": [
            [0],
            [0]
        ],
        "v_A": [
            [30],
            [30]
```

```
    ],
    "L_A": [
        [0.002],
        [0.002]
    ],
    "R_A": [
        [0.036],
        [0.036]
    ],
    "P_A": [
        [0.0],
        [0.0]
    ],
    "i_A_0": [
        [15],
        [15]
    ],
    "i_A_min": [
        [10],
        [10]
    ],
    "i_A_max": [
        [40],
        [40]
    ],
    "lambda_A_0": [
        [0.55],
        [0.55]
    ],
    "lambda_A_min": [
        [0],
        [0]
    ],
    "lambda_A_max": [
        [1],
        [1]
    ],
    "u_A_switch" : [
        [1],
        [1]
    ],
    "u_A_min": [
        [0],
        [0]
    ],
    "u_A_max": [
        [100],
        [100]
    ],
    "e_A_0": [
        [50],
        [50]
    ],
    "e_A_min": [
```

```
                [0],
                [0]
            ],
            "e_A_max": [
                [100],
                [100]
            ],
            "w_B_control": [0],
            "w_B_power": [0],
            "v_B_0": [170],
            "v_B_min": [0],
            "v_B_max": [500],
            "R_B": [25],
            "P_B": [0.0],
            "C_B": [0.004],
            "u_B_switch" : [1],
            "u_B_min": [-50],
            "u_B_max": [100],
            "e_B_0": [50],
            "e_B_min": [0],
            "e_B_max": [100]
        },
        "tighter_bus": {
            "v_B_min": [150],
            "v_B_max": [200]
        },
        "tighter_boost" : {
            "i_A_max": [
                [20],
                [20]
            ]
        }
    }
}
```

Note, this contains two different problem setups. We run both with the commands

```
solution=runScenario('single_dc','tighter_bus');
solution=runScenario('single_dc','tighter_boost');
```

This produces the solution

```
{
    "tighter_bus": {
        "u_A": [
            [4.999986786],
            [3.336407511]
        ],
        "i_A": [
            [10.00001783],
            [14.98616103]
        ],
        "i_A_dot": [
            [-4.99998217],
            [-0.0138389666]
        ],
        "lambda_A": [
```

```json
      [0.2309998948],
      [0.2186462107]
    ],
    "lambda_A_dot": [
      [-0.3190001052],
      [-0.3313537893]
    ],
    "p_A": [
      [49.99995701],
      [49.99994024]
    ],
    "e_A": [
      [4.299323572e-05],
      [5.976117575e-05]
    ],
    "v_B": 150.0000082,
    "v_B_dot": -19.99999183,
    "u_B": 0.3333299698,
    "p_B": 49.9994982,
    "e_B": 0.0005018021289,
    "metrics": {
      "optimality": 1.877830374e-11,
      "feasibility": 1.640902151e-14,
      "barrier": 1e-08
    },
    "derived": {
      "load_v_A": [
        [0.3500006775],
        [0.5394741193]
      ],
      "load_i_A": [
        [10.00001783],
        [14.98616103]
      ],
      "load_p_A": [
        [3.500013016],
        [8.084646025]
      ],
      "generation_A": [
        [350.0004919],
        [499.5847712]
      ],
      "storage_v_A": [
        [4.999986786],
        [3.336407511]
      ],
      "storage_i_A": [
        [10.00001783],
        [14.98616103]
      ],
      "storage_p_A": [
        [49.99995701],
        [49.99994024]
      ],
```

```json
        "storage_e_A": [
            [4.299323572e-05],
            [5.976117575e-05]
        ],
        "duty_A": [
            [0.2309998948],
            [0.2186462107]
        ],
        "load_v_B": 150.0000082,
        "load_i_B": 5.92000036,
        "load_p_B": 888.0001023,
        "generation_B": 49.9994982,
        "storage_v_B": 150.0000082,
        "storage_i_B": 0.3333299698,
        "storage_p_B": 49.9994982,
        "storage_e_B": 0.0005018021289
    }
},
"tighter_boost": {
    "u_A": [
        [4.999989611],
        [4.999989611]
    ],
    "i_A": [
        [10.00000228],
        [10.00000228]
    ],
    "i_A_dot": [
        [-4.999997725],
        [-4.999997725]
    ],
    "lambda_A": [
        [0.2688945834],
        [0.2688945834]
    ],
    "lambda_A_dot": [
        [-0.2811054166],
        [-0.2811054166]
    ],
    "p_A": [
        [49.99990749],
        [49.99990749]
    ],
    "e_A": [
        [9.251470286e-05],
        [9.251473122e-05]
    ],
    "v_B": 128.8608684,
    "v_B_dot": -41.13913163,
    "u_B": -0.3880146841,
    "p_B": -49.99990914,
    "e_B": 99.99990914,
    "metrics": {
        "optimality": 6.723195818e-11,
```

```json
            "feasibility": 2.675706272e-09,
            "barrier": 1e-08
        },
        "derived": {
            "load_v_A": [
                [0.3500000865],
                [0.3500000865]
            ],
            "load_i_A": [
                [10.00000228],
                [10.00000228]
            ],
            "load_p_A": [
                [3.500001661],
                [3.500001661]
            ],
            "generation_A": [
                [349.9999757],
                [349.9999757]
            ],
            "storage_v_A": [
                [4.999989611],
                [4.999989611]
            ],
            "storage_i_A": [
                [10.00000228],
                [10.00000228]
            ],
            "storage_p_A": [
                [49.99990749],
                [49.99990749]
            ],
            "storage_e_A": [
                [9.251470286e-05],
                [9.251473122e-05]
            ],
            "duty_A": [
                [0.2688945834],
                [0.2688945834]
            ],
            "load_v_B": 128.8608684,
            "load_i_B": 4.989878208,
            "load_p_B": 643.000039,
            "generation_B": -49.99990914,
            "storage_v_B": 128.8608684,
            "storage_i_B": -0.3880146841,
            "storage_p_B": -49.99990914,
            "storage_e_B": 99.99990914
        }
    }
}
```

5.2 Single AC Microgrid

Recall, the single AC microgrid has a topology found in Figure 4.8. We specify this with the parameter file

```json
{
    "Optizelle" : {
        "iter_max" : 200
    },
    "microgrid": {
        "ineq_scaling" : 1e-2,
        "Delta_t": 1.0,
        "ntime" : 1,
        "ninv" : 2,
        "nac" : 1,
        "Phi_inv_ac_7" : [
            [1],
            [1]
        ],
        "w_G_duty": [
            [1],
            [1]
        ],
        "w_G_control": [
            [0],
            [0]
        ],
        "w_G_loss": [
            [0],
            [0]
        ],
        "w_G_power": [
            [0],
            [0]
        ],
        "v_G": [
            [30],
            [30]
        ],
        "C_G_dc": [
            [0.004],
            [0.004]
        ],
        "R_G_dc": [
            [25],
            [25]
        ],
        "L_G": [
            [0.002],
            [0.002]
        ],
        "R_G": [
            [0.036],
            [0.036]
        ],
        "v_G_dc_0" : [
```

```json
        [30],
        [30]
    ],
    "v_G_dc_min": [
        [0],
        [0]
    ],
    "v_G_dc_max": [
        [500],
        [500]
    ],
    "i_G_d_0": [
        [15],
        [15]
    ],
    "i_G_d_min": [
        [0],
        [0]
    ],
    "i_G_d_max": [
        [40],
        [40]
    ],
    "i_G_q_0": [
        [15],
        [15]
    ],
    "i_G_q_min": [
        [10],
        [10]
    ],
    "i_G_q_max": [
        [40],
        [40]
    ],
    "lambda_G_0": [
        [0.55],
        [0.55]
    ],
    "lambda_G_min": [
        [0],
        [0]
    ],
    "lambda_G_max": [
        [1],
        [1]
    ],
    "u_G_switch" : [
        [1],
        [1]
    ],
    "u_G_min": [
        [0],
        [0]
```

```
            ],
            "u_G_max": [
                [100],
                [100]
            ],
            "e_G_0": [
                [50],
                [50]
            ],
            "e_G_min": [
                [0],
                [0]
            ],
            "e_G_max": [
                [100],
                [100]
            ],
            "w_F_control": [0],
            "w_F_power": [0],
            "omega_F": [376.9911184],
            "v_F_d_0": [170],
            "v_F_d_min": [0],
            "v_F_d_max": [500],
            "v_F_q_0": [170],
            "v_F_q_min": [0],
            "v_F_q_max": [500],
            "R_F": [25],
            "P_F_d": [0.0],
            "P_F_q": [0.0],
            "C_F": [0.004],
            "u_F_switch" : [1],
            "u_F_d_min": [-50],
            "u_F_d_max": [100],
            "u_F_q_min": [-50],
            "u_F_q_max": [100],
            "e_F_0": [50],
            "e_F_min": [0],
            "e_F_max": [100]
        },
        "default" : {}
}
```

and run it with the command

```
solution=runScenario('single_ac','default');
```

which produces the solution

```
{
    "default": {
        "v_F_d": 34.23299918,
        "v_F_q": 0.4331995667,
        "v_F_d_dot": -135.7670008,
        "v_F_q_dot": -169.5668004,
        "u_F_d": -0.7068348612,
        "u_F_q": 16.06807396,
```

```
"p_F": -17.23639454,
"e_F": 67.23639454,
"u_G": [
    [49.34068309],
    [49.40569838]
],
"i_G": [
    [0.6679797307],
    [0.6673053769]
],
"v_G_dc": [
    [62.64118982],
    [62.72306396]
],
"v_G_dc_dot": [
    [32.64118982],
    [32.72306396]
],
"i_G_d": [
    [0.4392688864],
    [0.4405683822]
],
"i_G_q": [
    [17.46487895],
    [17.42825446]
],
"i_G_d_dot": [
    [-14.56073111],
    [-14.55943162]
],
"i_G_q_dot": [
    [2.464878951],
    [2.428254458]
],
"lambda_G": [
    [0.5499999984],
    [0.5499999986]
],
"lambda_G_dot": [
    [-1.568584858e-09],
    [-1.361181287e-09]
],
"xi_G_s": [
    [0.06626578148],
    [0.06615978346]
],
"xi_G_c": [
    [0.9978020075],
    [0.9978090414]
],
"p_G": [
    [32.9585762],
    [32.96868818]
],
```

```
"e_G": [
    [17.0414238],
    [17.03131182]
],
"metrics": {
    "optimality": 1.191924204e-11,
    "feasibility": 8.728326814e-09,
    "barrier": 1e-08
},
"derived": {
    "load_v_F_d": 34.23299918,
    "load_v_F_q": 0.4331995667,
    "load_v_F": 34.23574002,
    "load_i_F_d": 0.1730024074,
    "load_i_F_q": 50.96120737,
    "load_i_F": 0.2446623509,
    "load_p_F": 27.99876422,
    "generation_F": -17.23639455,
    "storage_v_F": 34.23574002,
    "storage_i_F": 16.08361329,
    "storage_p_F": -17.23639454,
    "storage_e_F": 67.23639454,
    "load_v_G_d": [
        [-0.01330778232],
        [-0.01325840148]
    ],
    "load_v_G_q": [
        [0.6336654002],
        [0.6322736694]
    ],
    "load_v_G_ac": [
        [0.633805125],
        [0.6324126645]
    ],
    "load_i_G_d": [
        [0.4392688864],
        [0.4405683822]
    ],
    "load_i_G_q": [
        [17.46487895],
        [17.42825446]
    ],
    "load_i_G_ac": [
        [17.47040223],
        [17.43382213]
    ],
    "load_p_G_ac": [
        [11.06104381],
        [11.01358516]
    ],
    "load_v_G_dc": [
        [62.64118982],
        [62.72306396]
    ],
```

```json
        "load_i_G_dc": [
            [2.636212352],
            [2.639814814]
        ],
        "load_p_G_dc": [
            [165.1354783],
            [165.5772734]
        ],
        "generation_A": [
            [52.99796812],
            [52.98784949]
        ],
        "storage_v_G": [
            [49.34068309],
            [49.40569838]
        ],
        "storage_i_G": [
            [0.6679797307],
            [0.6673053769]
        ],
        "storage_p_G": [
            [32.9585762],
            [32.96868818]
        ],
        "storage_e_G": [
            [17.0414238],
            [17.03131182]
        ],
        "duty_G": [
            [0.5499999984],
            [0.5499999986]
        ]
    }
  }
}
```

Index