AGISTIN T4.6 Usage examples of the tool

CITCEA-UPC

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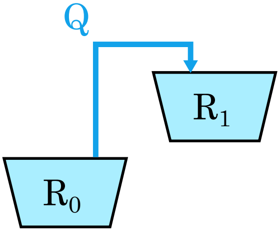
Contents

Introduction

- Built in Python3
- Using Pyomo library and extension Pyomo Network
- Object oriented approach

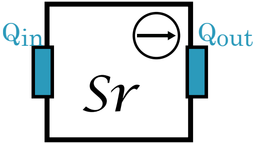
EXAMPLE 0

Two Reservoirs + one Source (imposes Q)



Example 0

Source



Var	Desc.	Units
$\mathbf{Q(t)}$	Flow	[m^3/s]
$Q_{in}(t)$	Inlet flow	[m^3/s]
$Q_{out}(t)$	Outlet flow	[m^3/s]

Port	Var
Q_{in}	$Q_{in}(t)$
Q_{out}	$Q_{out}(t)$

Equations

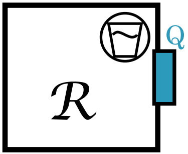
$$Q_{in}^{[k]} = -Q^{[k]}$$

$$Q_{out}^{[k]} = Q^{[k]}$$

Source

```python
import pyomo.environ as pyo
from pyomo.network import *


# data: Q(t)

def Source(b, t, data, init_data=None):

    # Parameters
    b.Q = pyo.Param(t, initialize=data['Q'])

    # Variables
    b.Qin = pyo.Var(t, initialize=data['Q'], within=pyo.Reals)
    b.Qout = pyo.Var(t, initialize=data['Q'], within=pyo.Reals)

    # Ports
    b.port_Qin = Port(initialize={'Q': (b.Qin, Port.Extensive)})
    b.port_Qout = Port(initialize={'Q': (b.Qout, Port.Extensive)})

    # Constraints
    def Constraint_Qin(_b, _t):
        return _b.Qin[_t] == -_b.Q[_t]
    b.c_Qin = pyo.Constraint(t, rule=Constraint_Qin)
    def Constraint_Qout(_b, _t):
        return _b.Qout[_t] == _b.Q[_t]
    b.c_Qout = pyo.Constraint(t, rule=Constraint_Qout)
```

Reservoir



Var	Desc.	Units
$\mathbf{W_0}$	Initial volume	[m^3]
$\underline{\mathbf{W}}$, $\overline{\mathbf{W}}$	min, max volume	[m^3]
$W(t)$	Volume	[m^3/s]
$Q(t)$	Flow	[m^3/s]

Port	Var
Q	$Q(t)$

Equations

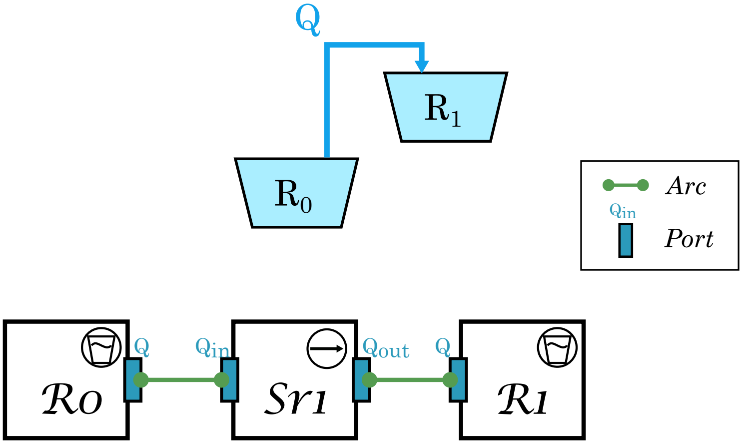
$$W^{[k]} = \begin{cases} W^{[k-1]} + Q^{[k]} & \text{if } k > 0 \\ W_0 + Q^{[k]} & \text{otherwise} \end{cases}$$

Reservoir

```
# data: W0, Wmin, Wmax
# init_data: Q(t), W(t)

def Reservoir_Ex0(b, t, data, init_data):

    # Parameters
    b.W0 = pyo.Param(initialize=data['W0'])

    # Variables
    b.Q  = pyo.Var(t, initialize=init_data['Q'], within=pyo.Reals)
    b.W = pyo.Var(t, initialize=init_data['W'], bounds=(data['Wmin'],data['Wmax']), within=pyo.NonNegativeReals)


    # Ports
    b.port_Q = Port(initialize={'Q': (b.Q, Port.Extensive)})

    # Constraints
    def Constraint_W(_b, _t):
        if _t>0:
            return _b.W[_t] == _b.W[_t-1] + (_b.Q[_t]) # TODO: - Qloss - gamma
        else:
            return _b.W[_t] == _b.W0 + (_b.Q[_t])
    b.c_W = pyo.Constraint(t, rule = Constraint_W)
```

Example 0

Connect *Blocks*' *Ports* with *Arcs*



Example 0

Create the *Blocks*

```
# ===== Create the system =====

# Source 1
m.Source1 = pyo.Block()
data_s1 = {'Q':[1,1,1,1,1]}
Source(m.Source1, m.t, data_s1)

# Reservoir0
m.Reservoir0 = pyo.Block()
data_r0 = {'W0':10, 'Wmin':0, 'Wmax':20}
init_r0 = {'Q':[0,0,0,0,0], 'W':[5,5,5,5,5]}
Reservoir_Ex0(m.Reservoir0, m.t, data_r0, init_r0)

# Reservoir1
m.Reservoir1 = pyo.Block()
data_r1 = {'W0':5, 'Wmin':0, 'Wmax':20}
init_r1 = {'Q':[0,0,0,0,0], 'W':[5,5,5,5,5]}
Reservoir_Ex0(m.Reservoir1, m.t, data_r1, init_r1)
```

Create the *Arcs*

```
# Connections
m.s1r0 = Arc(ports=(m.Source1.port_Qin, m.Reservoir0.port_Q), directed=True)
m.s1r1 = Arc(ports=(m.Source1.port_Qout, m.Reservoir1.port_Q), directed=True)

pyo.TransformationFactory("network.expand_arcs").apply_to(m) # apply arcs to model
```

Example 0

Run the optimization

```
#%% RUN THE OPTIMIZATION

# Objective function (Feasibility problem in this example)
def obj_fun(m):
    return 0
m.goal = pyo.Objective(rule=obj_fun, sense=pyo.minimize)

instance = m.create_instance()
solver = pyo.SolverFactory('ipopt')
solver.solve(instance, tee=False)
```

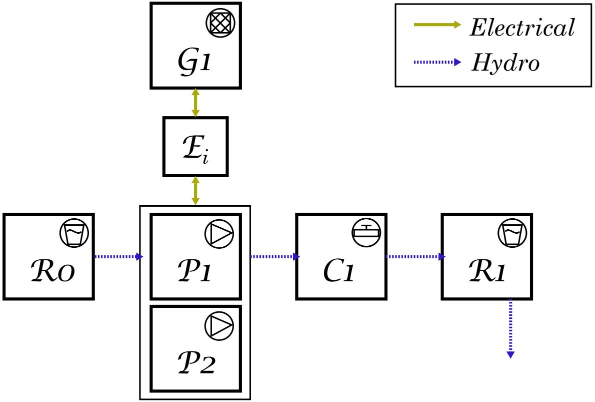
Results

```
instance.Reservoir1.W.pprint()
instance.Reservoir0.W.pprint()

# RESULTS:
    # W : Size=5, Index=t
    #     Key : Lower : Value : Upper : Fixed : Stale : Domain
    #       0 :     0 :   6.0 :    20 : False : False : NonNegativeReals
    #       1 :     0 :   7.0 :    20 : False : False : NonNegativeReals
    #       2 :     0 :   8.0 :    20 : False : False : NonNegativeReals
    #       3 :     0 :   9.0 :    20 : False : False : NonNegativeReals
    #       4 :     0 :  10.0 :    20 : False : False : NonNegativeReals
    # W : Size=5, Index=t
    #     Key : Lower : Value : Upper : Fixed : Stale : Domain
    #       0 :     0 :   9.0 :    20 : False : False : NonNegativeReals
    #       1 :     0 :   8.0 :    20 : False : False : NonNegativeReals
    #       2 :     0 :   7.0 :    20 : False : False : NonNegativeReals
    #       3 :     0 :   6.0 :    20 : False : False : NonNegativeReals
    #       4 :     0 :   5.0 :    20 : False : False : NonNegativeReals
```

EXAMPLE 1

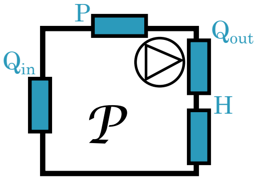
Two Reservoirs with Irrigation + two Pumps connected to Grid w/ time-dependent cost

Optimization: $\min \sum_{k=0}^{k=T} -P_{grid}(k) \cdot cost(k)\, \Delta k \qquad \text{w/ } cost = [10, 5, 1, 5, 10]$



Example 1

Pump



Var	Desc.	Units
$\mathbf{A}$, $\mathbf{B}$, η	Pump params	
$\mathbf{n_n}$, $\mathbf{Q_n}$	Nominal	
$Q_{in}(t)$, $Q_{out}(t)$	I/O flow	$[m^3/s]$
$H(t)$	Head	[m]
$n(t)$	Speed	[rad/s]
$P_h(t)$, $P_e(t)$	Power	[W]

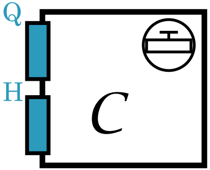
Port	Var
Q_{in}, Q_{out}	$Q_{in}(t)$, $Q_{out}(t)$
H	$H(t)$
P	$P_e(t)$

Equations (etc.)

$$Q_{in}^{[k]} = -Q_{out}^{[k]}$$

$$H^{[k]} = \frac{n^{2\,[k]}}{n_n^2} \cdot A + B \cdot {Q_{out}^2}^{[k]}$$

Pipe



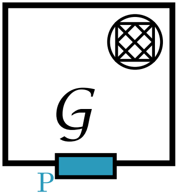
Var	Desc.	Units
$\mathbf{H_0}$	Height	[m]
$\mathbf{K}$	Losses cf.	
$\mathbf{Q_{max}}$	Max. flow	[m^3/s]
$Q(t)$	Flow	[m^3/s]
$H(t)$	Head	[m]

Port	Var
Q	$Q(t)$
H	$H(t)$

Equations (etc.)

$$H^{[k]} = H_0 + K \cdot Q^{2[k]}$$

Grid



Var	Desc.	Units
$\mathbf{P_{max}}$	Max power	[W]
$P(t)$	Power	[W]

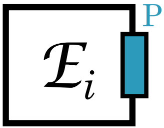
Port	Var
P	$P(t)$

Equations:

No constraints defined

Example 1

Hub[1]



Var	Desc.	Units
$P_{bal(t)}$	Power balance	[W]

Port	Var
P	$P_{bal}(t)$

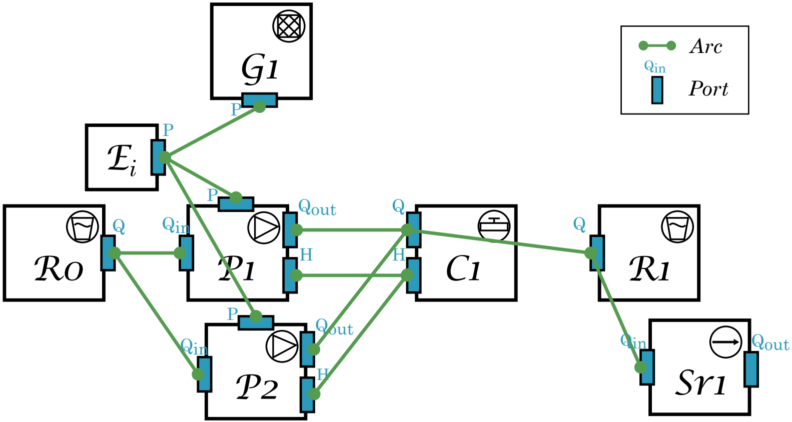
Equations:

$$P_{bal}^{[k]} = 0$$

[1] *E* for *Estació de Bombeig* (Pumping Station) in catalan. It is meant to be a *Node* block to define a power balance (i.e.: sum of powers equal to 0)

Example 1

Connect *Blocks*' *Ports* with *Arcs*



Create the *Blocks*

```
# ===== Create the system =====
m.Reservoir1 = pyo.Block()
m.Reservoir0 = pyo.Block()
m.Irrigation1 = pyo.Block()
m.Pump1 = pyo.Block()
m.Pump2 = pyo.Block()
m.Pipe1 = pyo.Block()
m.Grid = pyo.Block()
m.EB = pyo.Block()
```

```
data_irr = {'Q':[2,1,1,1,1]} # irrigation
Source(m.Irrigation1, m.t, data_irr, None)

data_res = {'W0':5, 'Wmin':0, 'Wmax':20} # reservoirs (both equal)
init_res = {'Q':[0,0,0,0,0], 'W':[5,5,5,5,5]}
Reservoir_Ex0(m.Reservoir1, m.t, data_res, init_res)
Reservoir_Ex0(m.Reservoir0, m.t, data_res, init_res)

data_c1 = {'H0':20, 'K':0.05, 'Qmax':50} # canal
init_c1 = {'Q':[0,0,0,0,0], 'H':[20,20,20,20,20]}
Pipe_Ex0(m.Pipe1, m.t, data_c1, init_c1)

data_p = {'A':50, 'B':0.1, 'n_n':1450, 'eff':0.9, 'Qmax':20, 'Qnom':5, 'Pmax':9810*50*20} # pumps (both equal)
init_p = {'Q':[0,0,0,0,0], 'H':[20,20,20,20,20], 'n':[1450,1450,1450,1450,1450], 'Pe'
        :[9810*5*20,9810*5*20,9810*5*20,9810*5*20,9810*5*20]}
Pump(m.Pump1, m.t, data_p, init_p)
Pump(m.Pump2, m.t, data_p, init_p)

Grid(m.Grid, m.t, {'Pmax':100e3}, None) # grid
EB(m.EB, m.t, None, None) # node
```

Example 1

Create the *Arcs*

```
# Connections
m.p1r0 = Arc(ports=(m.Pump1.port_Qin, m.Reservoir0.port_Q), directed=True)
m.p1c1_Q = Arc(ports=(m.Pump1.port_Qout, m.Pipe1.port_Q), directed=True)
m.p1c1_H = Arc(ports=(m.Pump1.port_H, m.Pipe1.port_H), directed=True)
m.p2r0 = Arc(ports=(m.Pump2.port_Qin, m.Reservoir0.port_Q), directed=True)
m.p2c1_Q = Arc(ports=(m.Pump2.port_Qout, m.Pipe1.port_Q), directed=True)
m.p2c1_H = Arc(ports=(m.Pump2.port_H, m.Pipe1.port_H), directed=True)
m.c1r1 = Arc(ports=(m.Pipe1.port_Q, m.Reservoir1.port_Q), directed=True)
m.r1i1 = Arc(ports=(m.Irrigation1.port_Qin, m.Reservoir1.port_Q), directed=True)
m.EBp1 = Arc(ports=(m.Pump1.port_P, m.EB.port_P), directed=True)
m.EBp2 = Arc(ports=(m.Pump2.port_P, m.EB.port_P), directed=True)
m.EBgrid = Arc(ports=(m.Grid.port_P, m.EB.port_P), directed=True)

pyo.TransformationFactory("network.expand_arcs").apply_to(m) # apply arcs to model
```

Example 1

Run the optimization[2] $cost = [10, 5, 1, 5, 10]$

```
#%% RUN THE OPTIMIZATION

# Objective function
def obj_fun(m):
    return sum(-m.Grid.P[t]*m.cost[t] for t in l_t)
m.goal = pyo.Objective(rule=obj_fun, sense=pyo.minimize)

instance = m.create_instance()
solver = pyo.SolverFactory('ipopt')
solver.solve(instance, tee=False)
```

Results

```
# P : Size=5, Index=t
#     Key : Lower     : Value                 : Upper    : Fixed : Stale : Domain
#       0 : -100000.0 :  9.317168734737 75e-09 : 100000.0 : False : False :  Reals
#       1 : -100000.0 :    -59037.07788285201 : 100000.0 : False : False :  Reals
#       2 : -100000.0 :             -100000.0 : 100000.0 : False : False :  Reals
#       3 : -100000.0 :   -59037.077882781225 : 100000.0 : False : False :  Reals
#       4 : -100000.0 : 9.317168818435555e-09 : 100000.0 : False : False :  Reals
```

[2]Notice that $P < 0$ implies power injected and $P > 0$ power consumed by an element. E.g.: Negative grid power means power consumed from the grid

Example 2

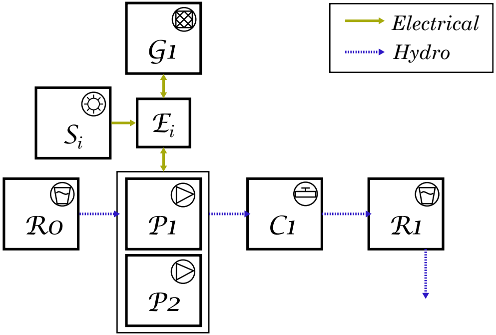
EXAMPLE 2

Add a solar PV plant to Example 1

Optimization:

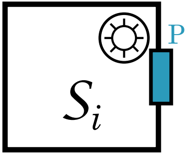
$$\min \sum_{k=0}^{k=T} \left[P_{buy,grid}(k) \cdot C_{buy}(k) - P_{sell,grid}(k) \cdot C_{sell}(k) \right] \Delta k + P_{inst,PV} \cdot C_{newPV}$$

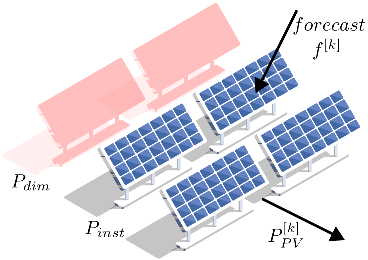
with: $C_{buy} = [10, 5, 1, 5, 10]$, $C_{sell} = \frac{C_{buy}}{2}$ and $C_{newPV} = 10$



Example 2

Solar PV plant





Var	Desc.	Units
$\mathbf{P_{inst}}$	Installed power	[W]
$\mathbf{P_{max}}$	Max available power	[W]
$\mathbf{f(t)}$	Forecast	[p.u.]
$P(t)$	Power	[W]
$P_{dim}(t)$	Dimensioned power[a]	[W]

Port	Var
P	$P(t)$

Equations

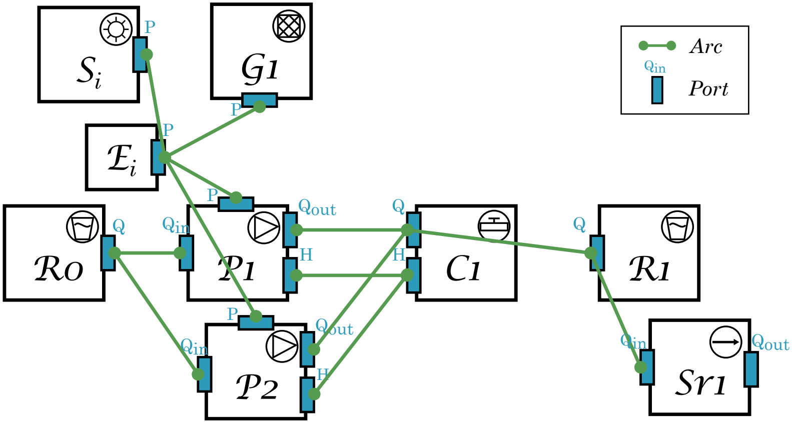
$$P_{max} \geq P_{inst} + P_{dim}$$

$$P^{[k]} \geq -(P_{inst} + P_{dim}) \cdot f^{[k]}$$

[a] Refers to new power to install

Example 2

Connect *Blocks*' *Ports* with *Arcs*



Create the *Blocks*

```
data_res = {'W0':5, 'Wmin':0, 'Wmax':20} # reservoirs (both equal)
init_res = {'Q':[0,0,0,0,0], 'W':[5,5,5,5,5]}
Reservoir_Ex0(m.Reservoir1, m.t, data_res, init_res)
Reservoir_Ex0(m.Reservoir0, m.t, data_res, init_res)

data_c1 = {'H0':20, 'K':0.05, 'Qmax':50} # canal
init_c1 = {'Q':[0,0,0,0,0], 'H':[20,20,20,20,20]}
Pipe_Ex0(m.Pipe1, m.t, data_c1, init_c1)

data_p = {'A':50, 'B':0.1, 'n_n':1450, 'eff':0.9, 'Qmax':20, 'Qnom':5, 'Pmax':9810*50*20} # pumps (both equal)
init_p = {'Q':[0,0,0,0,0], 'H':[20,20,20,20,20], 'n':[1450,1450,1450,1450,1450], 'Pe'
       :[9810*5*20,9810*5*20,9810*5*20,9810*5*20,9810*5*20]}
Pump(m.Pump1, m.t, data_p, init_p)
Pump(m.Pump2, m.t, data_p, init_p)

data_pv = {'Pinst':50e3, 'Pmax':100e3, 'forecast':[0.0,0.2,0.8,1.0,0.1]} # PV
SolarPV(m.PV, m.t, data_pv)

Grid(m.Grid, m.t, {'Pmax':100e3}) # grid

EB(m.EB, m.t)
```

Create the *Arcs*

```
# Connections
m.p1r0 = Arc(ports=(m.Pump1.port_Qin, m.Reservoir0.port_Q), directed=True)
m.p1c1_Q = Arc(ports=(m.Pump1.port_Qout, m.Pipe1.port_Q), directed=True)
m.p1c1_H = Arc(ports=(m.Pump1.port_H, m.Pipe1.port_H), directed=True)
m.p2r0 = Arc(ports=(m.Pump2.port_Qin, m.Reservoir0.port_Q), directed=True)
m.p2c1_Q = Arc(ports=(m.Pump2.port_Qout, m.Pipe1.port_Q), directed=True)
m.p2c1_H = Arc(ports=(m.Pump2.port_H, m.Pipe1.port_H), directed=True)
m.c1r1 = Arc(ports=(m.Pipe1.port_Q, m.Reservoir1.port_Q), directed=True)
m.r1i1 = Arc(ports=(m.Irrigation1.port_Qin, m.Reservoir1.port_Q), directed=True)
m.ebp1 = Arc(ports=(m.Pump1.port_P, m.EB.port_P), directed=True)
m.ebp2 = Arc(ports=(m.Pump2.port_P, m.EB.port_P), directed=True)
m.grideb = Arc(ports=(m.Grid.port_P, m.EB.port_P), directed=True)
m.pveb = Arc(ports=(m.PV.port_P, m.EB.port_P), directed=True)

pyo.TransformationFactory("network.expand_arcs").apply_to(m) # apply arcs to model
```

Run the optimization

```
#%% RUN THE OPTIMIZATION

# Objective function
def obj_fun(m):
    return sum((m.Grid.Pbuy[t]*m.cost[t] - m.Grid.Psell[t]*m.cost[t]/2) for t in l_t ) + m.PV.Pdim*cost_new_pv
m.goal = pyo.Objective(rule=obj_fun, sense=pyo.minimize)

instance = m.create_instance()
solver = pyo.SolverFactory('ipopt')
solver.solve(instance, tee=False)
```

Example 2

Results

```
instance.Reservoir1.W.pprint()
instance.Reservoir0.W.pprint()
instance.Grid.P.pprint()
instance.PV.Pdim.pprint()

# RESULTS
    # W : Size=5, Index=t
    #     Key : Lower : Value              : Upper : Fixed : Stale : Domain
    #       0 :     0 : 3.0000000000000004 :    20 : False : False : NonNegativeReals
    #       1 :     0 :  2.051624535242702 :    20 : False : False : NonNegativeReals
    #       2 :     0 : 1.7161061718196515 :    20 : False : False : NonNegativeReals
    #       3 :     0 : 0.9741875933941936 :    20 : False : False : NonNegativeReals
    #       4 :     0 :                0.0 :    20 : False : False : NonNegativeReals
    # W : Size=5, Index=t
    #     Key : Lower : Value             : Upper : Fixed : Stale : Domain
    #       0 :     0 : 4.999999999999999 :    20 : False : False : NonNegativeReals
    #       1 :     0 : 4.948375464757298 :    20 : False : False : NonNegativeReals
    #       2 :     0 : 4.283893828180348 :    20 : False : False : NonNegativeReals
    #       3 :     0 : 4.025812406605806 :    20 : False : False : NonNegativeReals
    #       4 :     0 : 4.000000009999997 :    20 : False : False : NonNegativeReals
    # P : Size=5, Index=t
    #     Key : Lower     : Value                  : Upper    : Fixed : Stale : Domain
    #       0 : -100000.0 :  9.444173782089441e-09 : 100000.0 : False : False :  Reals
    #       1 : -100000.0 : -8.895566856661031e-09 : 100000.0 : False : False :  Reals
    #       2 : -100000.0 :              -100000.0 : 100000.0 : False : False :  Reals
    #       3 : -100000.0 : -8.894453079458348e-09 : 100000.0 : False : False :  Reals
    #       4 : -100000.0 :  9.520949369890758e-09 : 100000.0 : False : False :  Reals
    # Pdim : Size=1, Index=None
    #     Key  : Lower : Value             : Upper   : Fixed : Stale : Domain
    #     None :     0 : 6271.117831362812 : 50000.0 : False : False : NonNegativeReals
```

AGISTIN T4.6 Usage examples of the tool

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