New Software Stack for Power Systems Modeling, Optimization, and Analysis

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FERC Technical Conference

to Increase Real-Time and Day-Ahead Market Efficiency Through Improved Software

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Contents

My Goal for the talk is have a few of you clone, fork the OS packages

Overview

Reliability and Efficiency Demands
Good Computational Software

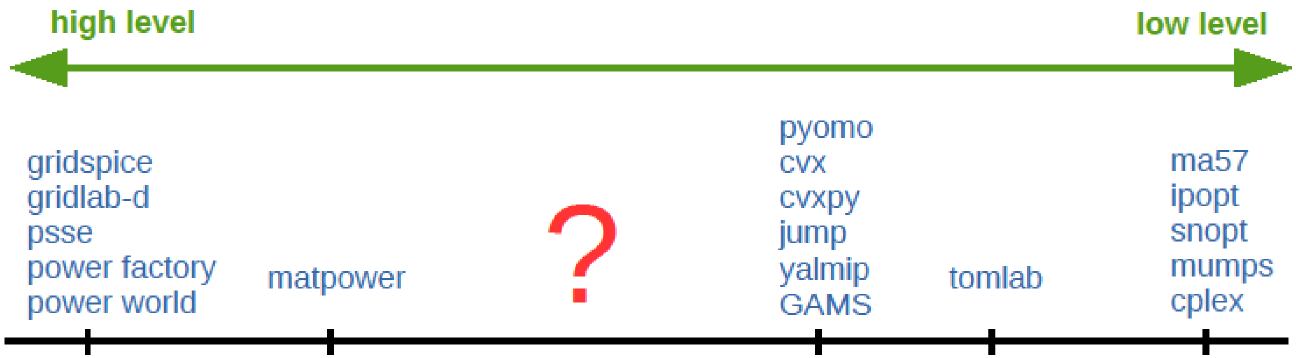
- There are good power system software applications

  → but can be difficult to modify and extend

- There are good optimization software packages

  → but can be difficult to apply for specific fields

Software Spectrum



- **Goals of new software stack**
  - Power system approachable
  - Open platform for sharing and testing new optimization ideas
  - Not just for toy cases (e.g., readily handles 60k+ bus cases)
  - Avoid repeated efforts
  - Fill gap in spectrum
  - Speed up time from research idea to industry applications

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History and Contributors

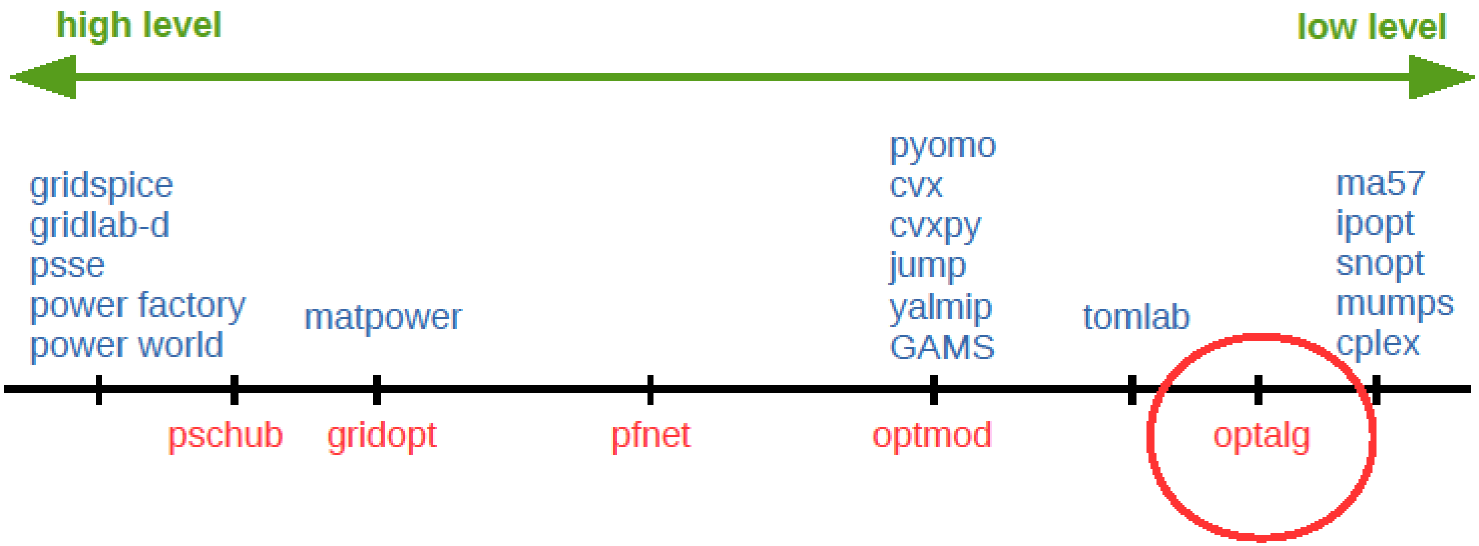
- Tomas Tinoco de Rubira (ETH Zurich)
  - Began software stack as a hobby
    - (the mastermind behind it)
  - Some algorithms based on PhD work at Stanford and EPRI

- Contributors
  - Martin Baltzinger (ETH)
  - Robert Entriken (EPRI)
  - Nick Henderson (EPRI, formerly)
  - Stavros Karagiannopoulos (ETH)
  - Dmitry Shchetinin (ETH)
  - Adam Wigington (EPRI)
  - Martin Zellner (ETH)

Open Source Software Stack

OPTALG Package

- Optimization solvers and interfaces to external solvers



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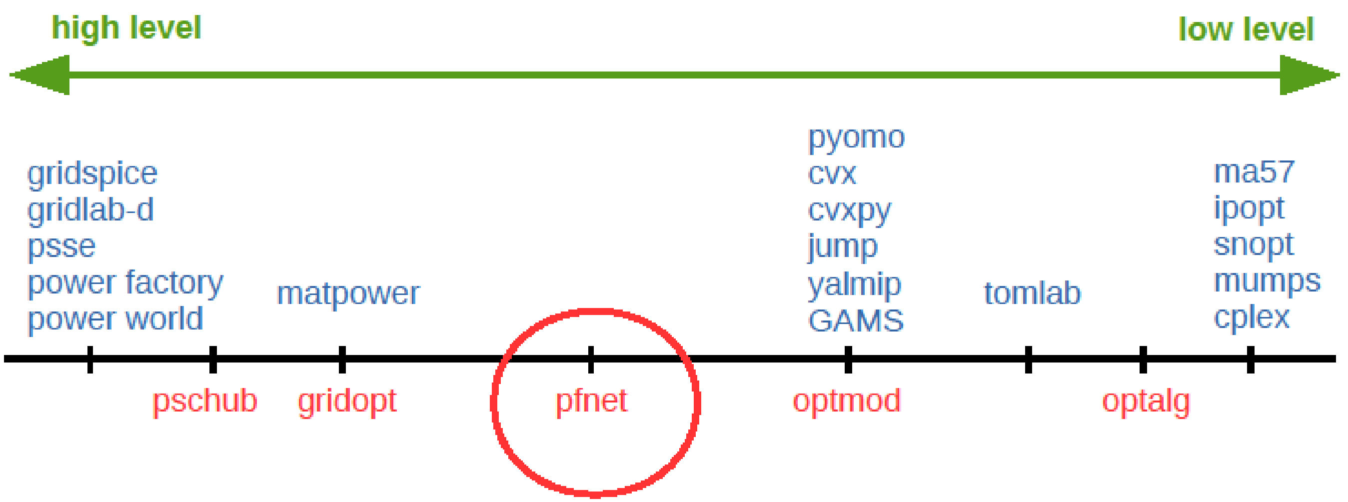
OPTALG Package

- Pure Python
- Optimization Algorithms:
  - Newton-Raphson
  - Interior-Point Quadratic Program
  - Augmented Lagrangian
- Interfaces:
  - IPOPT (interior-point nonlinear)
  - CLP (linear programming)
  - CBC (mixed-integer)
- Linear solver interfaces:
  - SuperLU (scipy)
  - mumps
- General form:

$$
\begin{array}{lll}
\text{minimize} & \varphi(x) & \\
\text{subject to} & Ax = b & : \lambda \\
 & f(x) = 0. & : \nu \\
 & l \leq x \leq u & : \pi, \mu \\
 & Px \in \{0,1\}^m, &
\end{array}
$$

PFNET Package

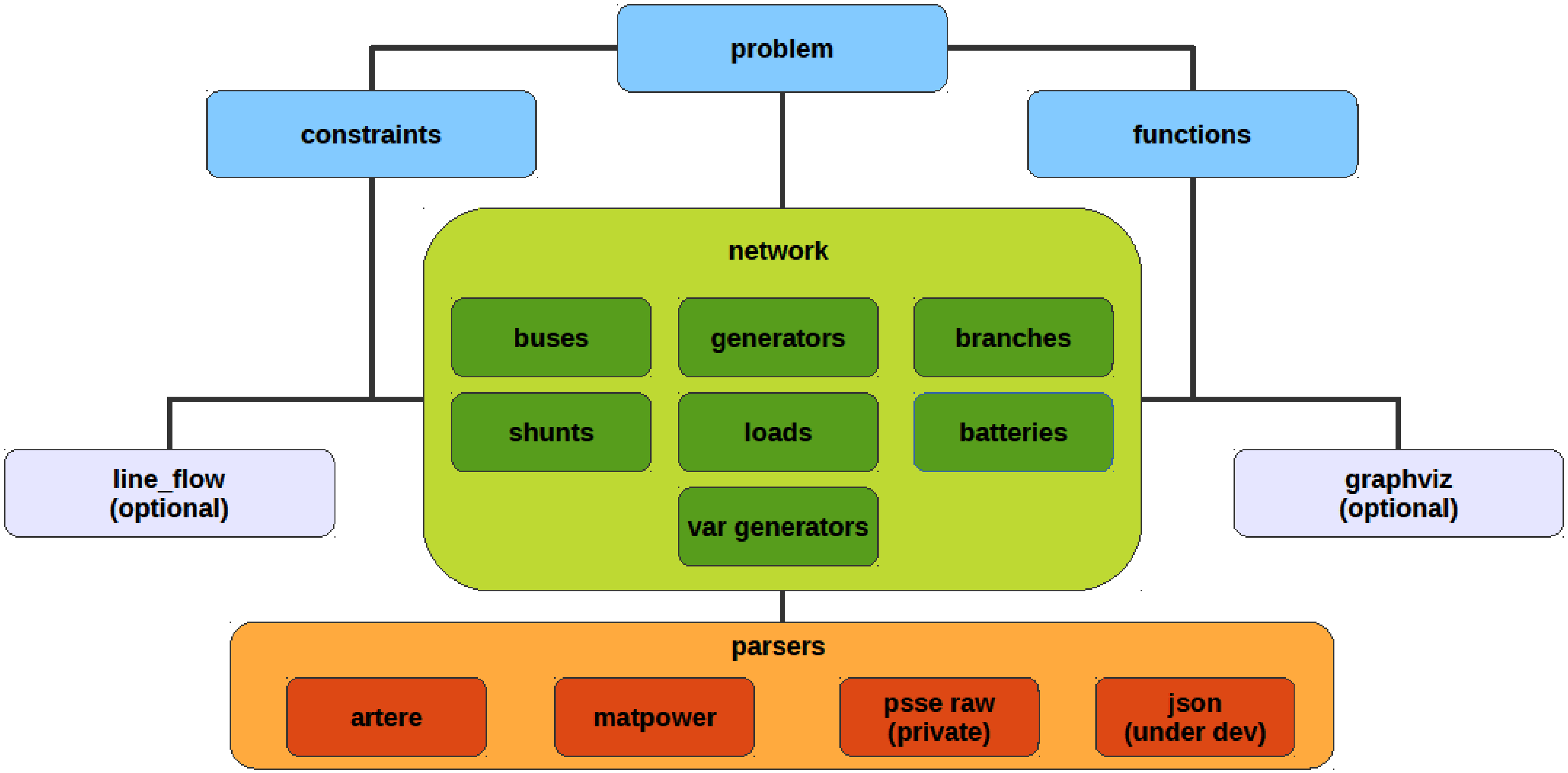
- Link between power system modeling and optimization problem formulation



PFNET Package

- C for numerical efficiency
  - Python wrapper
- Parsers
- Construct problems
  - (Problems get passed to solvers OPTALG)
  - Consists of
    - Variables
      - E.g., bus voltage mag, bus voltage angles, gen mvar powers
    - Objective function components (11 built-in)
      - E.g., generation cost, voltage mag regularization, tap regularization
    - Constraints (16 built-in)
      - E.g., AC power balance, gen mw participation, gen voltage regularization
  - Extensible, define your own!

PFNET Architecture



PFNET Example – Simple Newton-Raphson Solver

```python
def NRsolve(net):

    net.clear_flags()

    # bus voltage angles
    net.set_flags('bus',
                  'variable',
                  'not slack',
                  'voltage angle')

    # bus voltage magnitudes
    net.set_flags('bus',
                  'variable',
                  'not regulated by generator',
                  'voltage magnitude')

    # slack gens active powers
    net.set_flags('generator',
                  'variable',
                  'slack',
                  'active power')

    # regulator gens reactive powers
    net.set_flags('generator',
                  'variable',
                  'regulator',
                  'reactive power')

    p = pfnet.Problem(net)
    p.add_constraint(pfnet.Constraint('AC power balance',net))
    p.add_constraint(pfnet.Constraint('generator active power participation',net))
    p.add_constraint(pfnet.Constraint('generator reactive power participation',net))
    p.analyze()

    x = p.get_init_point()
    p.eval(x)

    residual = lambda x: hstack((p.A*x-p.b,p.f))

    while norm(residual(x)) > 1e-4:
        x = x + spsolve(bmat([[p.A],[p.J]],format='csr'),-residual(x))
        p.eval(x)

    net.set_var_values(x)
    net.update_properties()
```

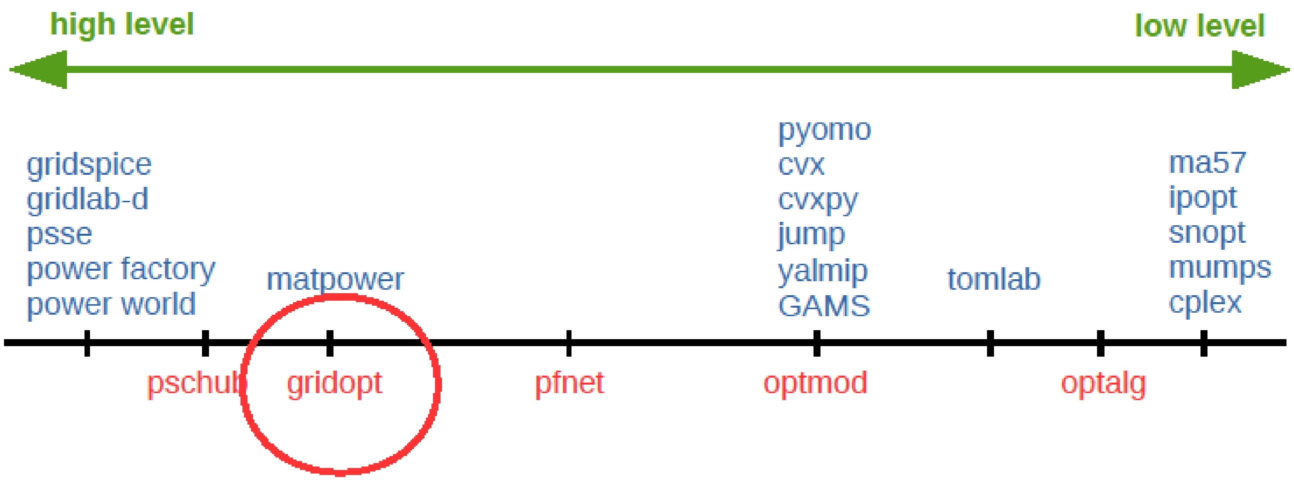
Define variables

Add constraints

Calculations

GRIDOPT Package

- Link between PFNET and OPTALG with ready built power flow and optimal power flow implementations



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GRIDOPT Package

- Pure Python

- Convenient methods
  - Formulate problems with PFNET
  - Solve with OPTALG

- Power flows
  - DC
  - Newton-Raphson w/ heuristics
  - Augmented Lagrangian

- Optimal power flows
  - DCOPF
  - Augmented Lagrangian
  - IPOPT wrapper

```
>>> import pfnet
>>> import gridopt

>>> net = pfnet.ParserMAT().parse('ieee14.mat')

>>> # max mismatches (MW,MVAr)
>>> print '%.2e %.2e' %(net.bus_P_mis,net.bus_Q_mis)
3.54e-01 4.22e+00

>>> method = gridopt.power_flow.new_method('NRPF')

>>> method.set_parameters({'quiet': True})

>>> method.solve(net)

>>> results = method.get_results()

>>> print results['status']
solved
```

Augmented Lagrangian Method

- Robust to ill-conditioned Jacobians

- Complementarity constraints instead of heuristics for PV-PQ switching

- If it does not solve PF equations, it still converges to a minimum and will provide sensitivities that can help

- General form

$$
\begin{array}{lll}
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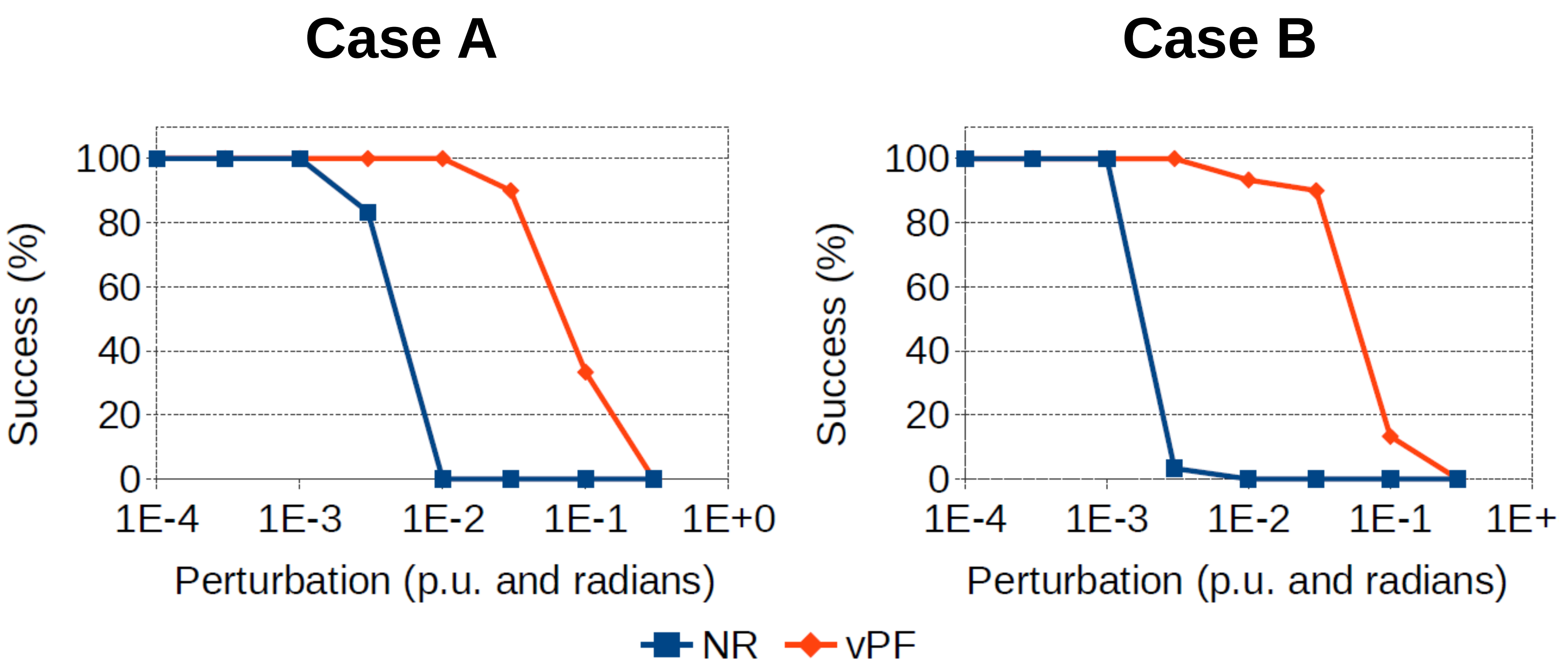
Augmented Lagrangian Method



Random perturbations of starting point for all variables

Early version of Augmented Lagrangian (vPF) more robust to poor starting points

EPRI Extensions

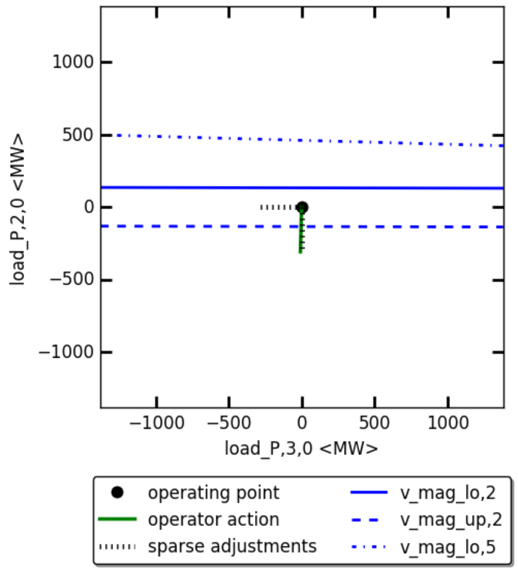
EPRI Extensions to Software Stack

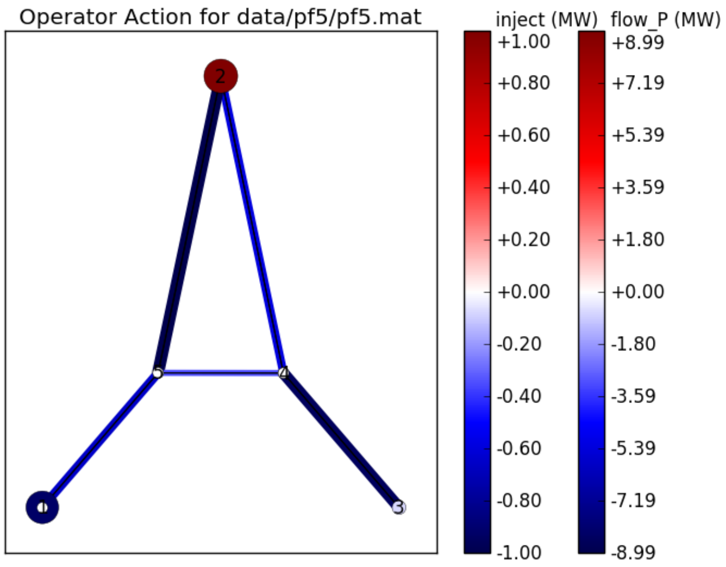
- Practical tools
  - Tracking, naming cases
  - Comparison of networks and results
- Contingency analysis
- Critical operating boundaries
- New Functions and Constraints
  - Interface flows
  - Minimize losses*
  - Voltage control areas*

*TODO

Contribute back to OS tools when appropriate (eg. modeling limitations)

Critical Operating Boundaries





Identify voltage and thermal limits of most concern 1D or 2D Recommended Actions

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Getting Started

How to Get Started

- Clone, fork the OS repositories
  - PFNET https://github.com/ttinoco/PFNET
  - OPTALG https://github.com/ttinoco/OPTALG
  - GRIDOPT https://github.com/ttinoco/GRIDOPT
- PFNET building and installing
  - Builds using Autotools for Unix-like system
  - Cmake builds for Windows (tested using mingw) *coming soon*
- Python is easy
  - pypi *coming soon*
- *To come – Unit Commitment, Json file format, ???*

- **or just clone PSCHUB https://github.com/ttinoco/PSCHUB**
  - **JupyterHub docker containe**r

Become a Contributor!

Become a Contributor to the OS Stack

- Find bugs
- Improve documentation
- Add modeling capability
  - E.g., Power flow controllers
- Create new Parsers
- Create new Functions
- Create new Constraints
- Add wrappers to other solvers
- ...

Become a Contributor!

Together…Shaping the Future of Electricity

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