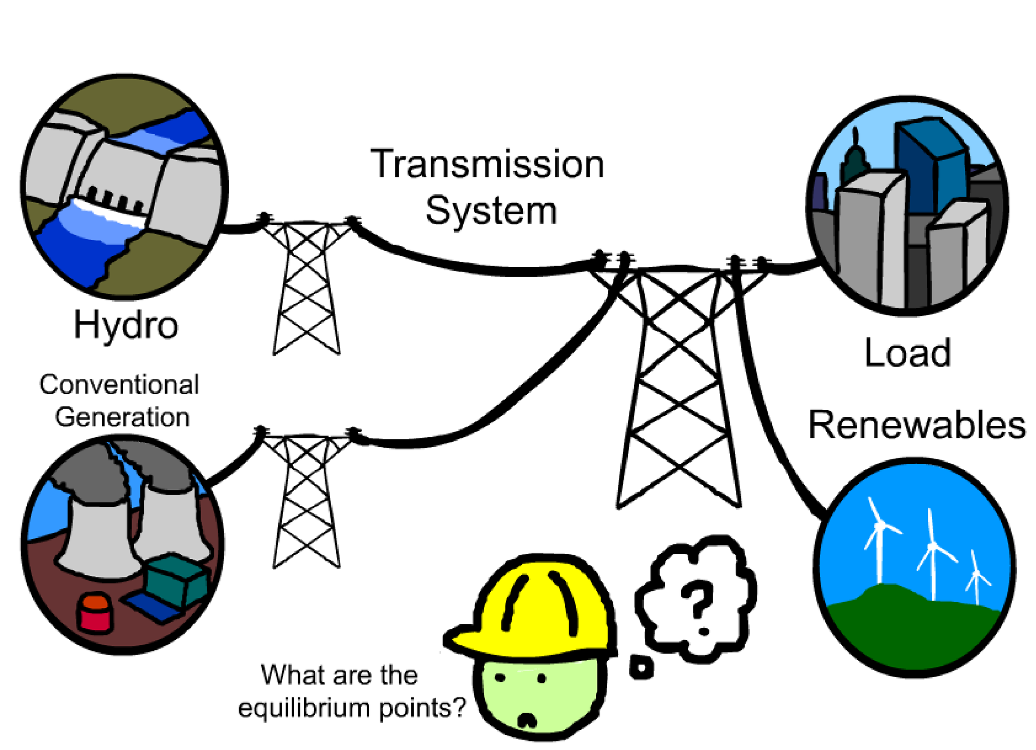
A Distributed Modeling, Computing and Communications Framework for Power Flow and Equilibria Calculation in Future Energy Grids

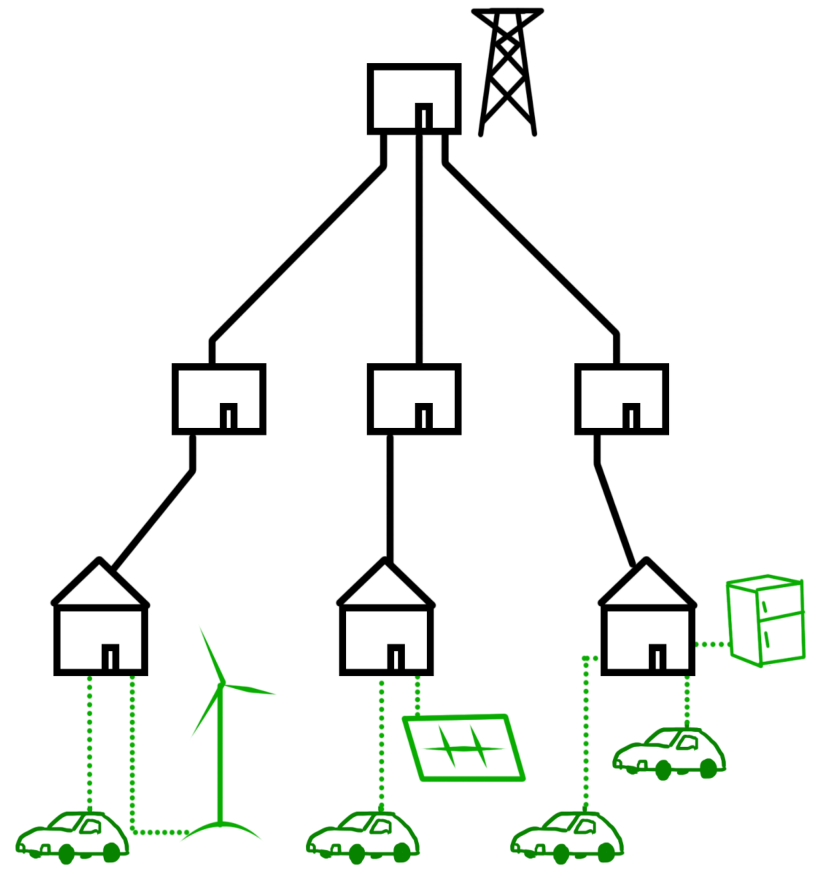
Andrew Hsu and Marija Ilić

Motivation

- Current SCADA: state estimation and power flow to verify topology
- Uses for power flow calculation
  - Congestion monitoring
- Towards plug-and-play smart grids framework
- Dealing with many small and varying participants
- Mathematical method inspired by distributed optimization method for transportation networks
- We extend this to electric energy power flow

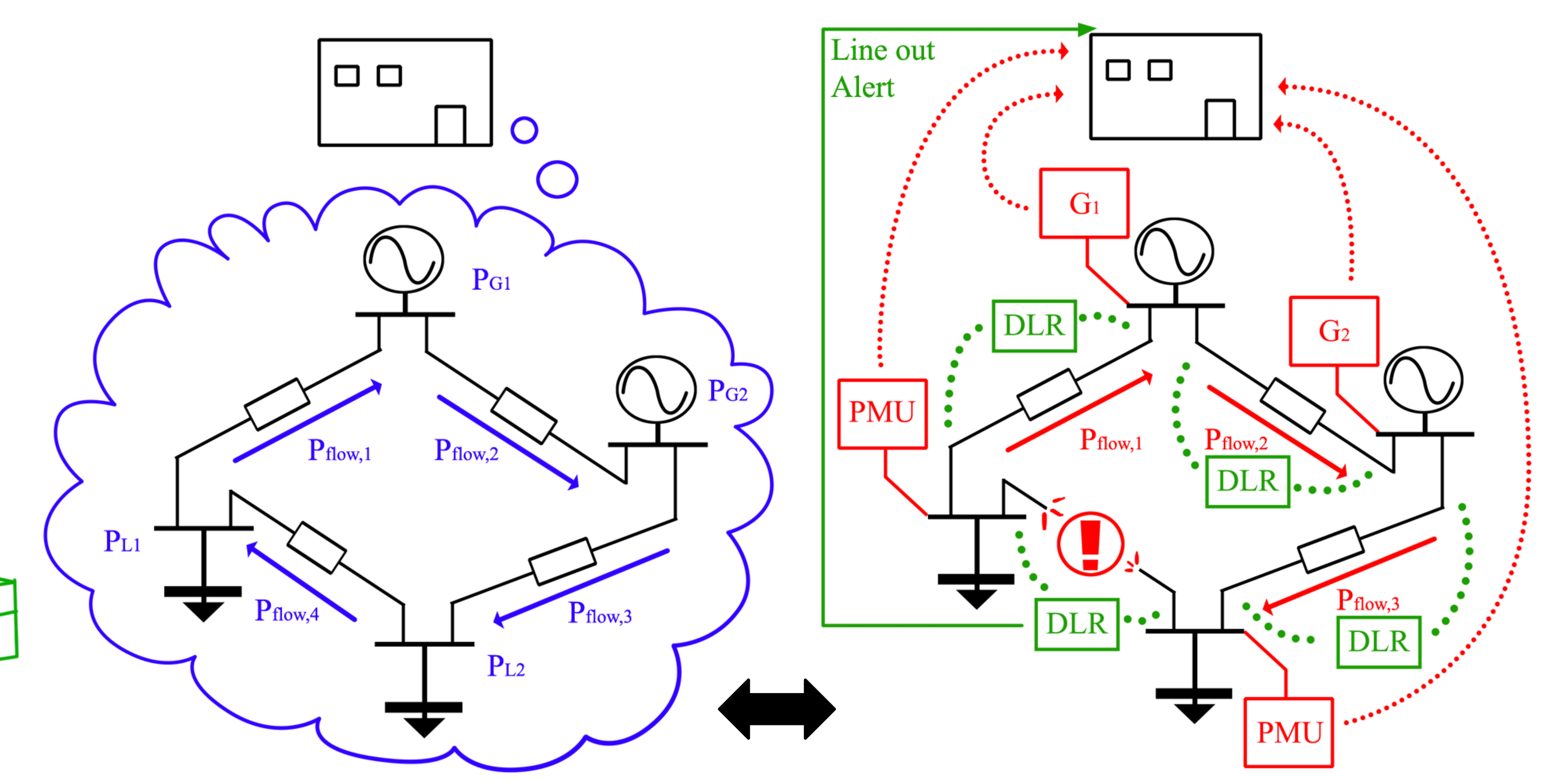
Future Power Systems





How do we deal with addition of renewable and future energy system components that add complexity to the grid.

Proposed Framework



Proposed framework for designing smart devices for local components is to complement existing methods.

Problem Posing

Equations describing the system's components

- For component on node i:
  - $\dot{z}_i = f_i(z_i, u_i, \rho_i) = 0$ Internal dynamics
  - $b_i = g_i(z_i, u_i, \rho_i)$ Flow to rest of system
  - $y_i = y_i(z_i, u_i, \rho_i, x_i)$ Physical Network Variables (potential differences)
- For a branch connecting nodes i and j:
  - $x_e = h_e(y_i, y_j, \rho_e)$ where line e connects nodes i, j

x = line flows, u = inputs, ρ = parameters

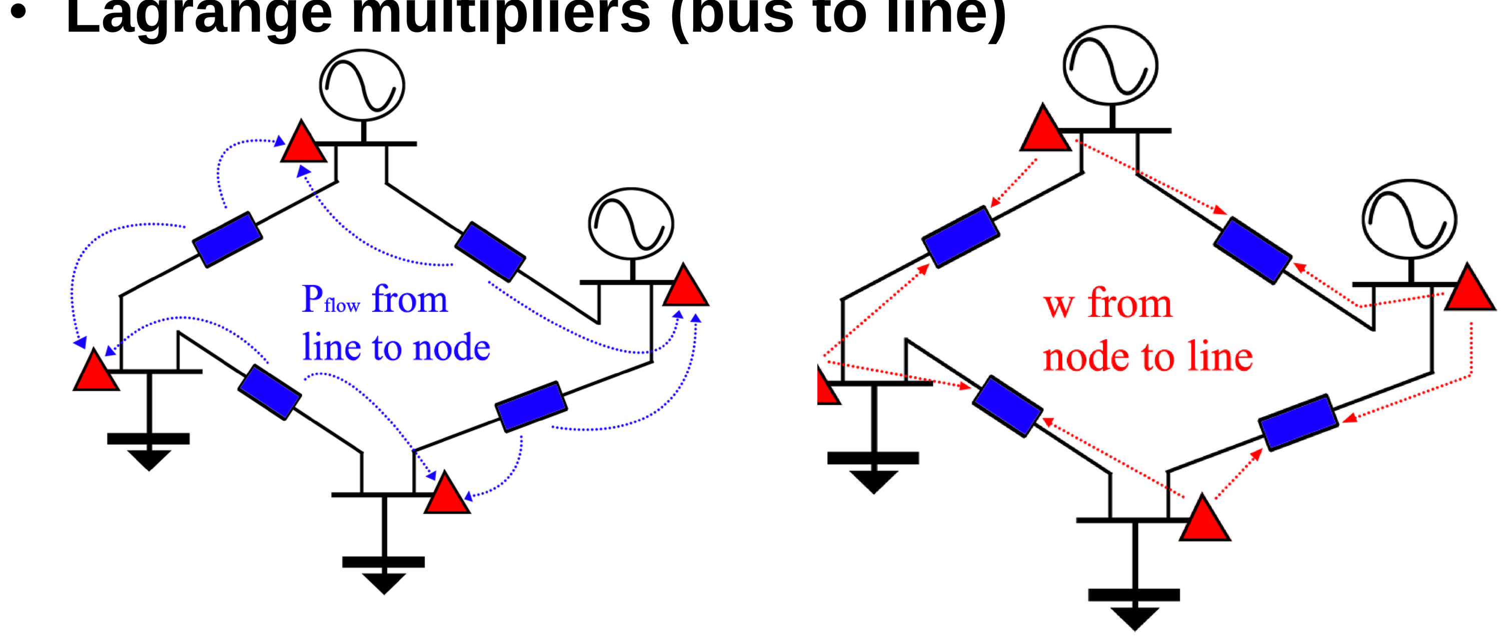
Introduce new objective function

- $\min_{x_f} F(x_f) = \Sigma_e (x_{f,e} - x_{phys,e})^2$
  s.t. $Ax_f = b$
  (Can be solved with distributed optimization method, e.g. distributed Newton method)
- To comply with physical laws:
  - $x_{phys,e} = h_e(y_i, y_j, \rho_e)$ where line e connects nodes i, j
  - $0 = f_i(z_i, u_i, \rho_i)$ Internal dynamics
  - $b_i = g_i(z_i, u_i, \rho_i)$ Flow to rest of system
  - $y_i = y_i(z_i, u_i, \rho_i, x_i)$ Physical Network Variables

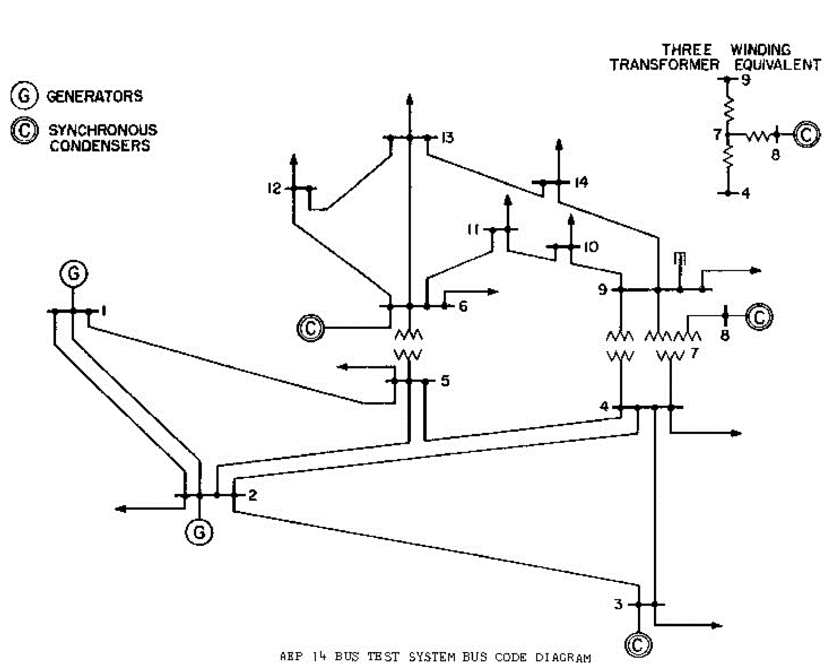
  (To be solved in local iteration steps)

Newton method based iterative method determines which variables to exchange per iteration

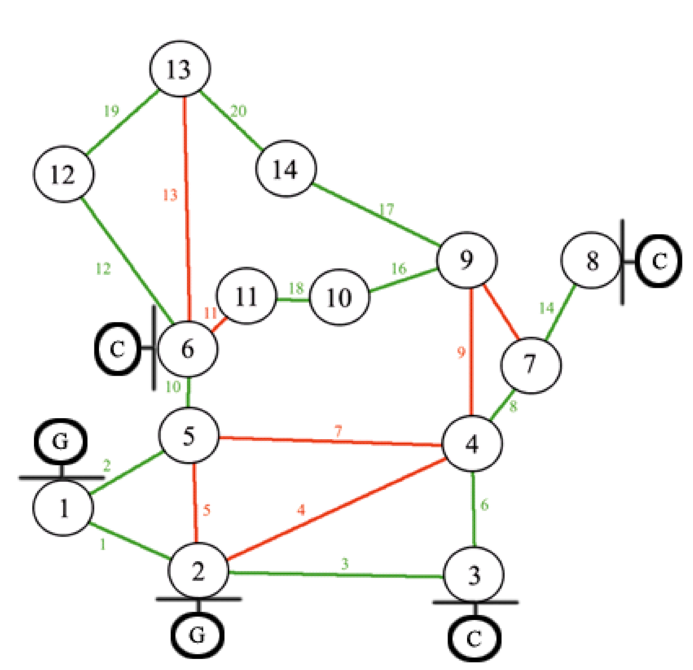
- Flow variable (line to bus)
- Lagrange multipliers (bus to line)



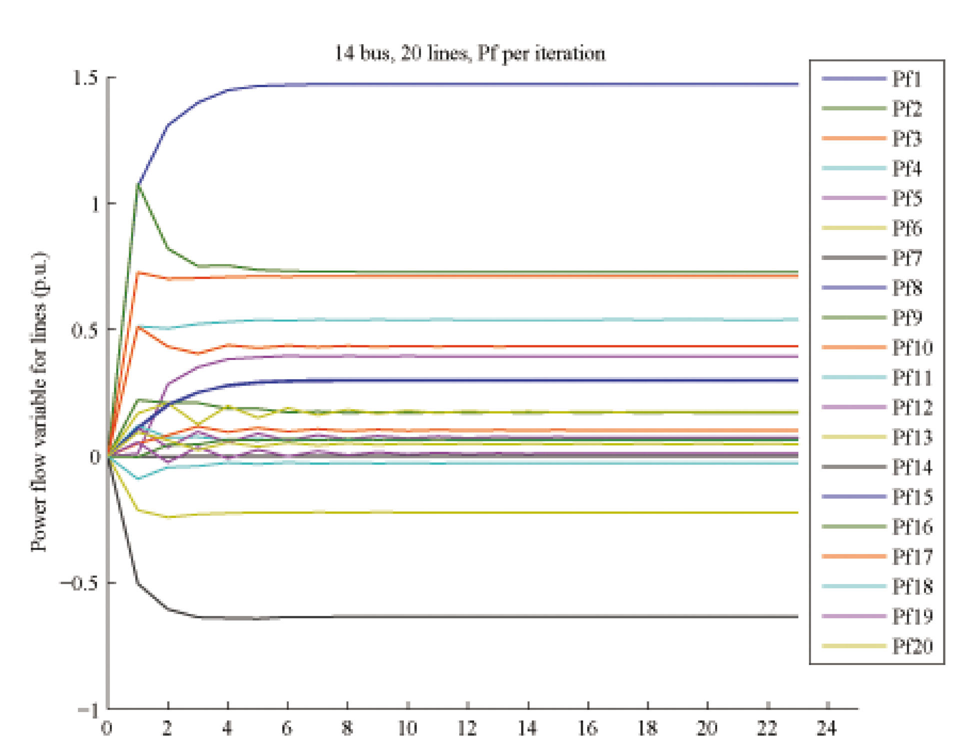
Example : IEEE 14 bus



14 bus example



14 bus example graphical representation



Convergence of distributed method on the 14 bus system took 23 iterations, and 11 iterations using Matlab's fsolve (centralized). Convergence tolerance: 0.001 p.u. Max. Deviation: 0.0184 p.u./3%

Table VII
P_f SOLUTIONS OF IEEE 14 BUS SYSTEM

Centralized vs. Distributed Solution		
Line No.	P_f Centr.	P_f Distr.
1	1.4889	1.4705
2	0.7408	0.7285
3	0.7246	0.7115
4	0.5467	0.5395
5	0.4047	0.3957
6	-.2285	-.2217
7	-0.6260	-0.6331
8	0.2907	0.3031
9	0.1666	0.1727
10	0.4196	0.4349
11	0.0634	0.0650
12	0.0732	0.0752
13	0.1728	0.1752
14	0.0000	0.0014
15	0.2907	0.2975
16	0.0619	0.0658
17	0.1014	0.1028
18	-0.0281	-0.0272
19	0.0119	0.0116
20	0.0487	0.0482

Discussion And Future Work

- Proof of concept example for distributed power flow shown
- Explore information exchange framework to support algorithm and potential uses
- Future work will take into account uncertainty in data and/or measurements
- Proof of convergence, range of initial conditions, and other numerical considerations to be examined

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