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Electric Energy Systems Group

Electrical & Computer Engineering

# A Proposed Framework For A Simple Information Exchange Standard Protocol For Distributed State Estimation

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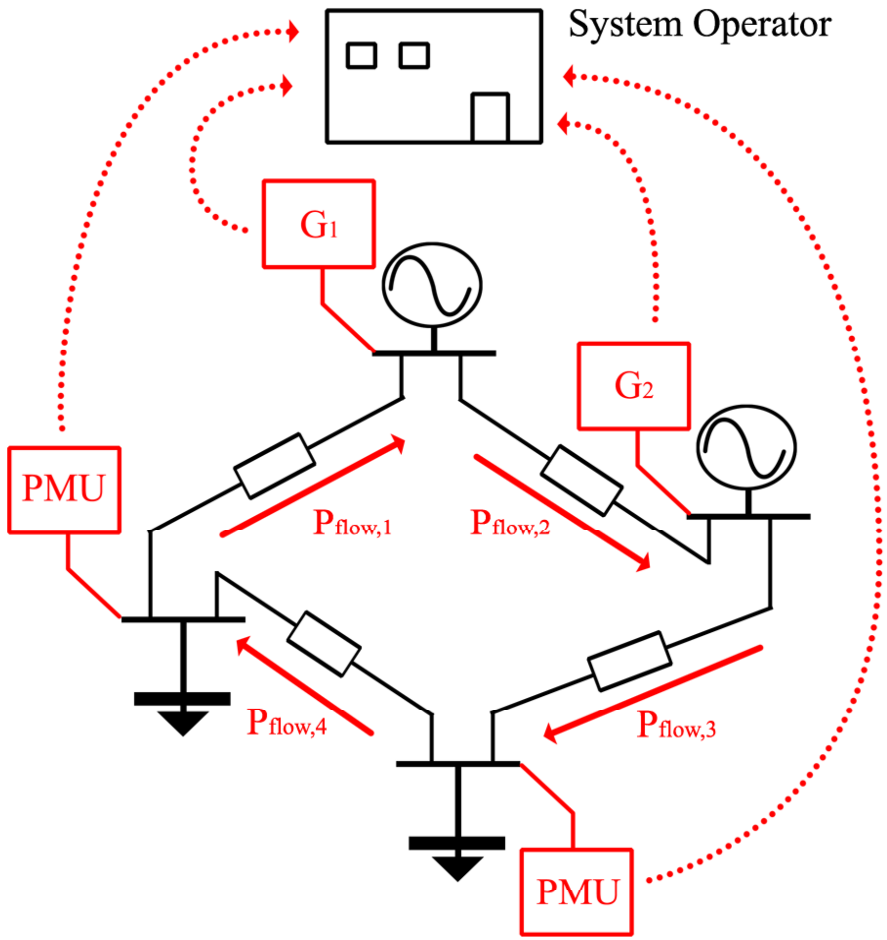
Carnegie Mellon University

# Outline

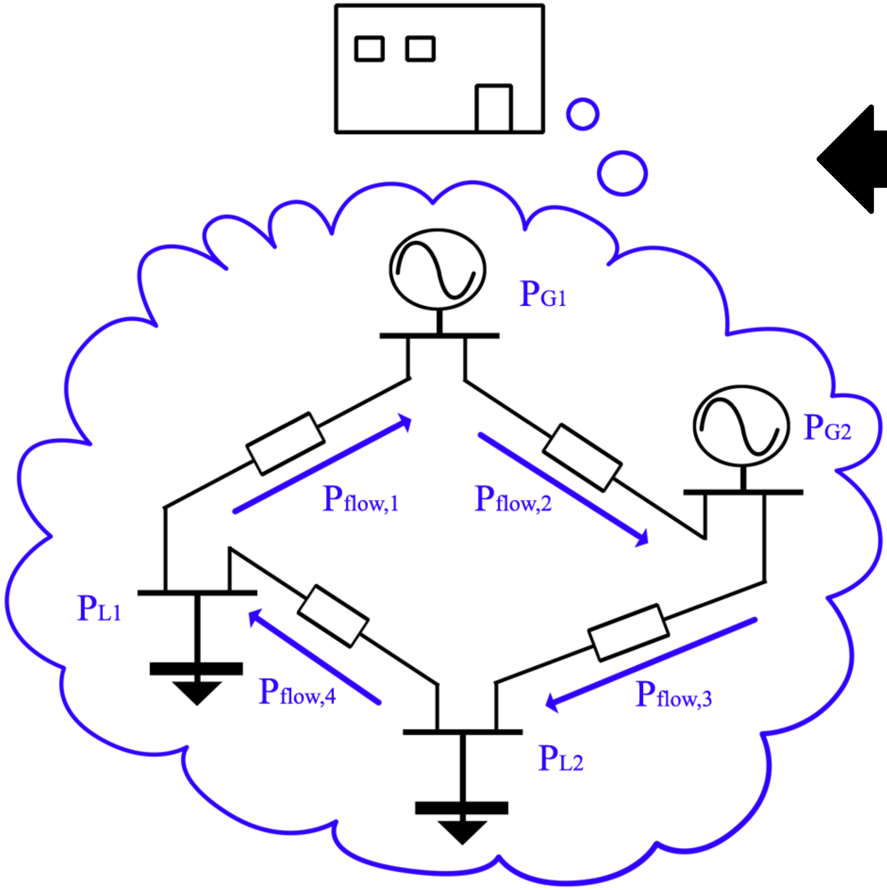
- Current SCADA: state estimation and power flow to verify topology
- Uses for power flow calculation
  - Congestion monitoring
- Towards plug-and-play smart grids framework
  - Dealing with many small and varying participants
- Mathematical method inspired by distributed optimization method for transportation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

# Current SCADA

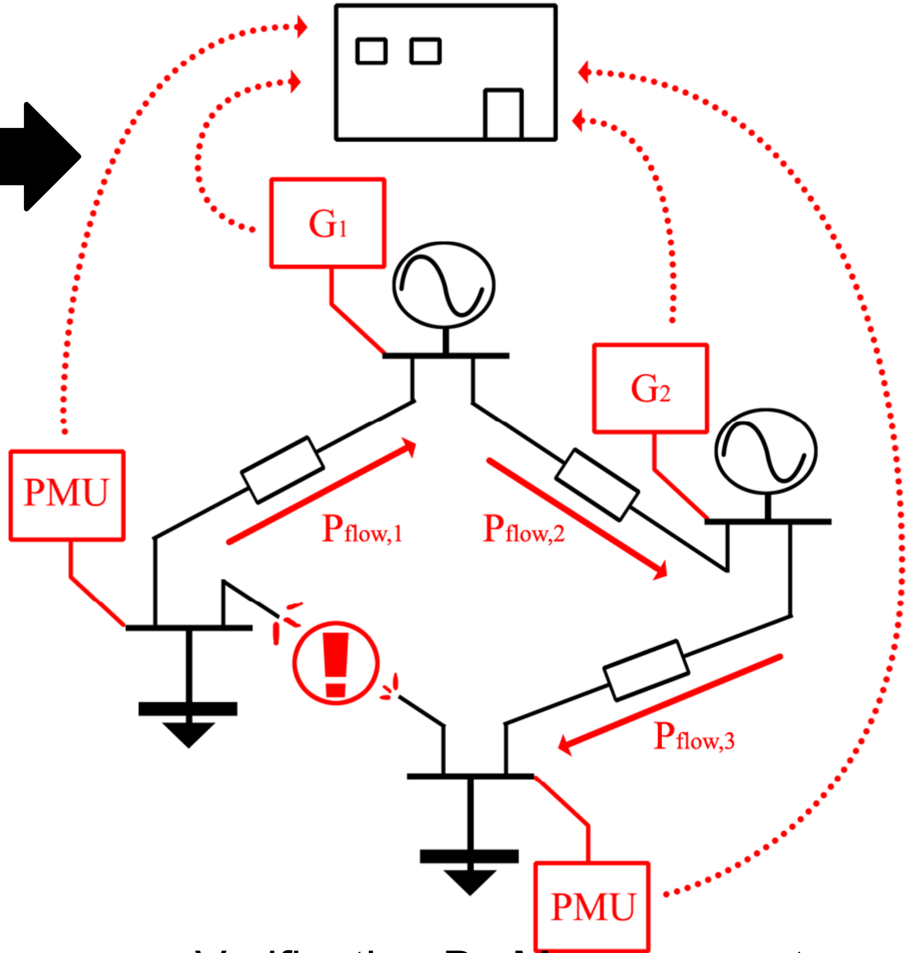
- State estimation using system measurements
  - Measurements taken from system by sensors and communicated back to control center
  - Compared with power flow calculation to verify topology of system (starts with known topology)
  - High volume of data and redundant measurements



# Power Flow To Verify Topology



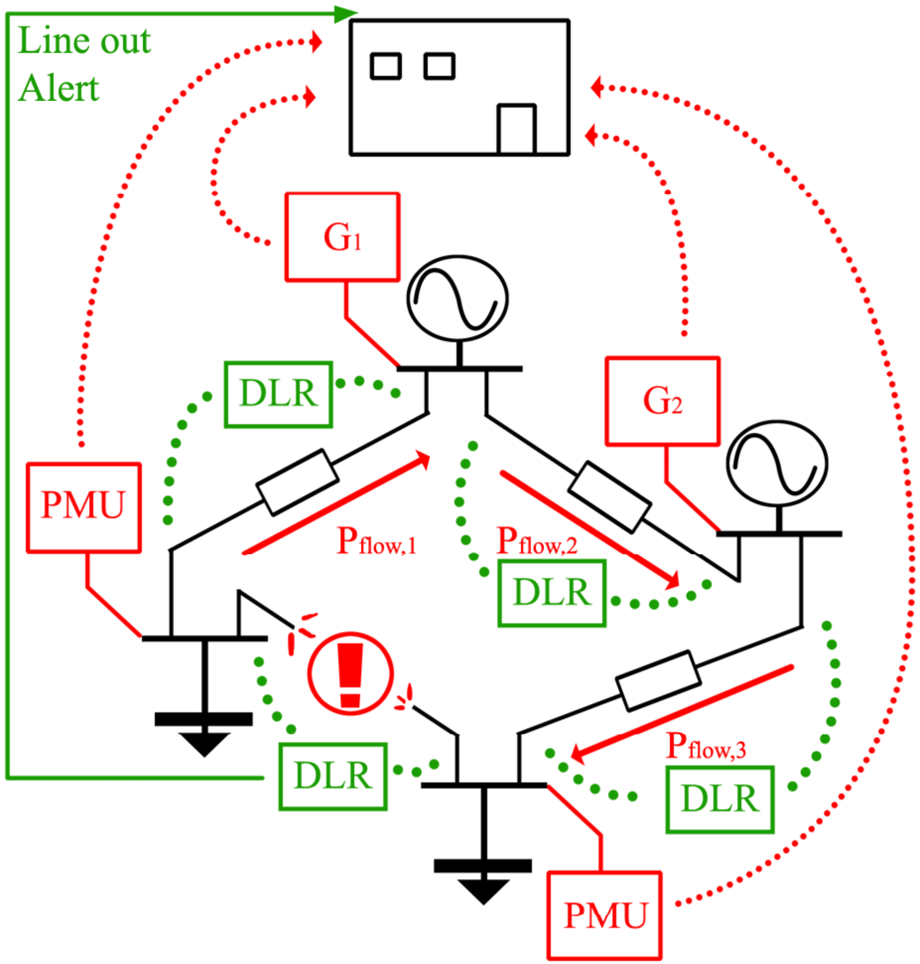

Power Flow




Verification By Measurement

# Power Flow Calculators For Contingency Screening

- Power flow calculators may help identify line congestion in conjunction with other “smart” components, such as dynamic line rating units (DLR’s)
- Contingency check can be done without central operator
- Central operator can be sent an alert upon contingency, thus complementing existing systems



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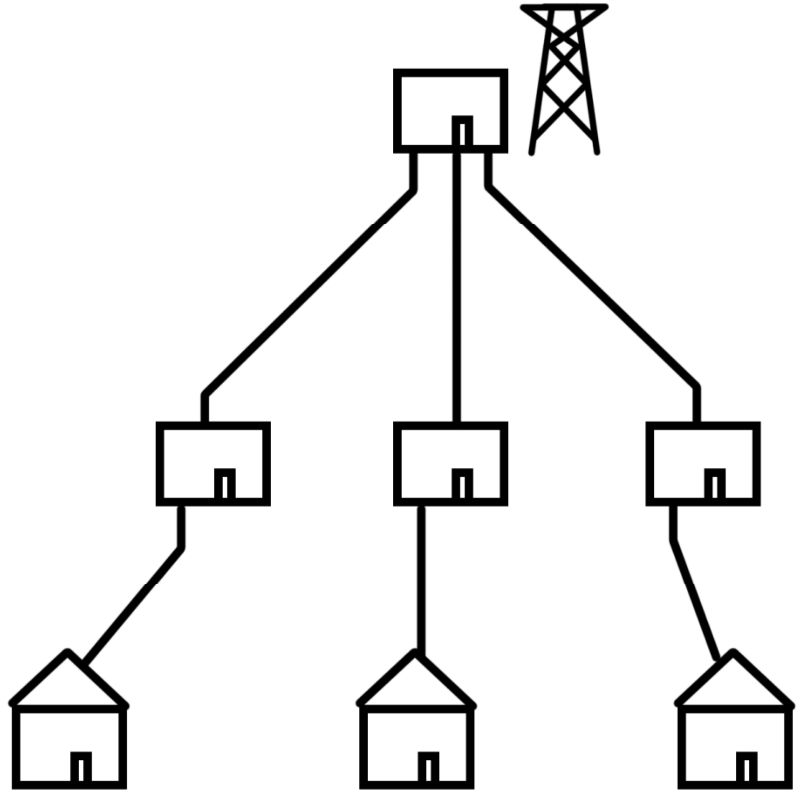
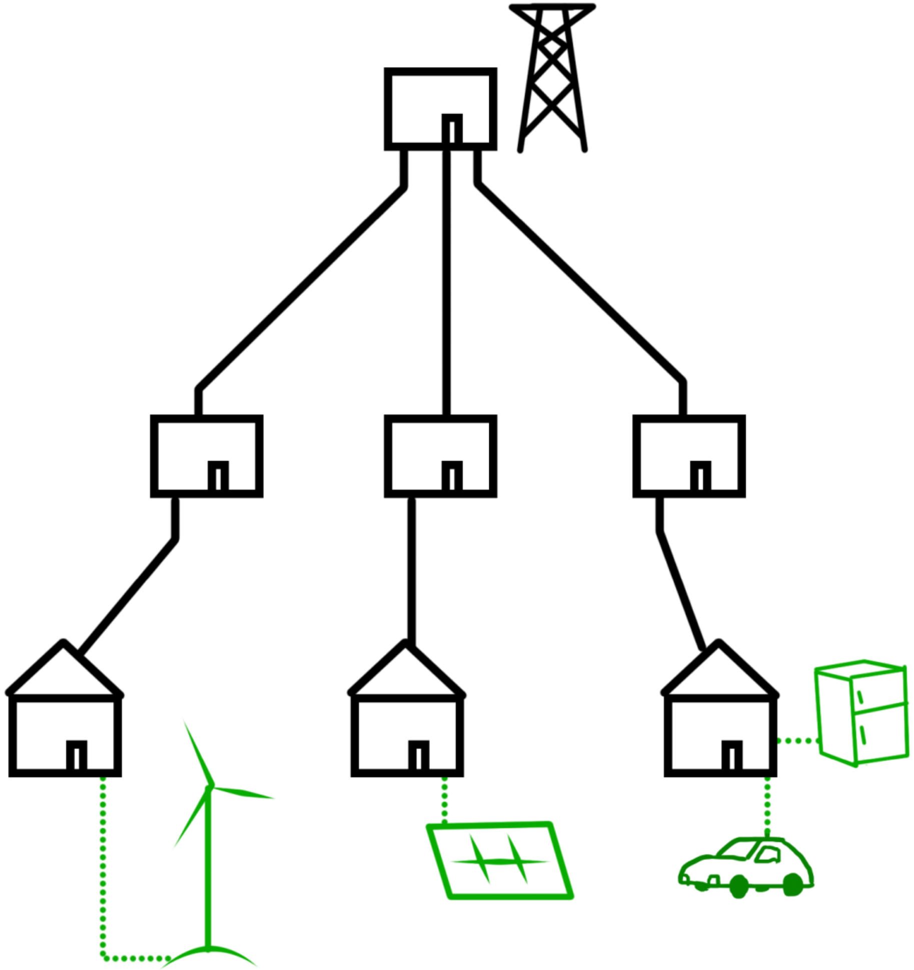
# Plug-And-Play For Distribution Networks

- Addition of many new and unconventional types of resources
- Local system operator may wish
- to use power flow information (aggregation useful for power flow on higher level system)



# Plug-And-Play For Distribution Networks

- A standardized information exchange protocol would let new components know what is necessary to participate in distributed network calculations (only communicate with neighbors)
- Helps deal with many small and varying participants without the system operator needing all information



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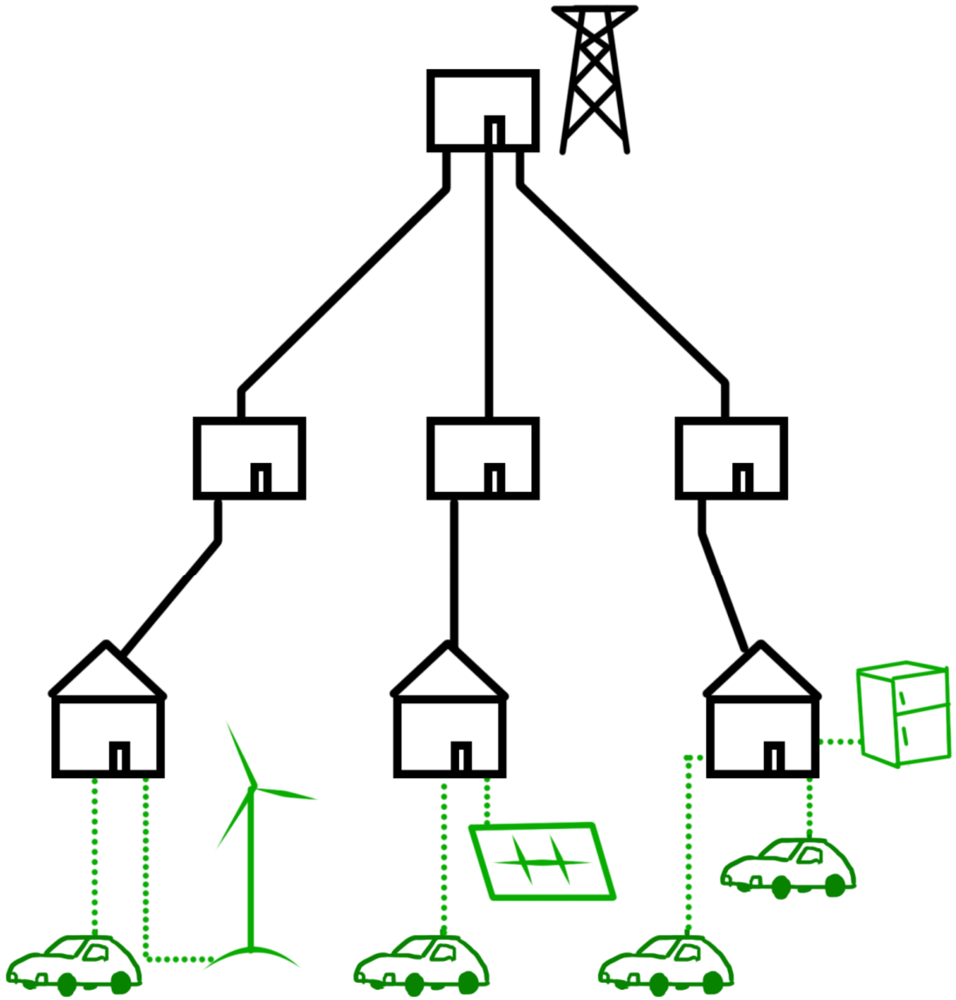
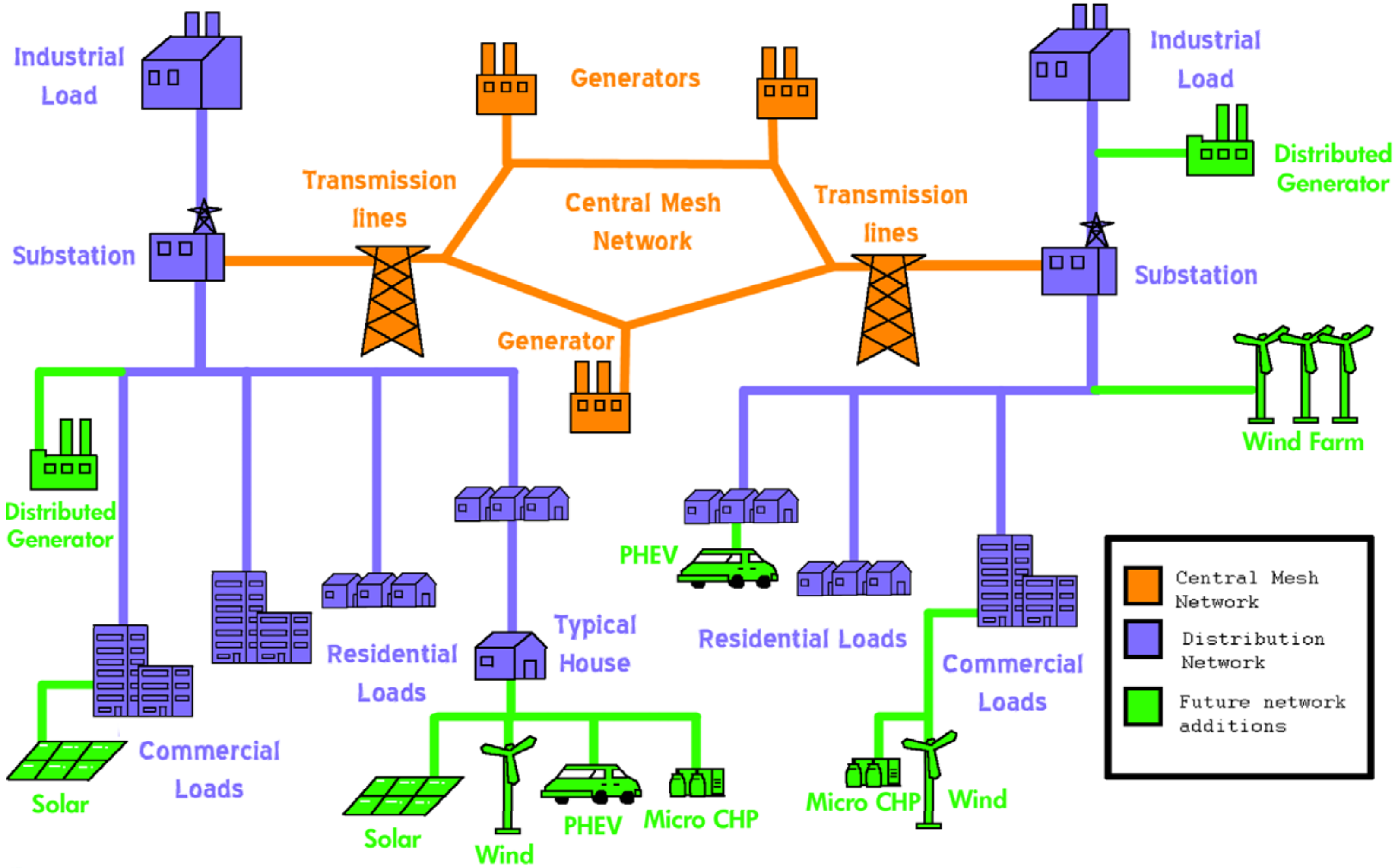


# Adding Detail To System



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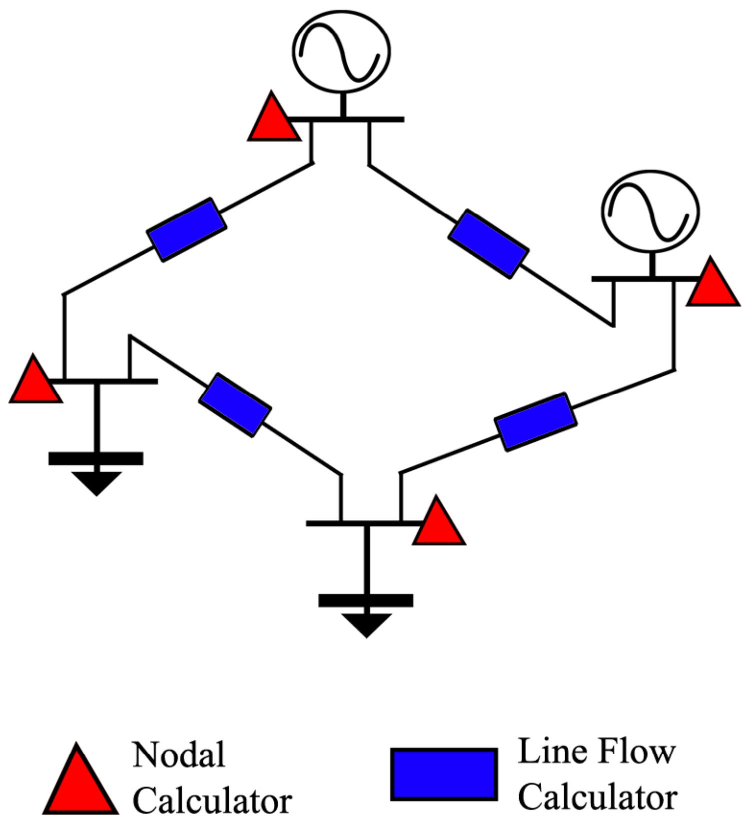
# Distributed Power Flow Framework

- Data exchange between neighboring components, e.g. line connected to bus[1][2]
  - Power flow calculators for each line
  - Power injection sensor/data for each bus
- Newton method based iterative method determines which variables to exchange per iteration
  - Flow variable (line to bus)
  - Lagrange multipliers (bus to line)




[1] Jadbabaie, A.; Ozdaglar, A.; Zargham, M.; , "A Distributed Newton Method for network optimization," *Decision and Control, 2009 held jointly with the 2009 28th Chinese Control Conference. CDC/CCC 2009. Proceedings of the 48th IEEE Conference on* ,pp.2736-2741, 15-18 Dec. 2009
[2] Ilić, M. and Hsu, A. "Toward Contingency Screening Using Distributed Line Flow Calculators and Dynamic Line Rating Units (DLRs)" *To appear in HICSS Conference, January 2012*

# Information Exchange

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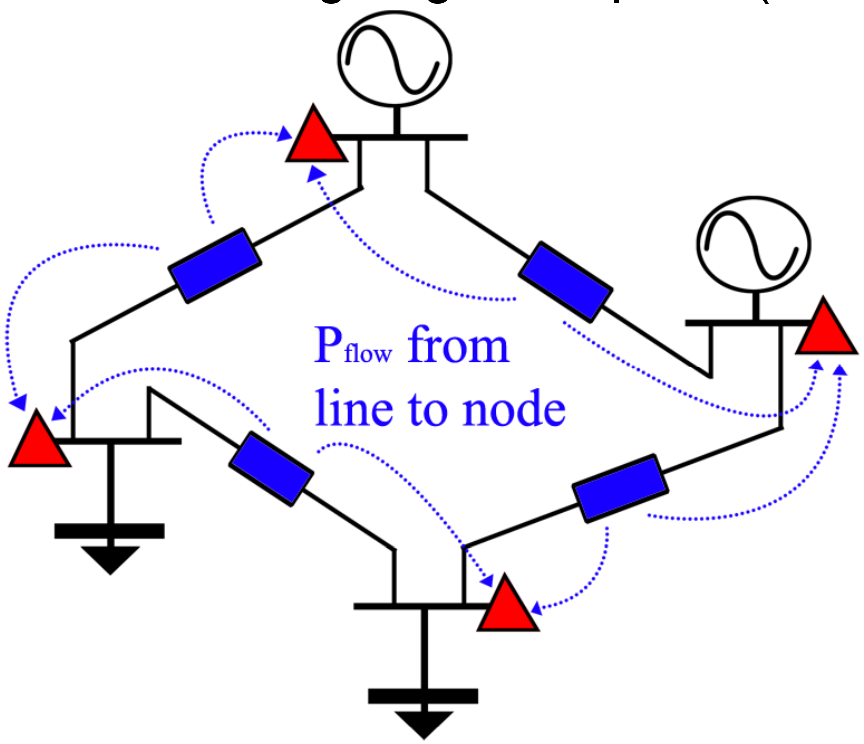
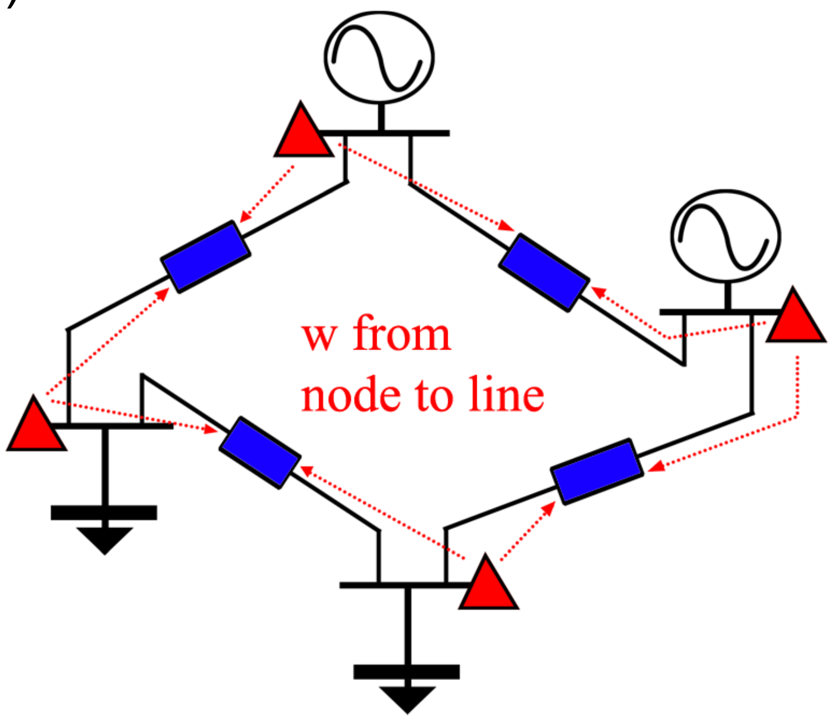


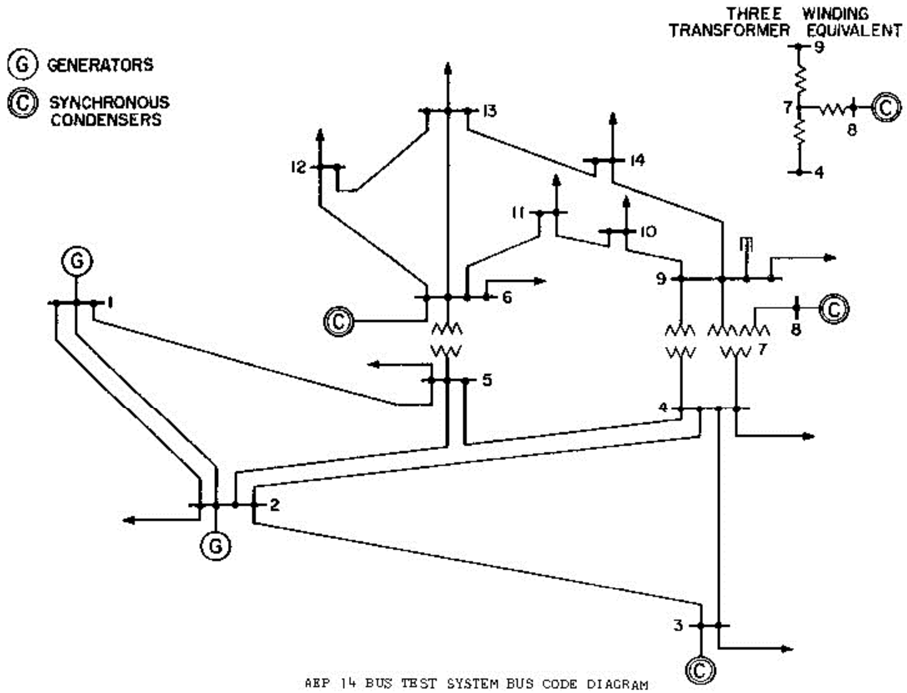



# Decoupled Real Power Simulations

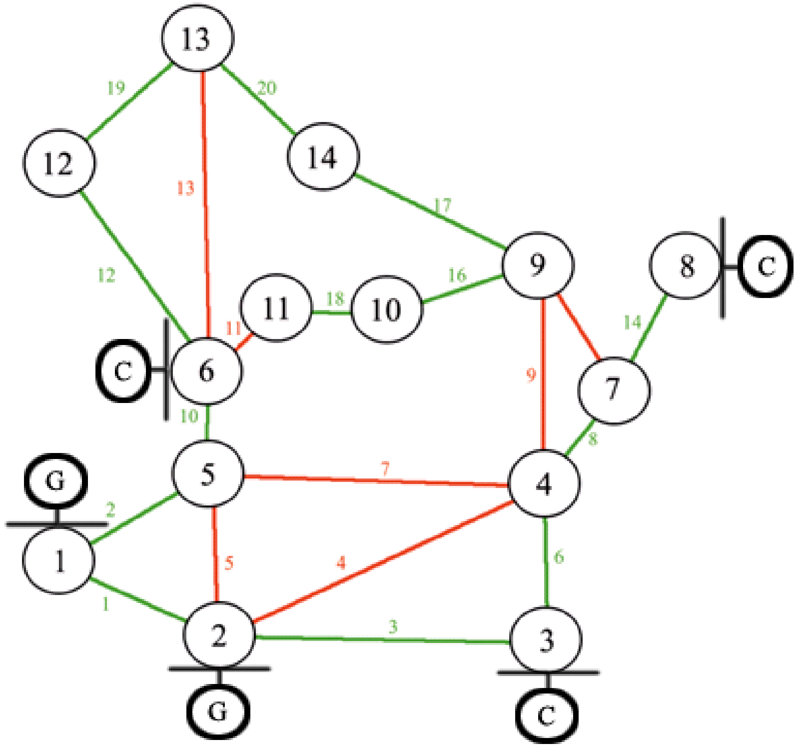
- IEEE 14 bus simulation done for real power decoupled power flow example[2][3]
- Solution checked using simultaneous equation solver in Matlab

[2] Ilić, M. and Hsu, A. "Toward Contingency Screening Using Distributed Line Flow Calculators and Dynamic Line Rating Units (DLRs)" *To appear in HICSS Conference, January 2012*
[3] Ilić, M. and Hsu, A. "GENERAL METHOD FOR DISTRIBUTED LINE FLOW COMPUTING WITH LOCAL COMMUNICATIONS IN MESHED ELECTRIC NETWORKS." Application number: 13/343,997. Filed: January 5, 2012

# 14 Bus System




14 bus example



14 bus example
graphical representation

# 14 bus – Results

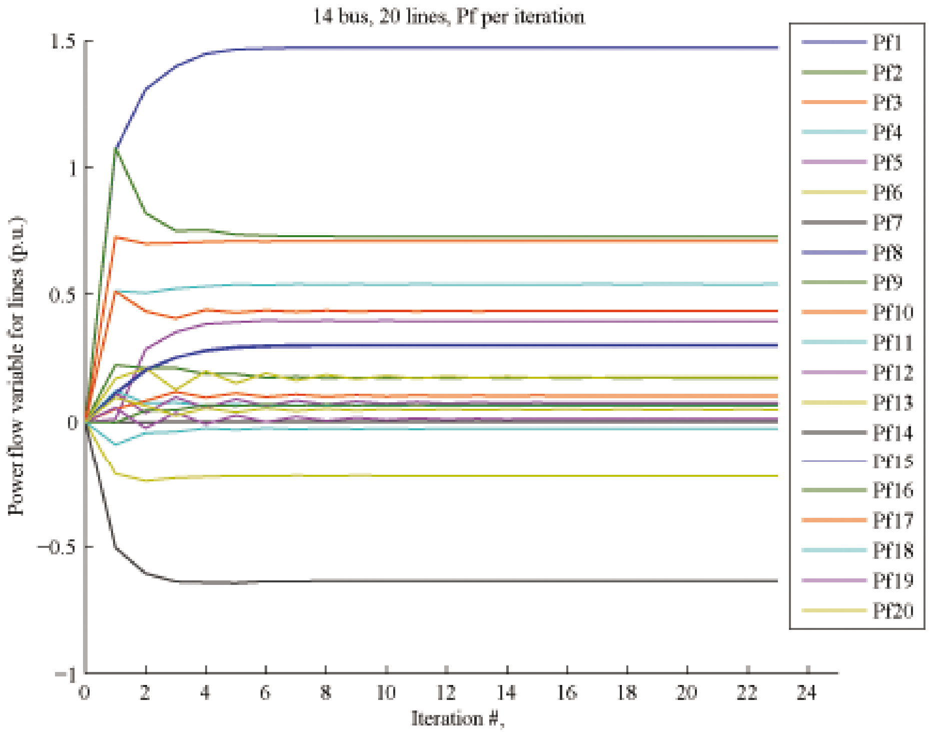



Table VII
$P_f$ SOLUTIONS OF IEEE 14 BUS SYSTEM

| 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 |

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%

# Conclusions and Future Work

- Proof of concept example for distributed power flow shown
- Explore information exchange framework and uses in complementing existing system
- 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

# Questions?

# References

[1] Jadbabaie, A.; Ozdaglar, A.; Zargham, M.; , "A Distributed Newton Method for network optimization," *Decision and Control, 2009 held jointly with the 2009 28th Chinese Control Conference. CDC/CCC 2009. Proceedings of the 48th IEEE Conference on* ,pp.2736-2741, 15-18 Dec. 2009

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