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Electrical & Computer ENGINEERING

Zooming-in and Zooming-out Methods for Directing Power Flows

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Motivation

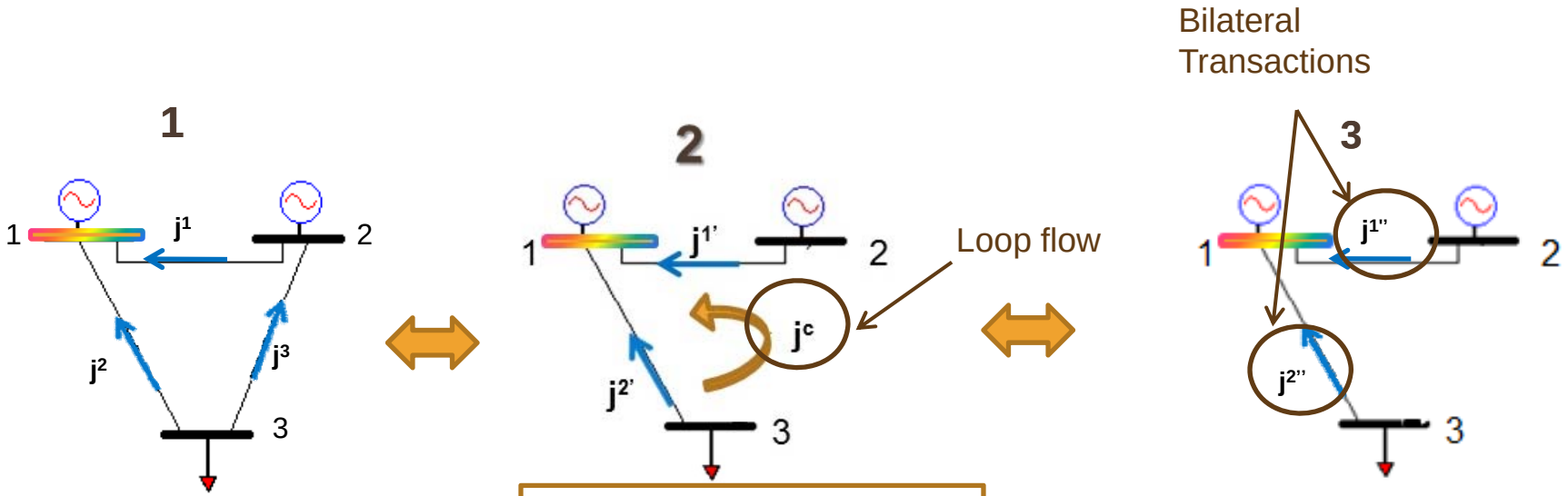
- Ability to direct power flows
- Increased congestion in transmission systems
- Direct power flows to
  - Provide mechanisms for line loading/unloading
  - Increase network utilization and ATC
  - Enable the concept of contract paths and wheeling
- New transmission pricing:
  - Proper allocation of transmission charges

Outline

- Motivation for directing power flows
- Framework for modeling
  - Directed power flows as bilateral transactions
  - Deviations as loop flows
- Directing power flows with
  - Additional power generation
  - Phase Angle Regulators (PARs)
  - Distributed generation displacement

Framework demonstration: Single-Area Case

❖ **Transformation of a meshed network into a spanning tree**



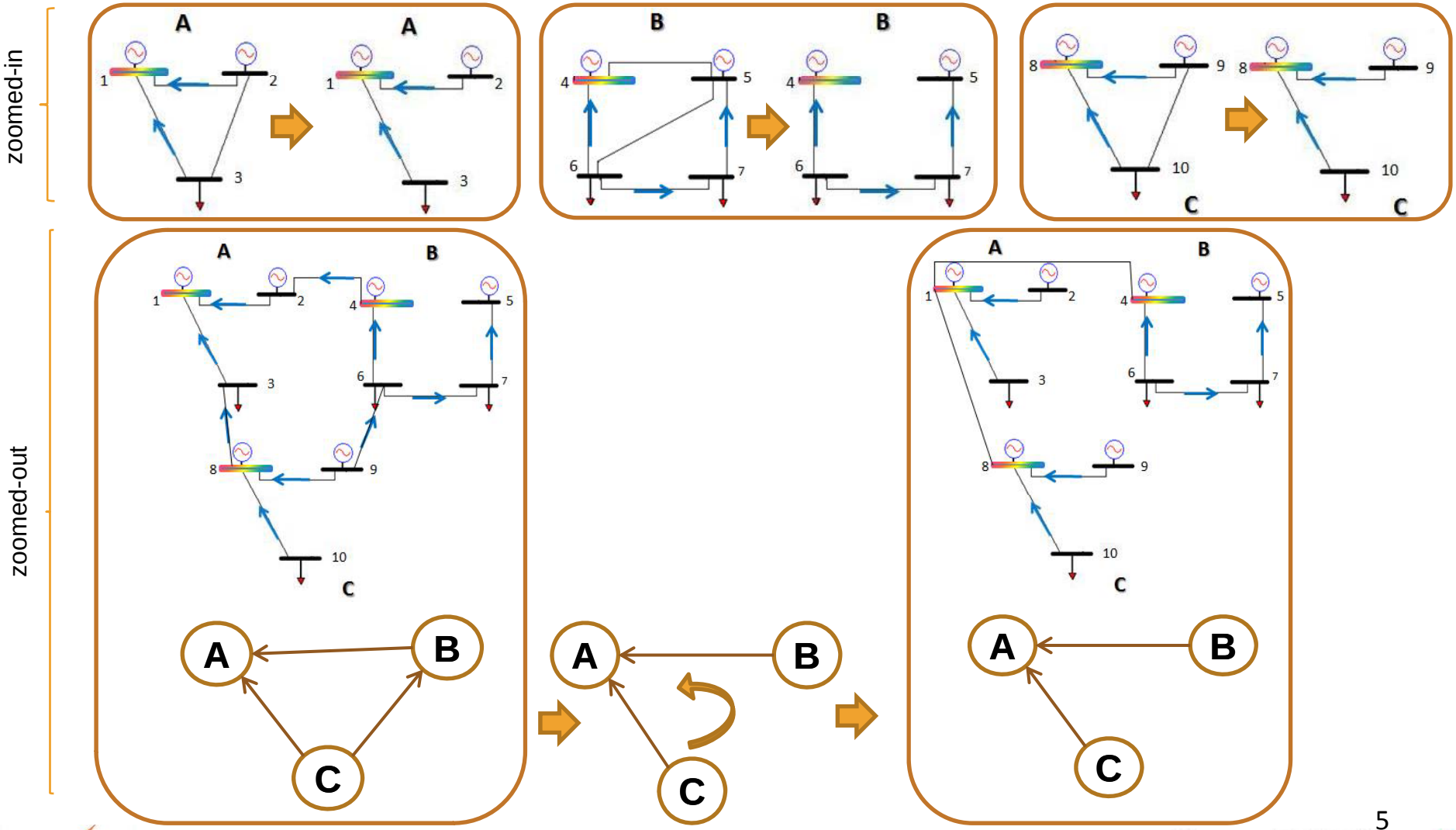
Loop flow tracing:

$$j^c = a_1 j^{1\prime} + a_2 j^{2\prime}$$

Bilateral trans. tracing:

$$\begin{bmatrix} j^1 \\ j^2 \\ j^3 \end{bmatrix} = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \\ b_{31} & b_{32} \end{bmatrix} \cdot \begin{bmatrix} j^{1\prime\prime} \\ j^{2\prime\prime} \end{bmatrix}$$

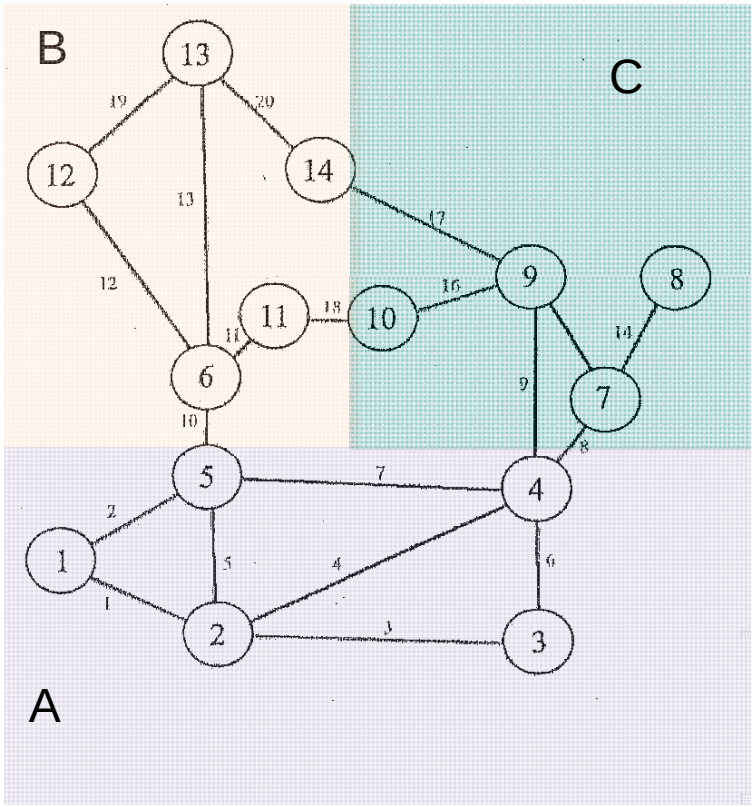
Framework demonstration: Multi-Area Case



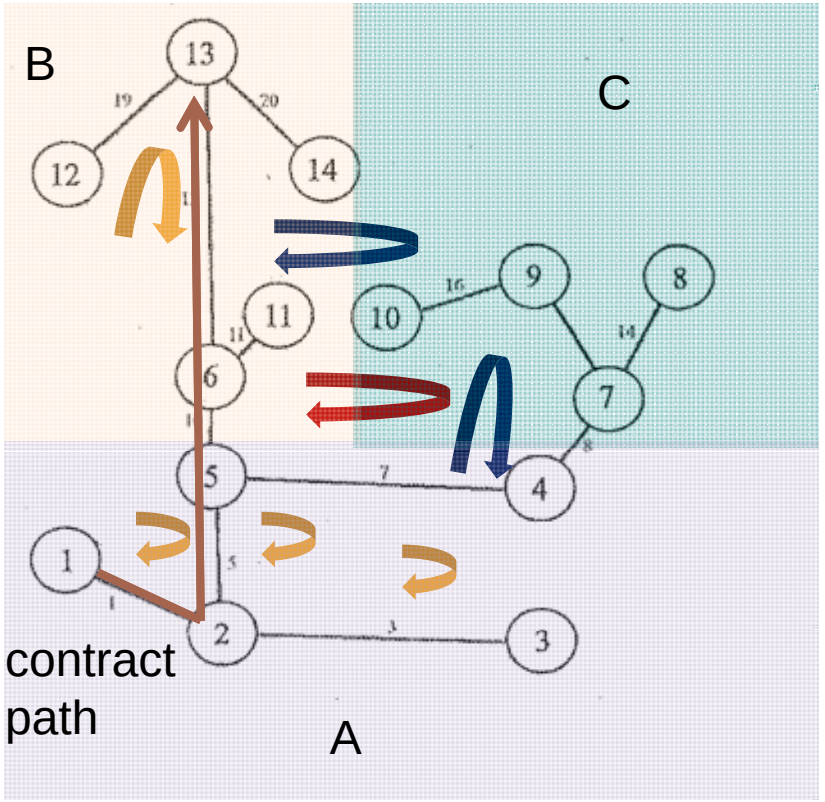
14-bus system

- loop flows inside one area
- loop flows between two areas
- loop flows among three or more areas

Physical Network



Spanning Tree



Optimization Objectives

- **Various objectives: minimize**
  - loop flows across 3 or more areas
  - loop flows between 2 areas
  - Loop flows we care about (cause congestion, etc.)
- **The objective function:**
  - $Obj = \sum \| j^{c_k} \|^2$
- **Optimization**

$$\underbrace{min}_{j^{contr}} \sum_k \| j^{c_k} \|^2$$

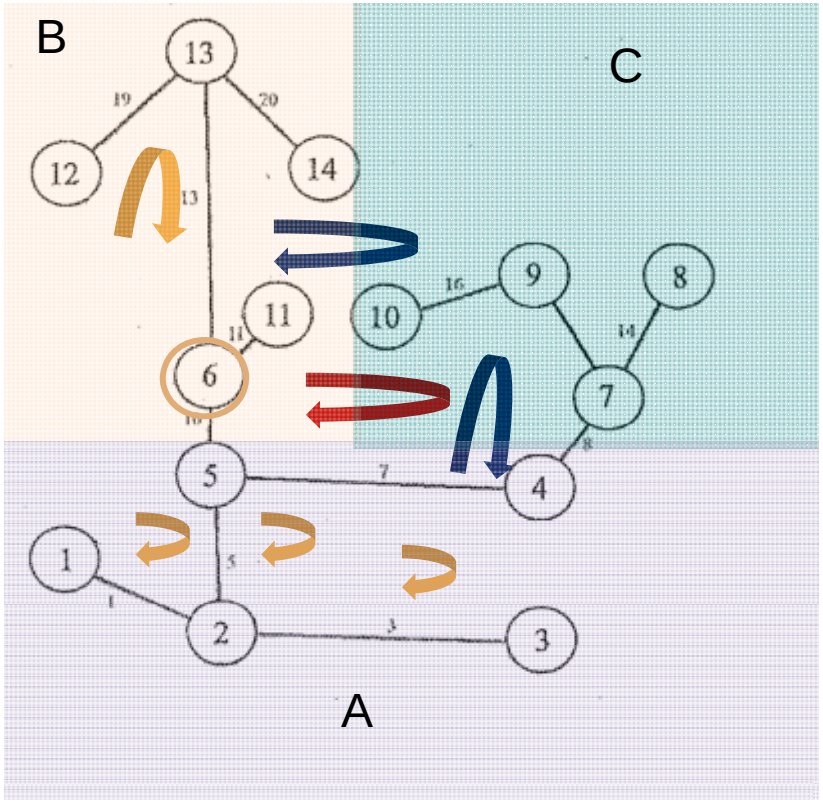
$$s.t$$

$$j^{c_k} = \sum_l c_{kl} \cdot j^{Tl}, \forall k$$

$$j^{contr\_min} \leq j^{contr} \leq j^{contr\_max}$$

Directing flows with additional generation

- **What is additional generation from gen. at bus 6 in order to:**



- minimize the (red) loop flow across area C?
  - initially: $Obj = 0.0021$

$P_{g6} = 0.232$

$\rightarrow Obj = 0$

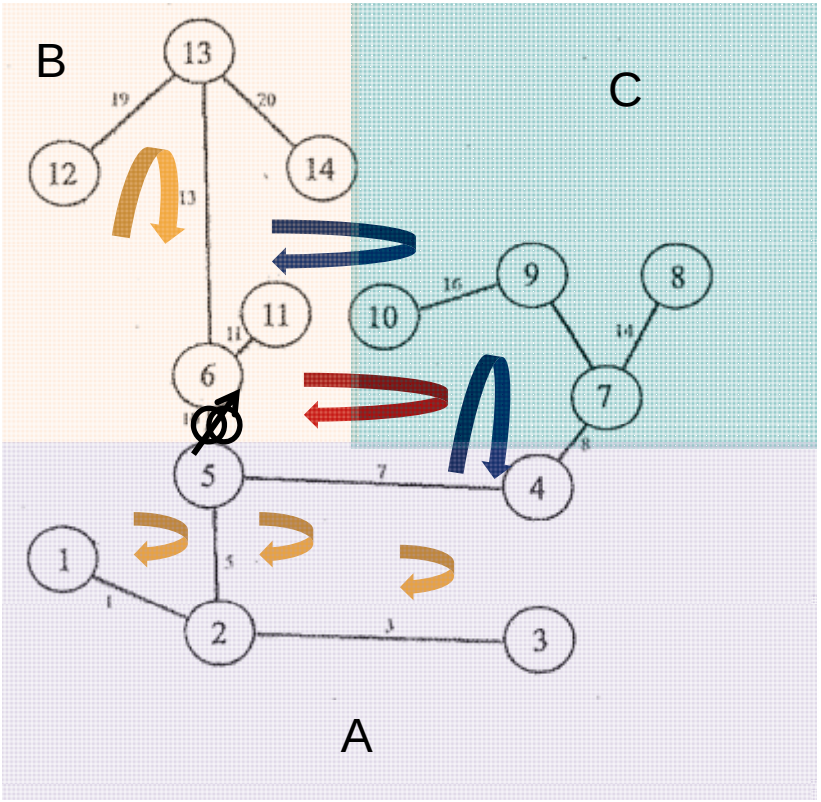
- minimize all inter-area loop flows?
  - initially: $Obj = 0.0335$

$P_{g6} = 0.225$

$\rightarrow Obj = 0.0247$

Directing flows with PARs

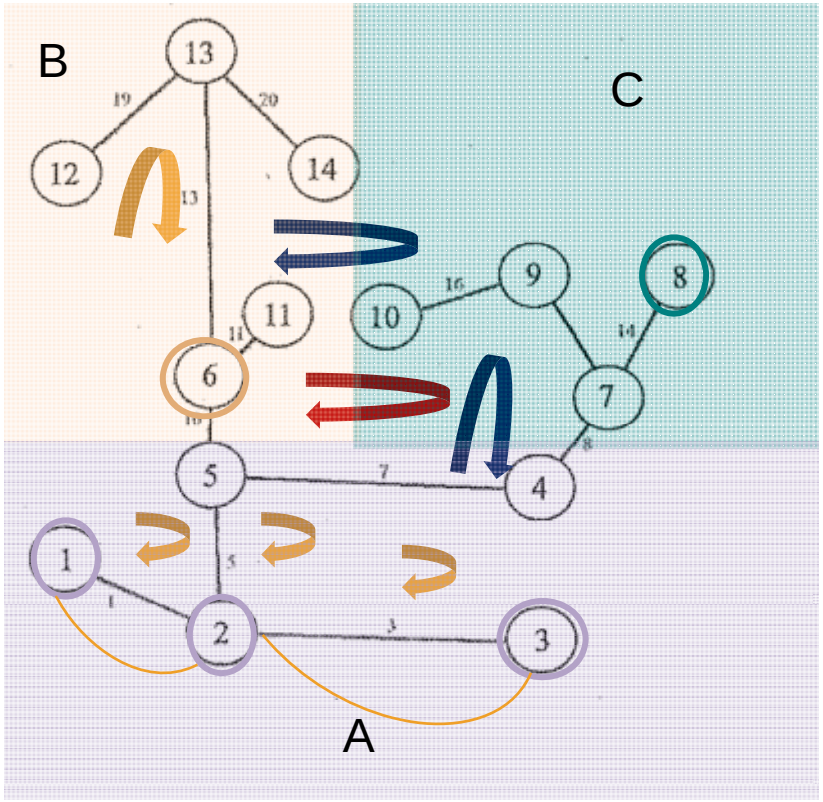
- **What is the set point of the PAR in order to:**



- minimize the (red) loop flow across area C?
  - initially: $Obj = 0.0021$
    $\alpha = 3.52°$
    $\rightarrow Obj = 0$
- minimize all inter-area loop flows?
  - initially: $Obj = 0.0335$
    $\alpha = 3.42°$
    $\rightarrow Obj = 0.0247$

Directing flows with power displacement

- **How can areas A and B displace their internal generation in order to:**



- minimize the (red) loop flow across area C?
  - initially: $Obj = 0.0021$

$P_{g1} = 2.59, P_{g2} = 0, P_{g3} = 0$

$\rightarrow Obj = 0.0020$

- minimize all inter-area loop flows?
  - initially: $Obj = 0.0335$

$P_{g1} = 2.59, P_{g2} = 0, P_{g3} = 0$

$\rightarrow Obj = 0.0331$

- initial generation: $P_{g1} = 2.19, P_{g2} = 0.4, P_{g3} = 0$

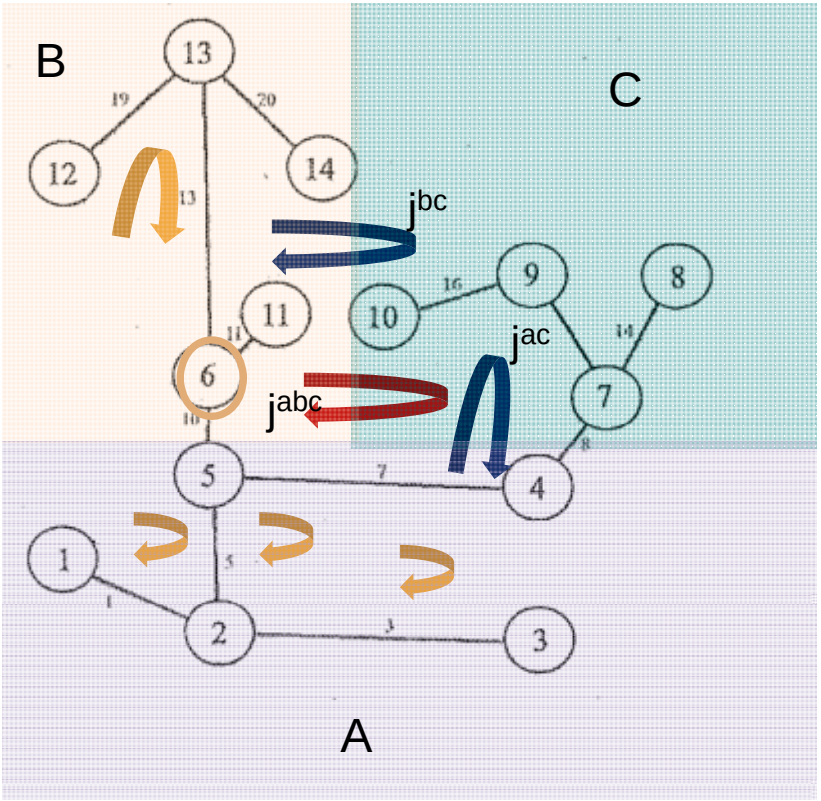
Conclusions and Future Work

- **Loop flow cancelation based on**
  - A framework for explicit modeling of loop flows
  - Using multiple techniques
  - Proof of concept
- **Larger systems to be examined**
- **Distributed loop flow cancelation with minimum information exchange**

QUESTIONS?

Directing flows with additional generation

- **What is additional generation from gen. at bus 6 in order to:**



- minimize the (red) loop flow across area C?
- If $P_{g6} = 23.2MW$:
  - $j^{abc} = 7.1MW \rightarrow j^{abc} = 0$
- minimize all inter-area loop flows?
- If $P_{g6} = 22.5MW$:

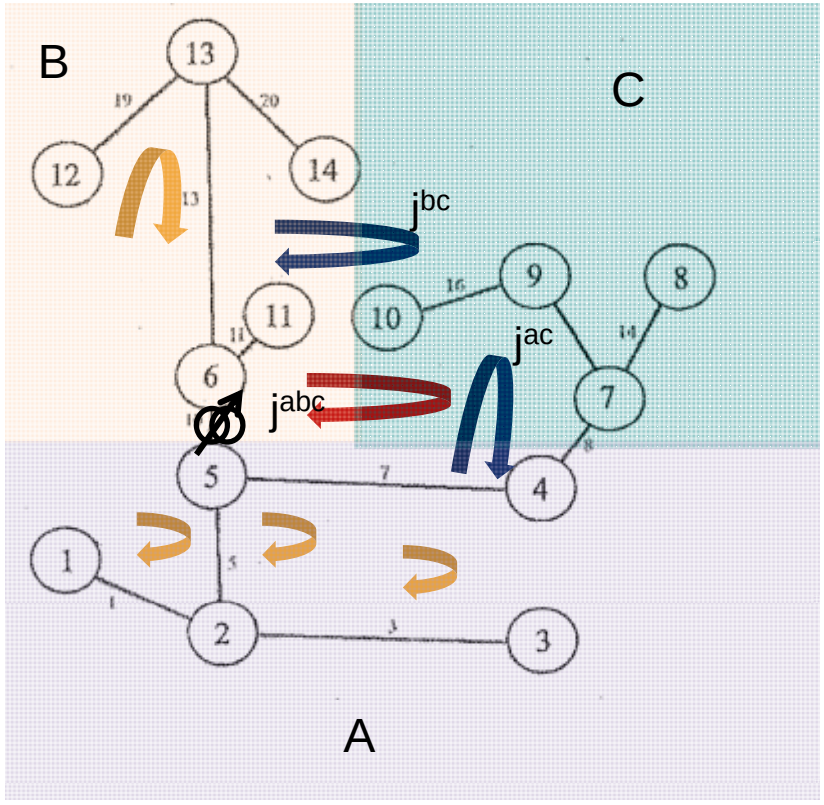
$j^{abc} = 7.1MW \rightarrow j^{abc} = -0.6MW$

$j^{ac} = 16.6MW \rightarrow j^{ac} = 13.8MW$

$j^{bc} = -2.8MW \rightarrow j^{bc} = -7.4MW$

Directing flows with PARs

- **What is the set point of the PAR in order to:**



- minimize the (red) loop flow across area C?
- If $\alpha = 3.52°$:
  - $j^{abc} = 7.1MW \rightarrow j^{abc} = 0$
- minimize all inter-area loop flows?
- If $\alpha = 3.42°$:

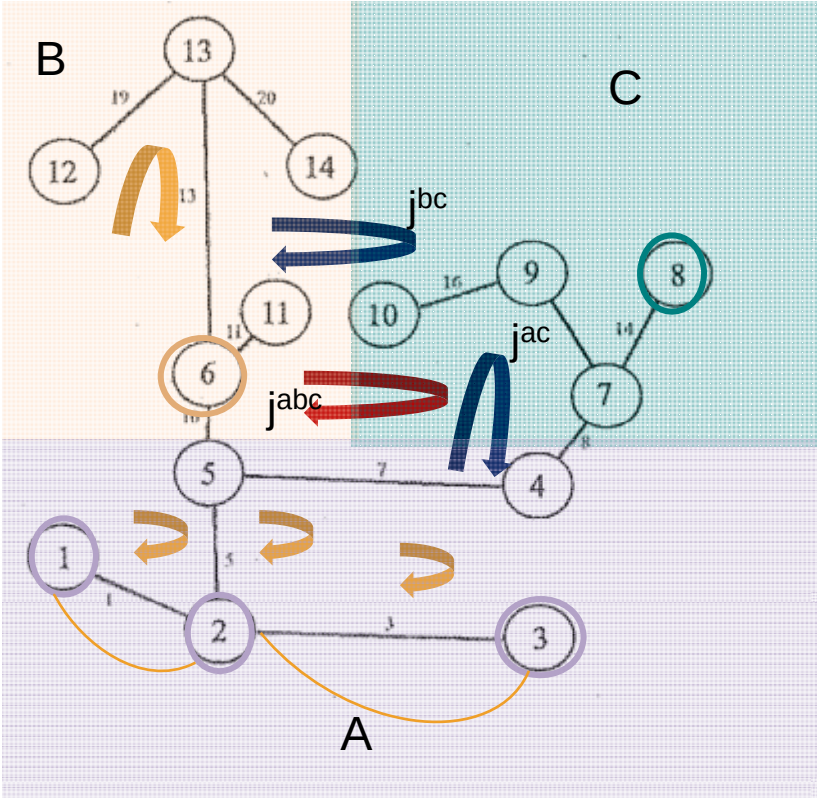
$j^{abc} = 7.1MW \rightarrow j^{abc} = -0.6MW$

$j^{ac} = 16.6MW \rightarrow j^{ac} = 13.8MW$

$j^{bc} = -2.8MW \rightarrow j^{bc} = -7.4MW$

Directing flows with power displacement

- **How can areas A and B displace their internal generation in order to:**



- minimize the (red) loop flow across area C?
- If $P_{g1} = 259MW, P_{g2} = 0, P_{g3} = 0$:
  - $j^{abc} = 7.1MW \rightarrow j^{abc} = 6.9MW$
- minimize all inter-area loop flows?
- If $P_{g1} = 259MW, P_{g2} = 0, P_{g3} = 0$:

$j^{abc} = 7.1MW \rightarrow j^{abc} = 6.9MW$

$j^{ac} = 16.6MW \rightarrow j^{ac} = 16.5MW$

$j^{bc} = -2.8MW \rightarrow j^{bc} = -2.9MW$

- initial generation: $P_{g1} = 219MW, P_{g2} = 40MW, P_{g3} = 0$