IEEE/PES General Meeting, Vancouver
July 25, 2013

Panel session

State Estimation for Distribution Operations: sharing the experiences of implementation, usage and complexities

DEALING WITH TWO TIME SCALES IN DISTRIBUTION SYSTEM STATE ESTIMATORS

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Germany

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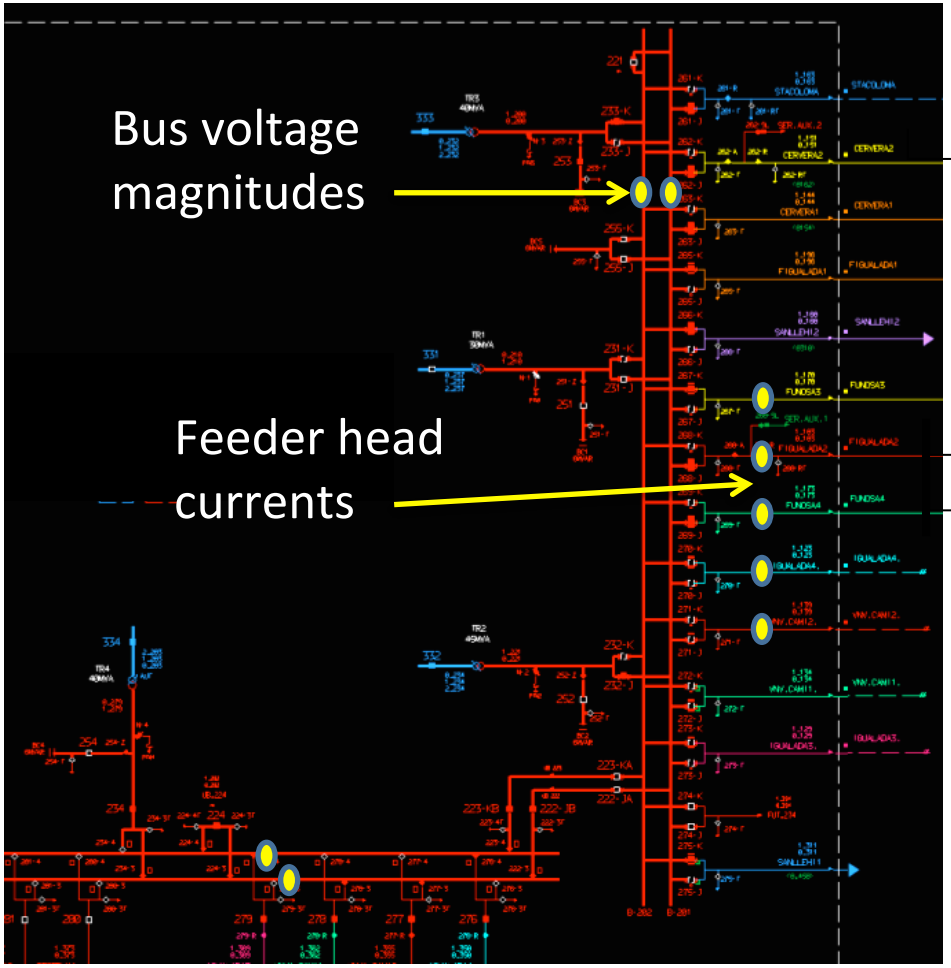
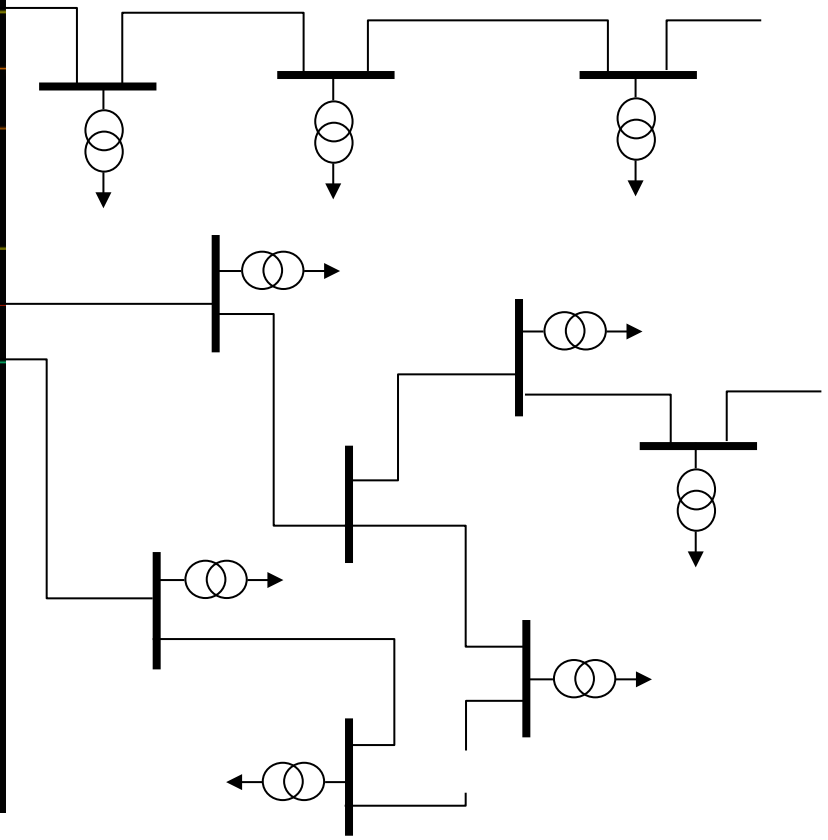
- Motivation
- Distribution-level information
- State Estimation with two time scales
- Preliminary results
- Conclusions

MOTIVATION

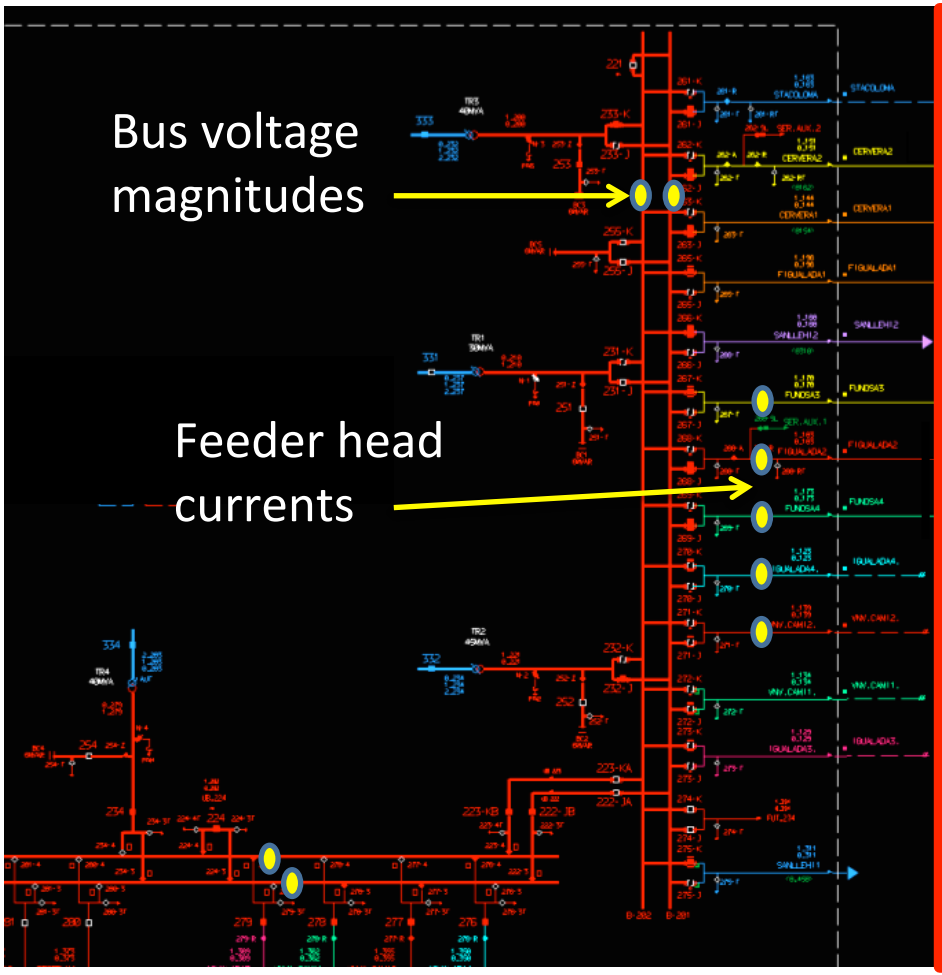
Telemetered information in today's distribution substations





MOTIVATION

The consequence is...

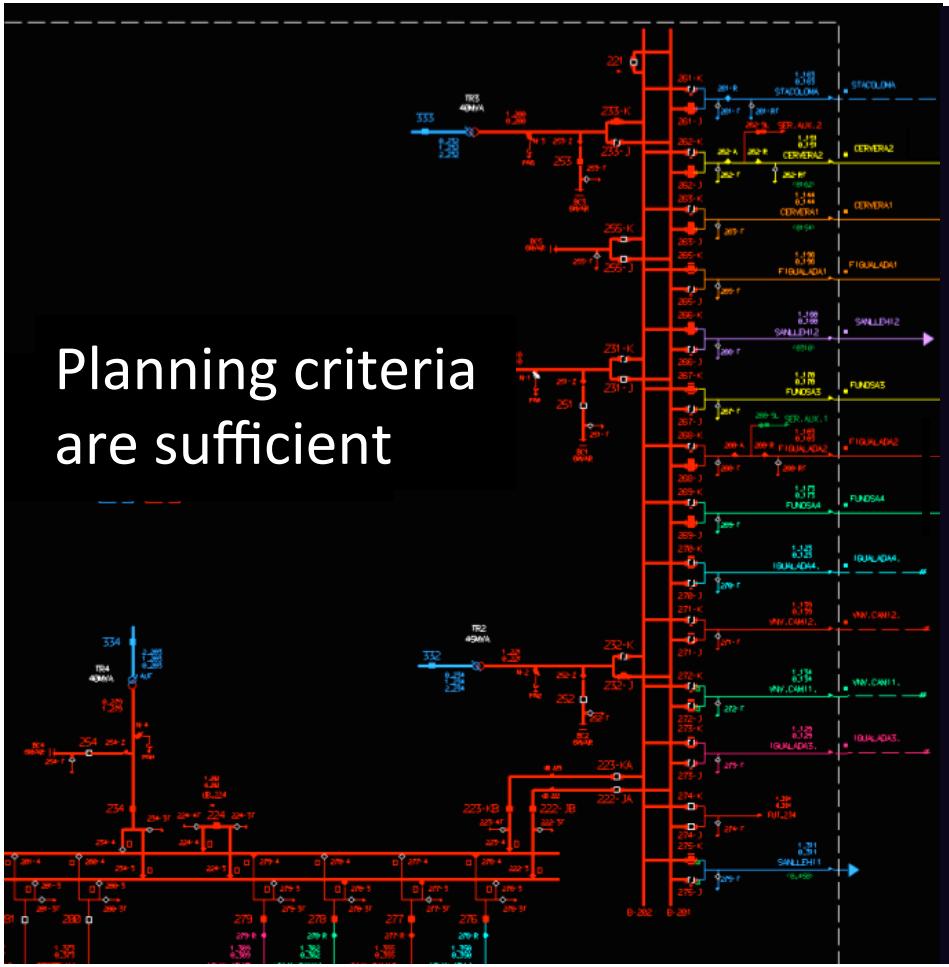


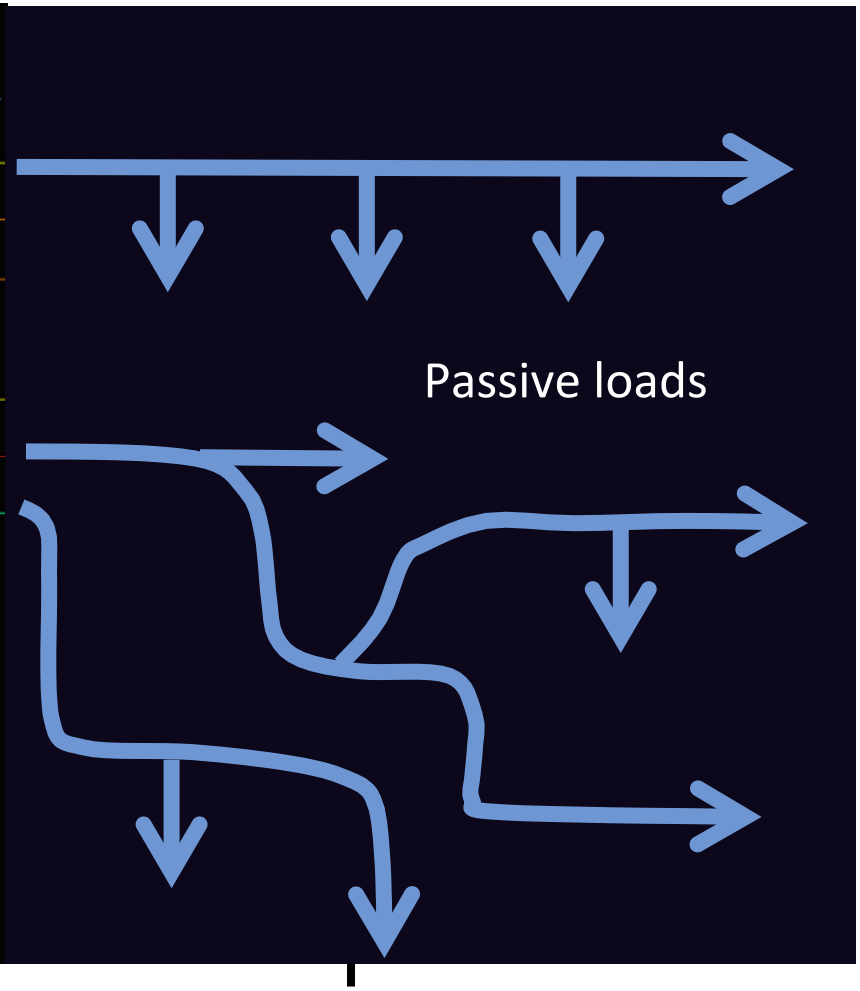
MV & LV feeder system is literally a

BLACK BOX

MOTIVATION

Is it satisfactory?





MOTIVATION

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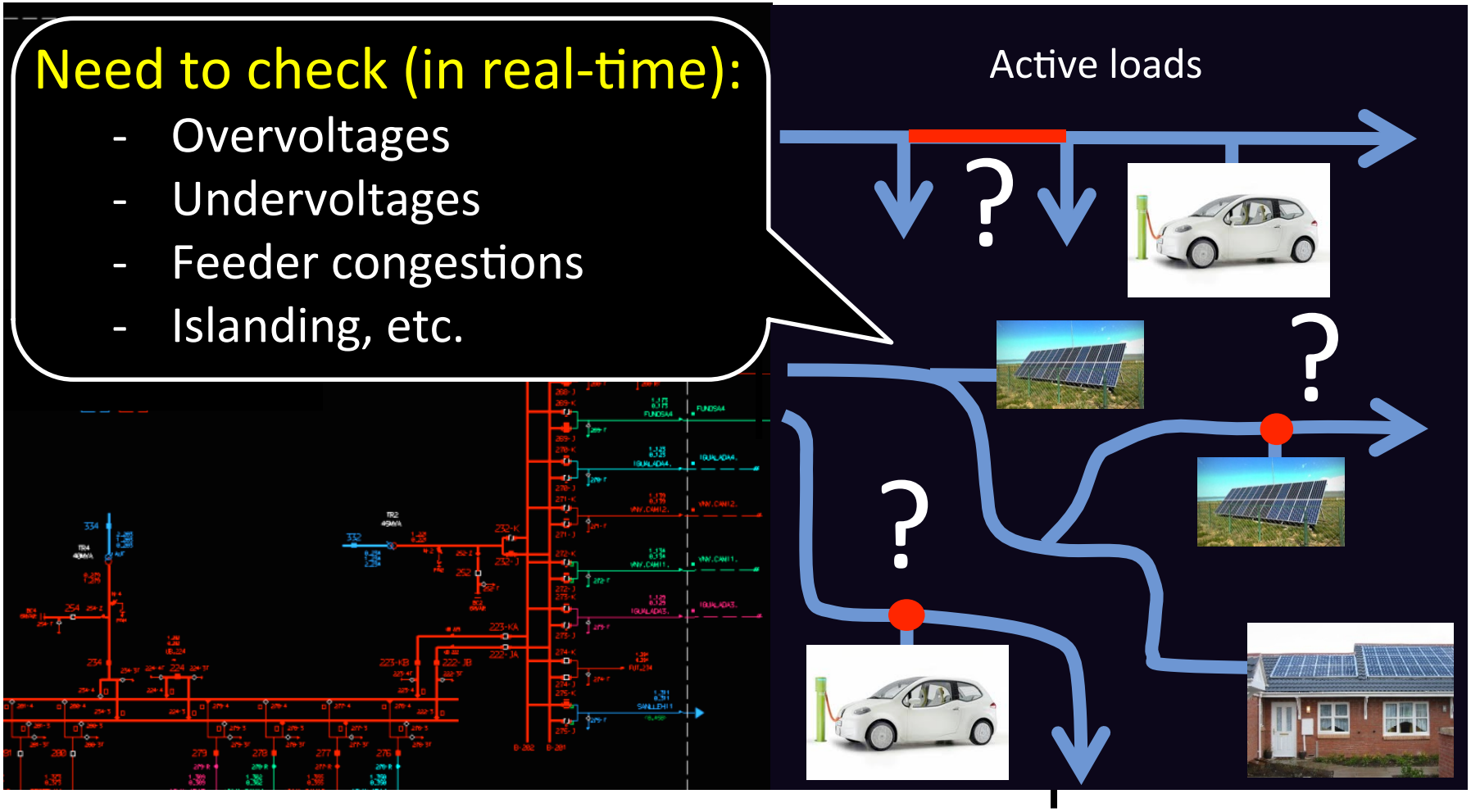
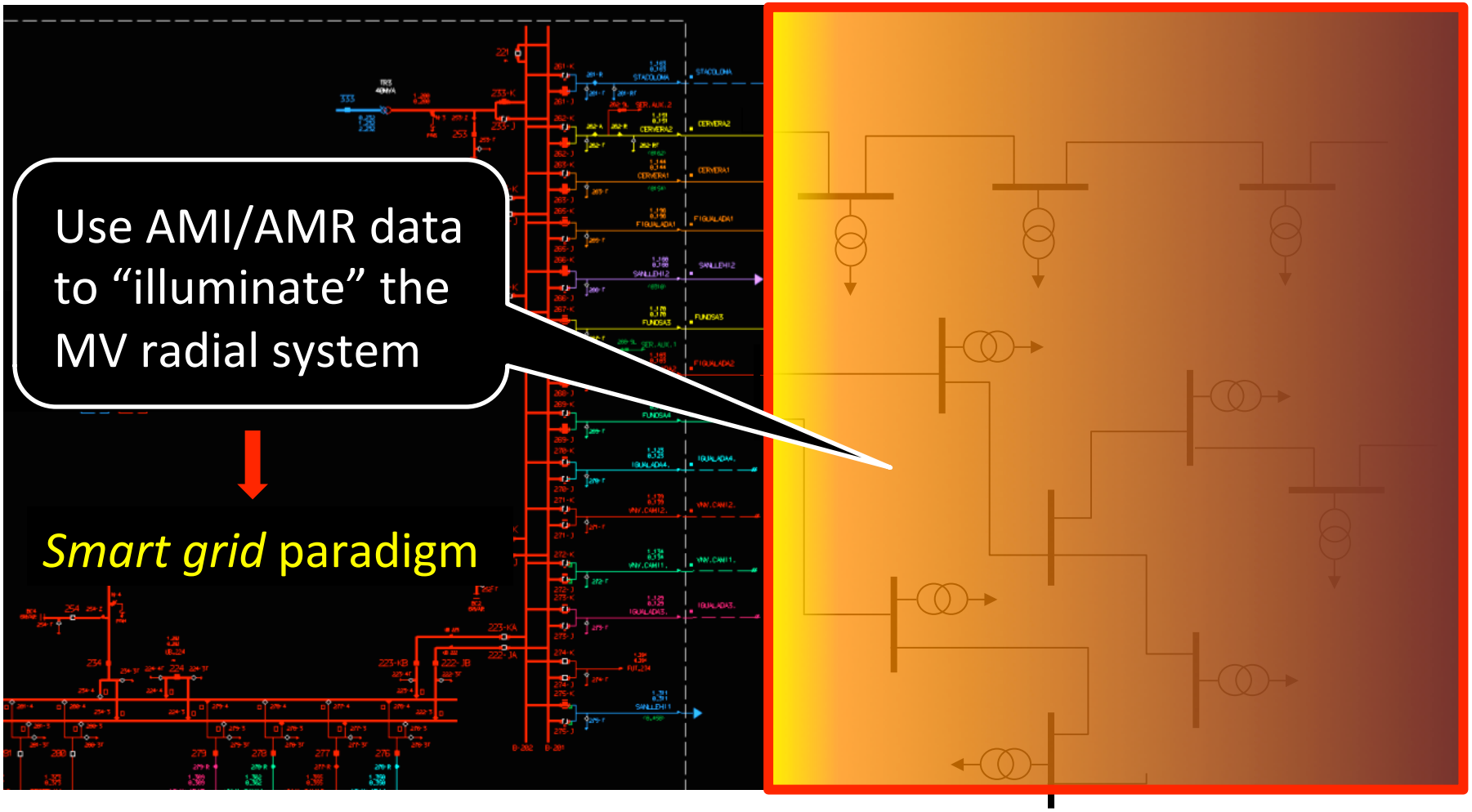


MOTIVATION

What can we do to improve dramatically the situation?



Distribution-level information

Several (heterogeneous) information sources in upcoming *Smart Grids:*

- SCADA & DMS
- Feeder automation devices
- Distributed generators
- Historic load patterns/profiles
- AMI data (Smart Meters concentrators)

Distribution-level information

- **SCADA & DMS**
- Feeder a
- Distribute
- Historic loa
- AMI data (S

- Very few RTU measurements captured at HV-MV substations
- Sampled every few seconds

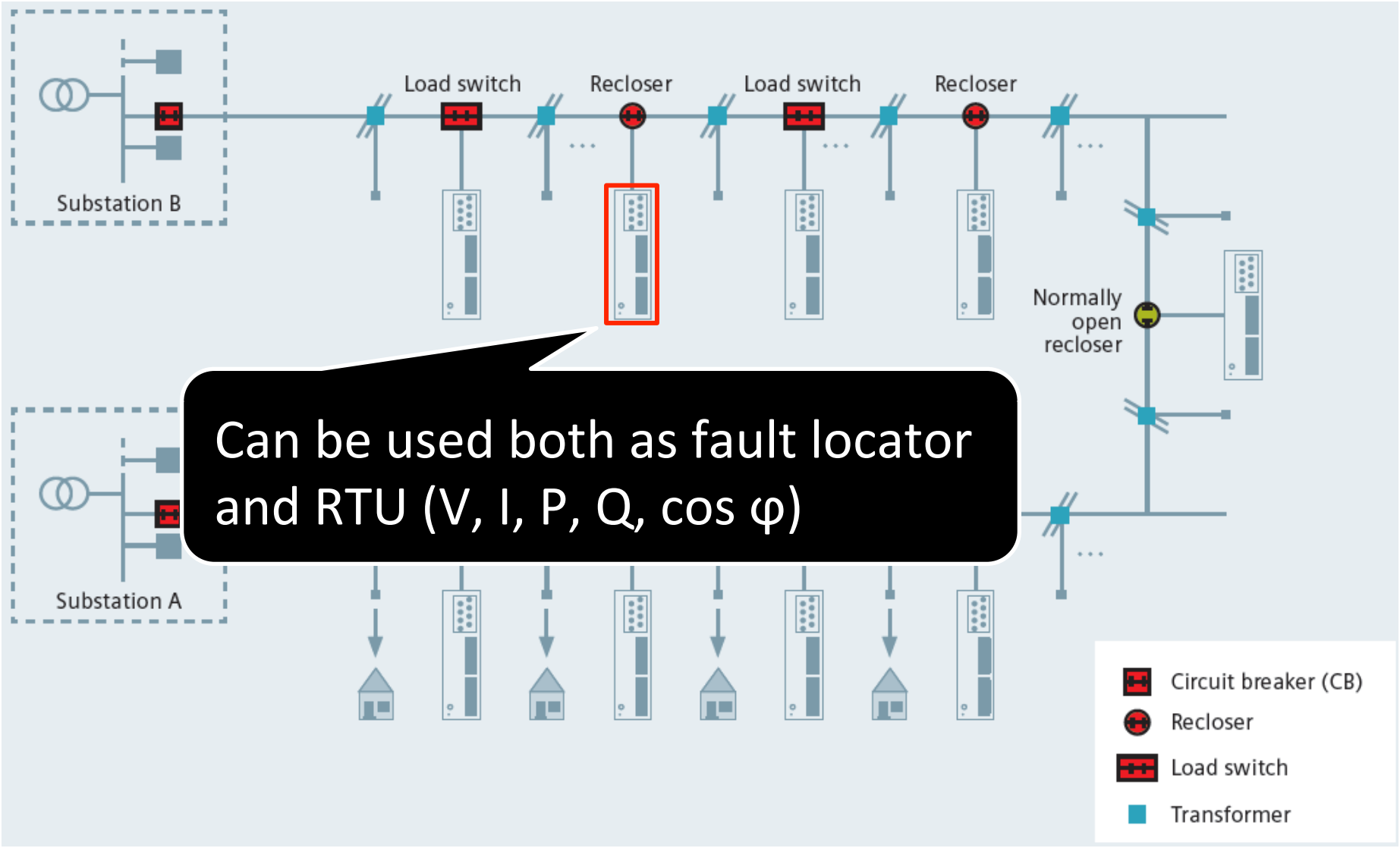
Distribution-level information

- SCADA & DMS
- **Feeder automation devices**
- Distribu[illegible]d
- Historic lo[illegible]
- AMI data (S[illegible]

- Intermediate switching points for fault management
- Can be used as additional telemeasured points (RTUs)

Example of feeder automation devices

Siemens Feeder Automation controller: **SIPROTEC 7SC80**



Distribution-level information

- SCADA & DMS
- Feeder automation devices
- **Distributed generators**
- Historic load
- AMI data

Depending on specific regulation:

- Day-ahead hourly forecasting of energy production
- Real production periodically submitted to DMS

Distribution-level information

- SCADA & DMS
- Distribution automation devices
- Distributed generators
- **Historic load patterns/profiles**
- AMI da

- Day-ahead hourly load forecasting
- Assumed PF for typical loads
  - Hourly values of P&Q

Distribution-level information

- SCAD
- Distri
- Distri
- Historic l[illegible] patterns/profiles
- **AMI data (Smart Meters concentrators)**

- Involves DMS-AMI communications
- Depending on bandwidth availability:
  - From 15' to 24h snapshot latency

Two different latencies

- SCADA & DMS
- Feeder automation devices
- Distributed generators
- Historic load patterns/profiles
- AMI data (Sm[illegible]eters concentrators)

- Snapshots updated from few sec. to about a minute
- Insufficient to assure network observability

Two different latencies

- SCADA
- Feeder automation devices
- Distributed generators
- Historic load patterns/profiles
- AMI data (Smart Meters concentrators)

- Snapshots updated from 15' to 24h
- Barely critical information to assure network observability

Two different latencies

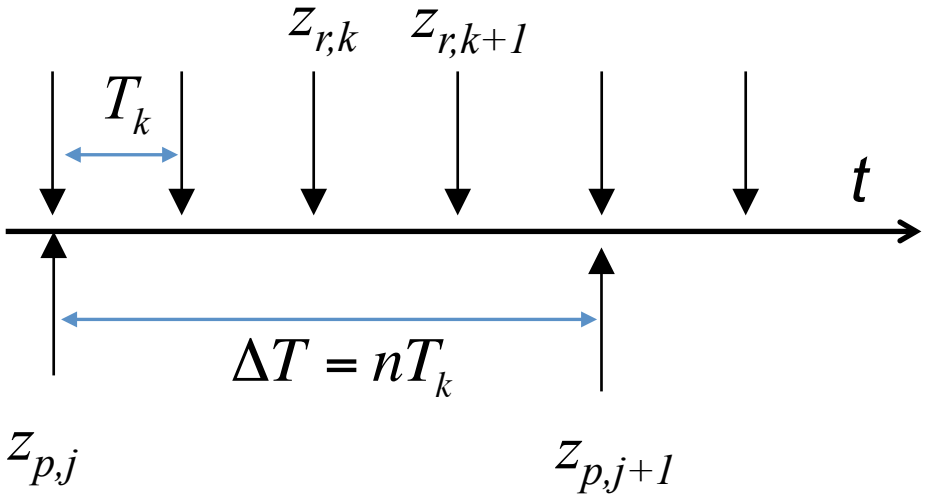
- SCADA
- Feeder automation devices
- Distributed generators
- Historic load patterns/profiles
- AMI data (Smart Meters concentrators)

Minimum redundancy levels obtained only when both information types are properly combined

State Estimation with two measurement latencies

Two distinct sets of measurements, captured at different rates:

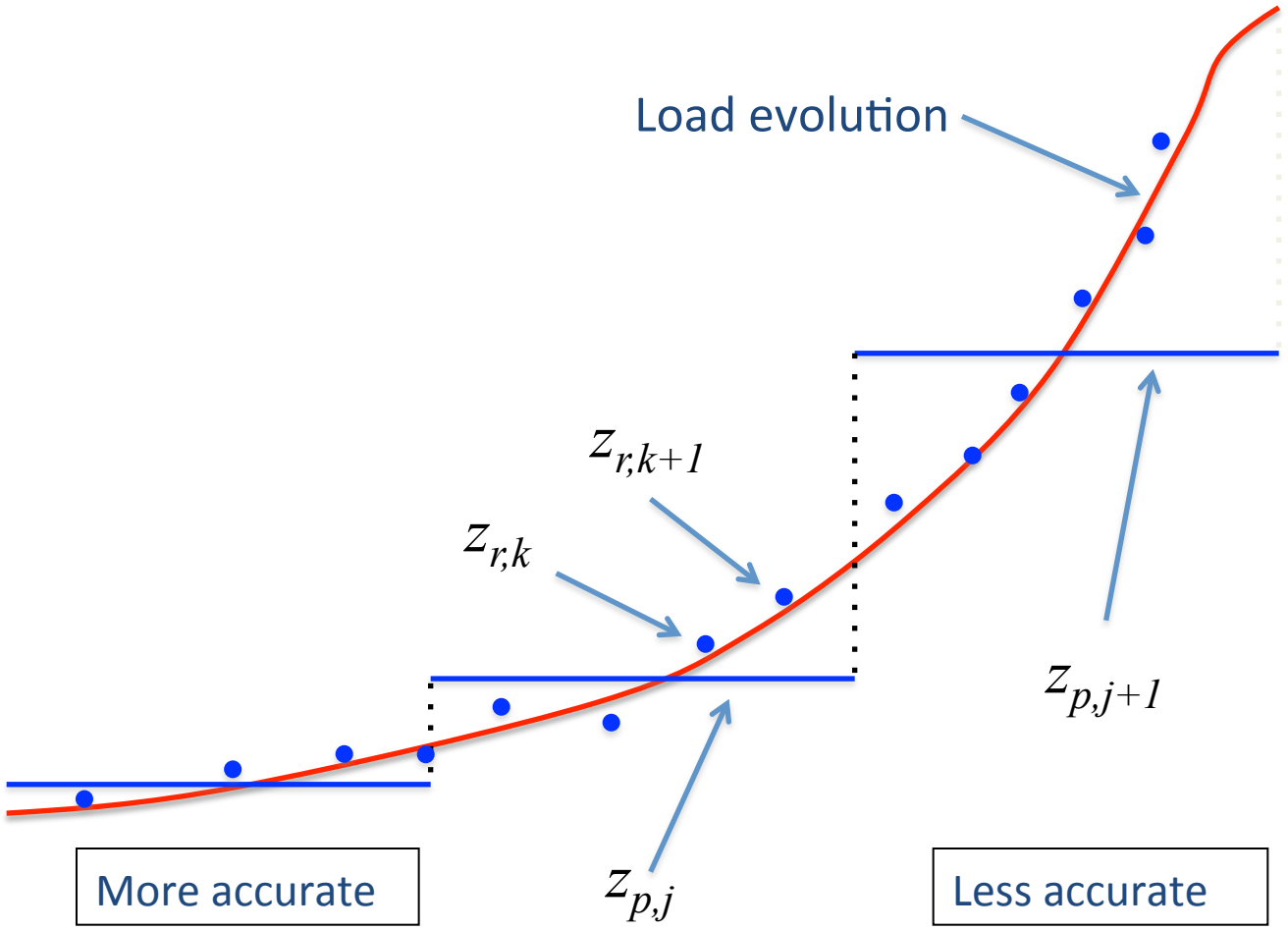
Real-time incomplete information system (fast rate)



Pseudomeasurements: less accurate, "complete" information system (slow rate)

State Estimation with two measurement latencies

Accuracy of Zp,j depends on the **rate of change of loads**



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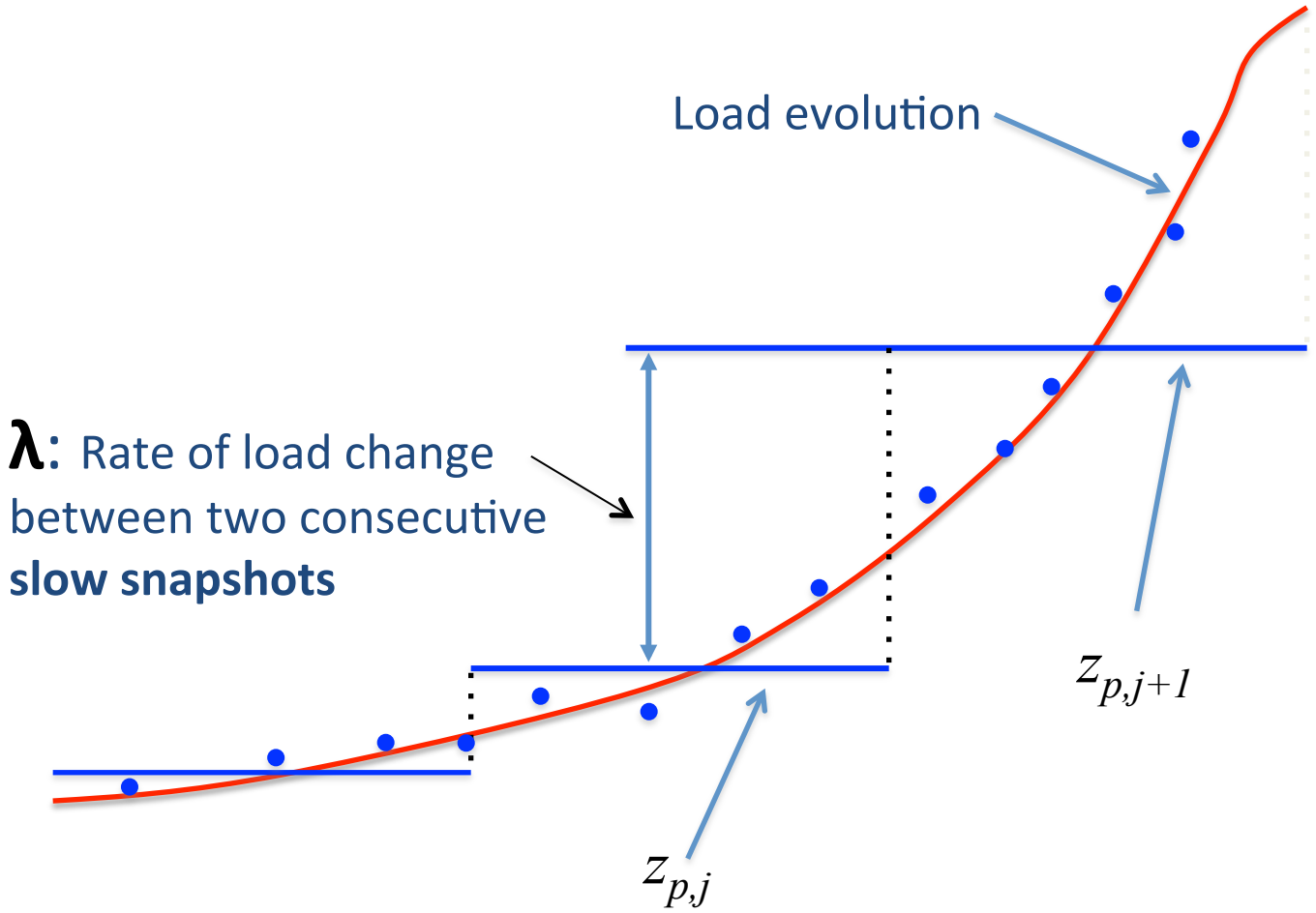


State Estimation with two measurement latencies

Mathematical model: WLS estimation with z_p *and* z_r

$$\begin{bmatrix} z_p \\ z_r \end{bmatrix} = \begin{bmatrix} h_p(x) \\ h_r(x) \end{bmatrix} + \begin{bmatrix} \varepsilon_p \\ \varepsilon_r \end{bmatrix}$$

Gauss-Newton methodology (Normal equations):

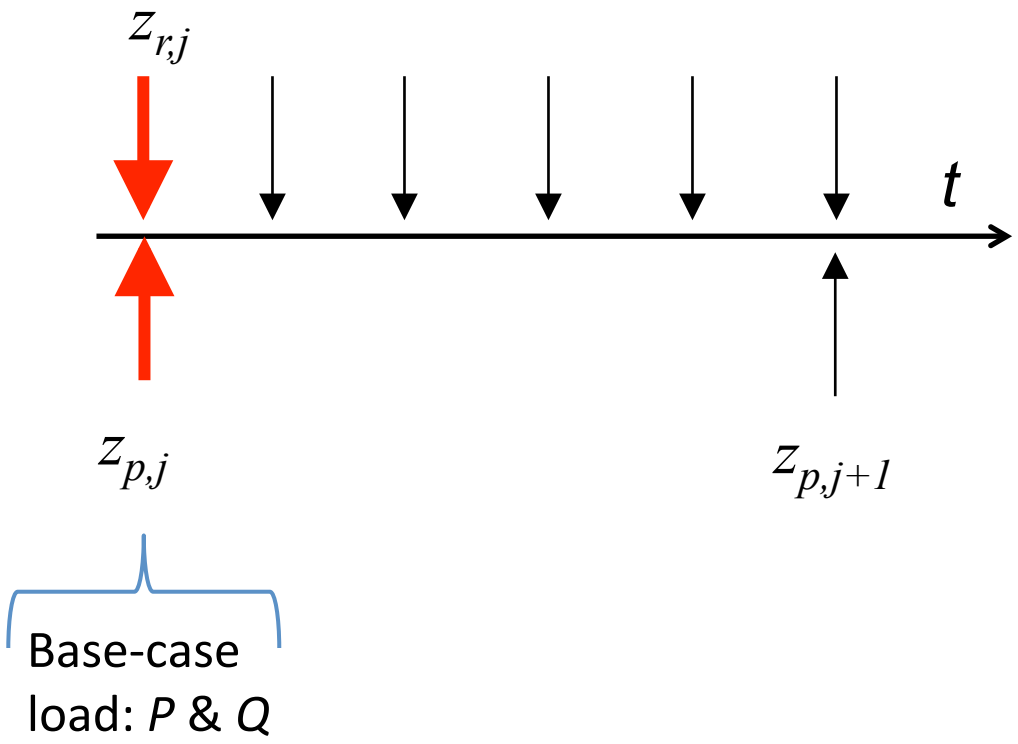
$$\left(H_p{}^t W_p H_p + H_r{}^t W_r H_r\right)\Delta x = H_p{}^t W_p \left(z_p - h_p(x)\right) + H_r{}^t W_r \left(z_r - h_r(x)\right)$$

where

$$\mathrm{cov}(\varepsilon_p) = W_p^{-1} \qquad \mathrm{cov}(\varepsilon_r) = W_r^{-1}$$

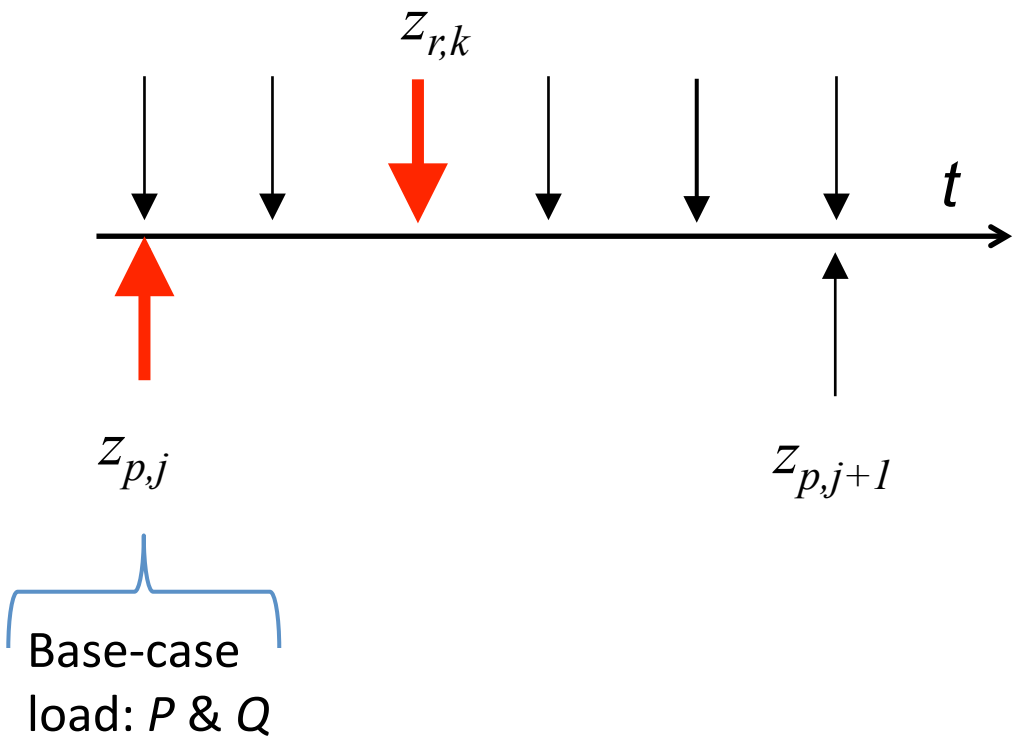
State Estimation with two measurement latencies

- **First (cold) execution:** both z_p and z_r updated



State Estimation with two measurement latencies

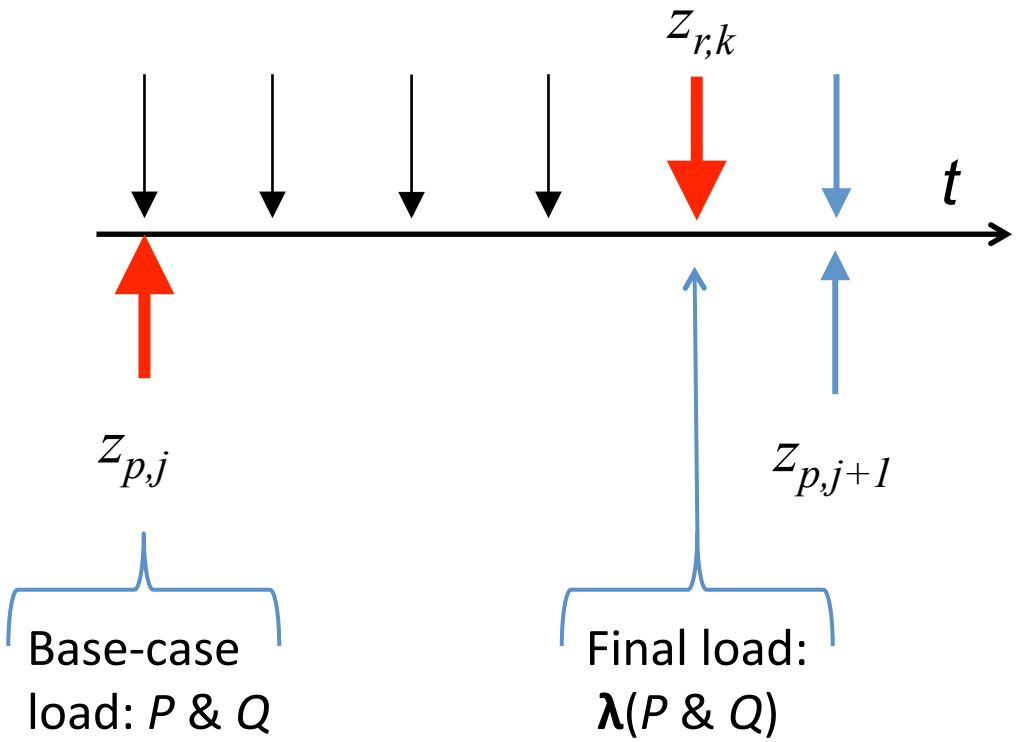
- ***n*-1 "warm" executions:** only z_r updated



Latest estimate used to start iterations

State Estimation with two measurement latencies

- ***n*-1 "warm" executions:** only z_r updated



Latest estimate used to start iterations

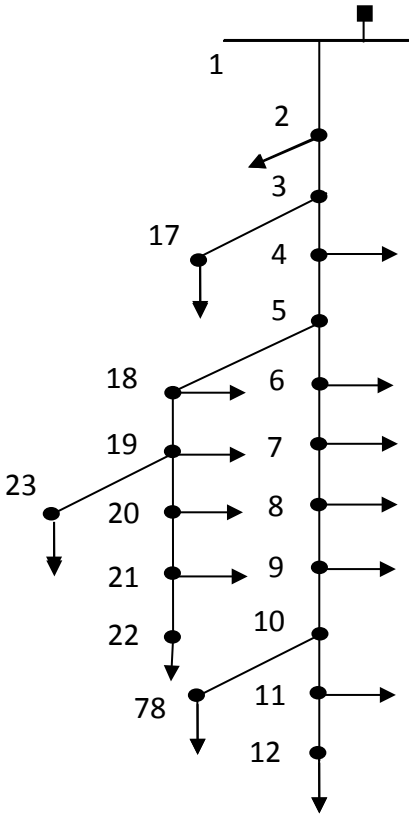
Case study

Can a small subset of "real-time" measurements, when combined with a critical set of (outdated) pseudomeasurements, provide accurate enough estimates ? (reconstruction of network state)

Case study

- Small radial distribution system (20 buses)
- **Pseudomeasurements** ($\boldsymbol{z_p}$): V_1 and P & Q at all buses

$N_x = N_{zp} = 39$



Case study

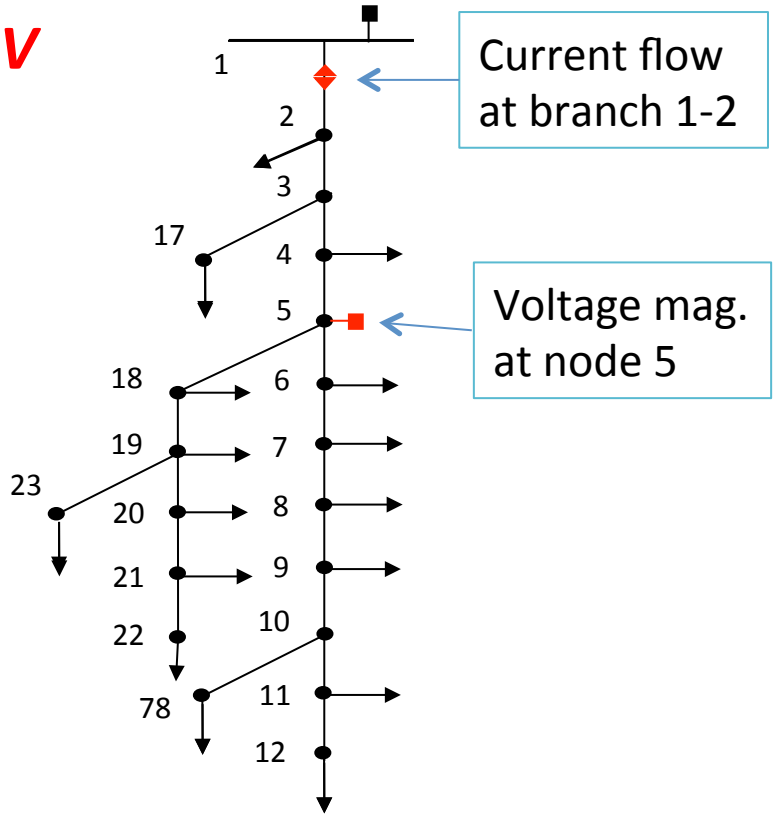
- Small radial distribution system (20 buses)
- **Pseudomeasurements** (z_p): V_1 and P & Q at all buses

$N_x = N_{zp} = 39$

- **Real-time measurements** (z_r): ***I* & *V***
  - Very few in practice
  - In our tests limited to:

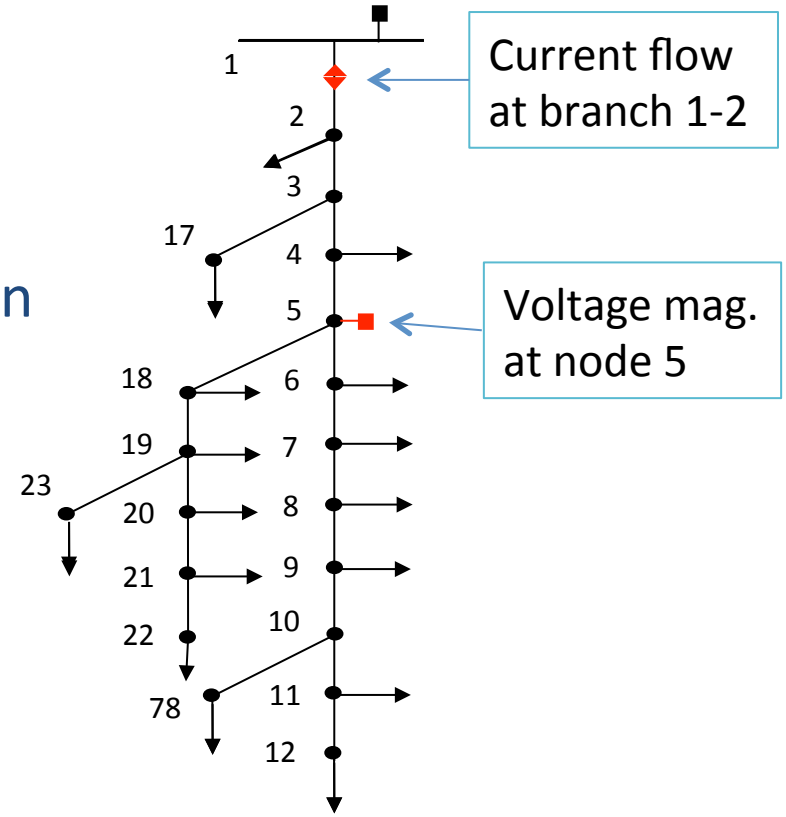
$N_{zr} = 5$

Redundancy = 1.128



Case study

- Small radial distribution system (20 buses)
- **Pseudomeasurements** (z_p): V_1 and P & Q at all buses
- Different scenarios for **real-time measurements** (z_r):
  - Measurement type: ***I* & *V***
  - Measurement locations
  - Rate of load change: $\lambda^{max}=1.5$
  - Change in power flow direction



Case study

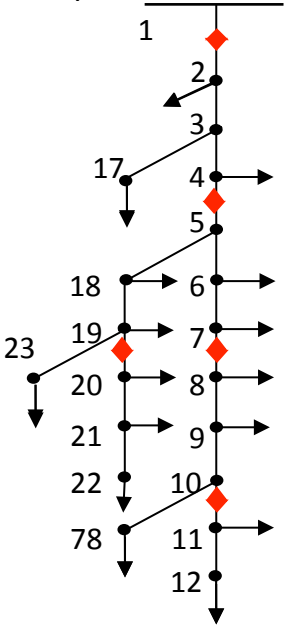
- Small radial distribution system (20 buses)
- **Pseudomeasurements** ($\boldsymbol{z_p}$): V_1 and P & Q at all buses
- Different scenarios for **real-time measurements** ($\boldsymbol{z_r}$):
  - Measurement type: ***I* & *V***
  - Measurement locations
  - Rate of load change: $\boldsymbol{\lambda^{max}=1.5}$
  - Change in power flow direction
- WLS solutions compared with exact state:
  - z_p values "frozen" with base-case load
  - z_r values updated according to load evolution
    [$1< \lambda <1.5$; $\Delta\lambda=0.05$]

Test 1: Comparison of measurement type: ***I*** versus ***V***

Set z_r: uniformly distributed sets of measurements

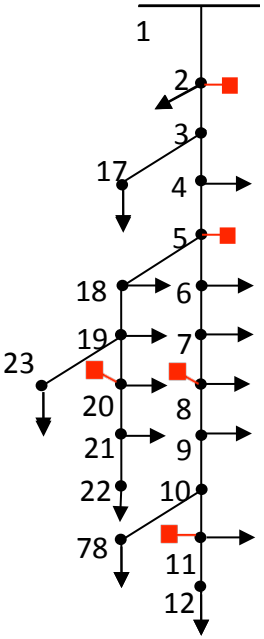
- A -

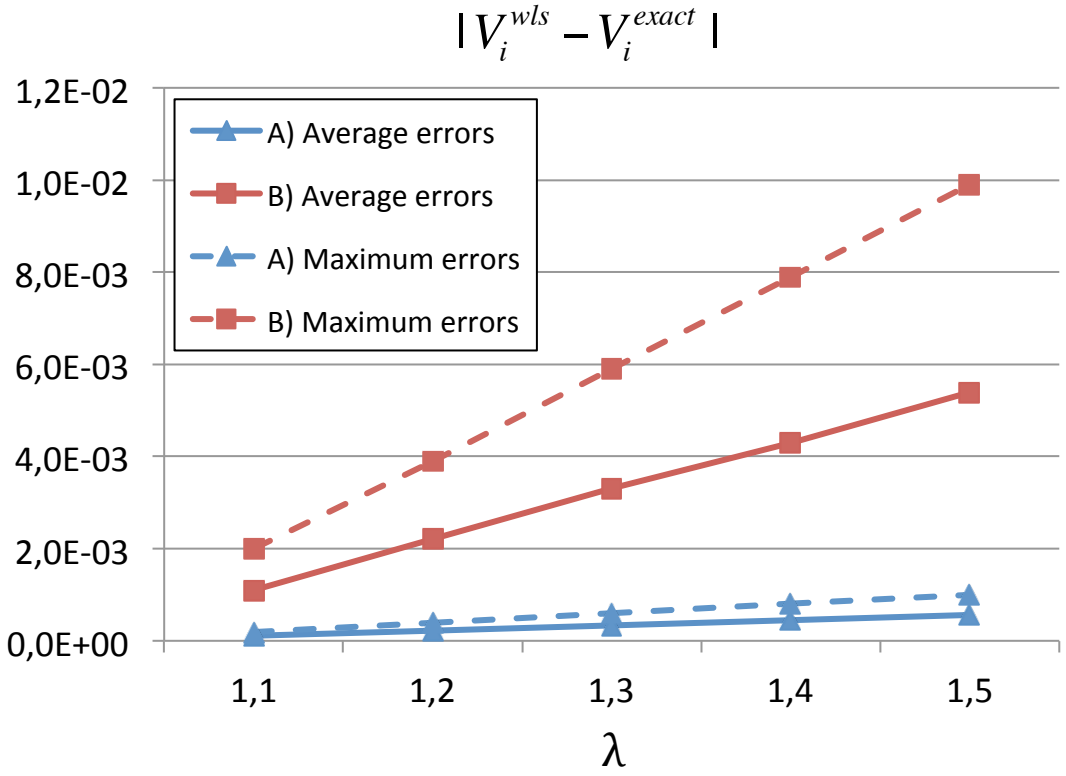
z_r = currents



- B -

z_r = voltages





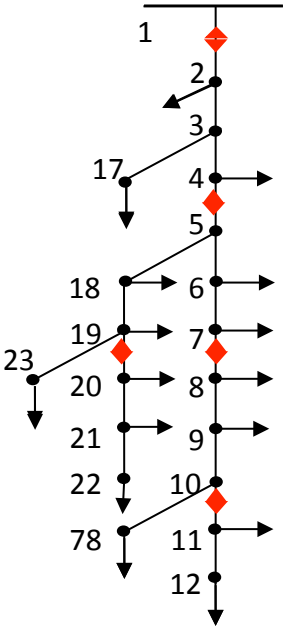
- Current meas. better than voltage meas. (up to 10 times lower voltage error)
- Errors increase linearly with load growth (pseudomeasurement obsolescence)

Test 2: Comparison of measurement location

Sets z_r: current measurements, different locations

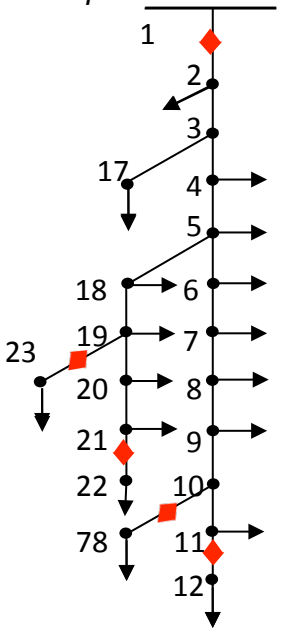
- A -

z_r uniform

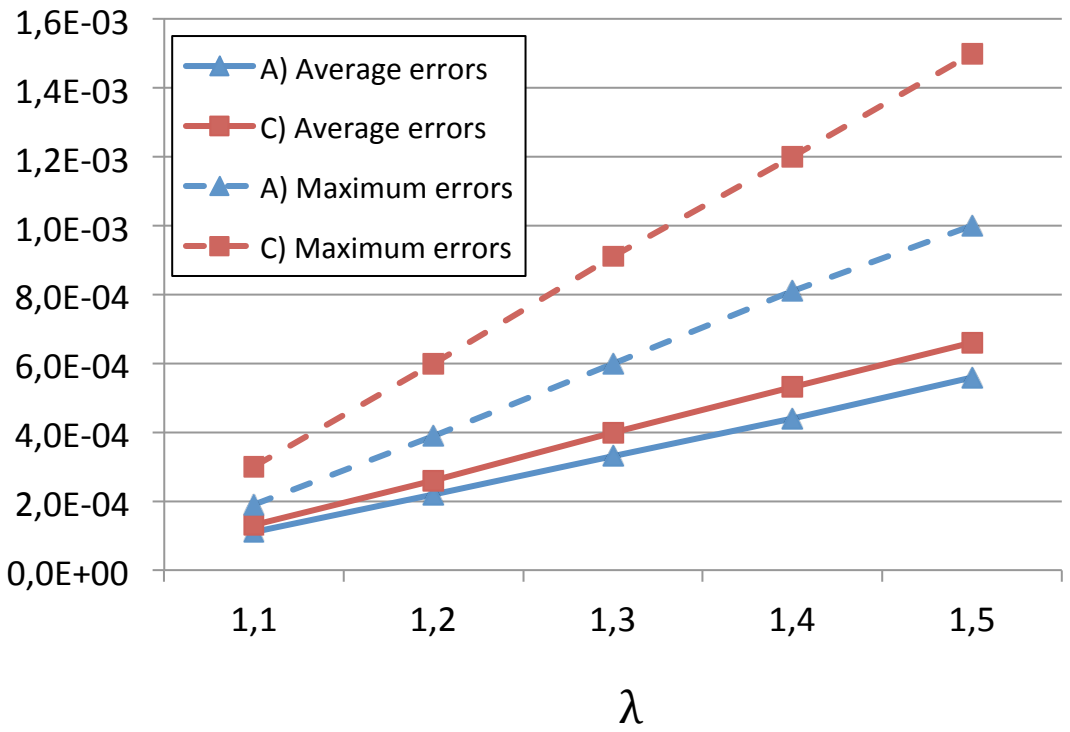


- C -

z_r at the ends



Voltage errors $|V_i^{wls} - V_i^{exact}|$



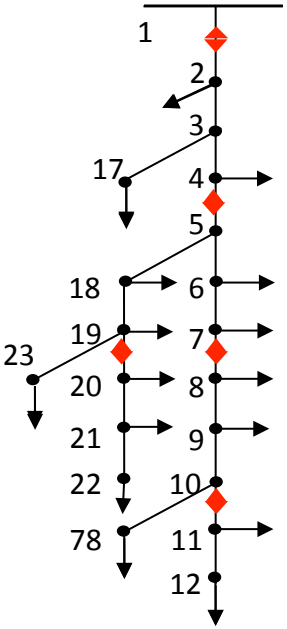
- Better results with uniformly distributed current measurements

Test 2: Comparison of measurement location

Sets z_r: current measurements, different locations

- A -

z_r uniform



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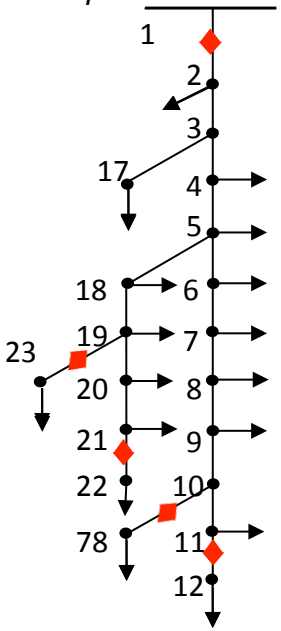
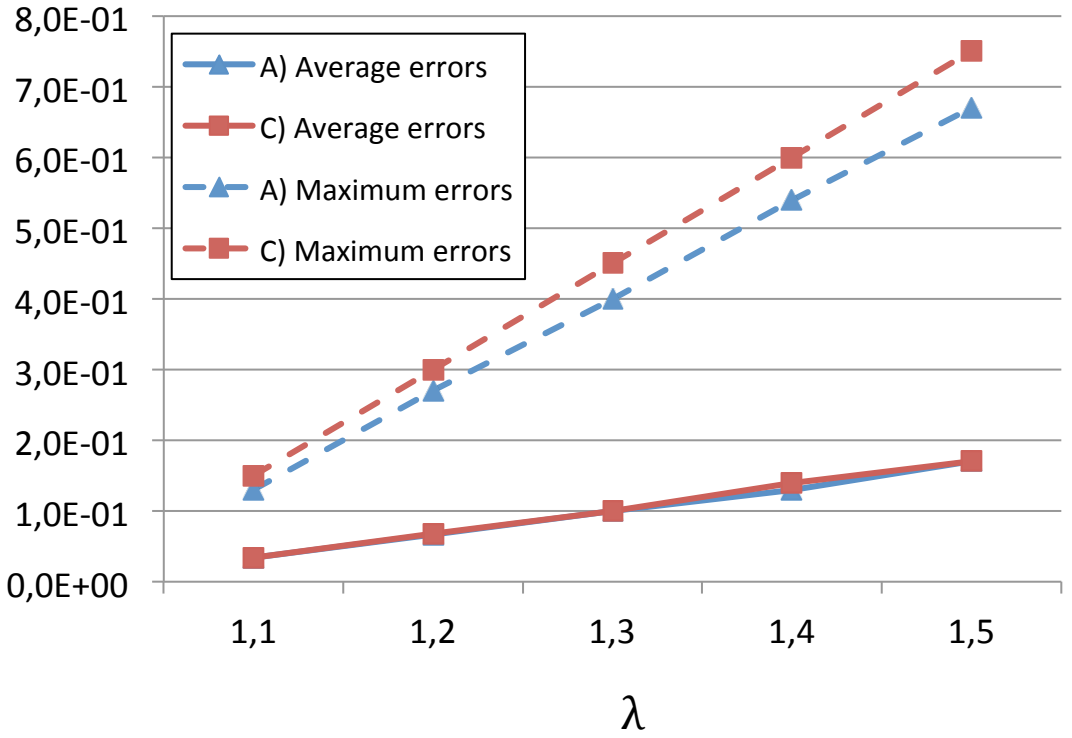
z_r at the ends



Injection errors $|S_i^{wls} - S_i^{exact}|$



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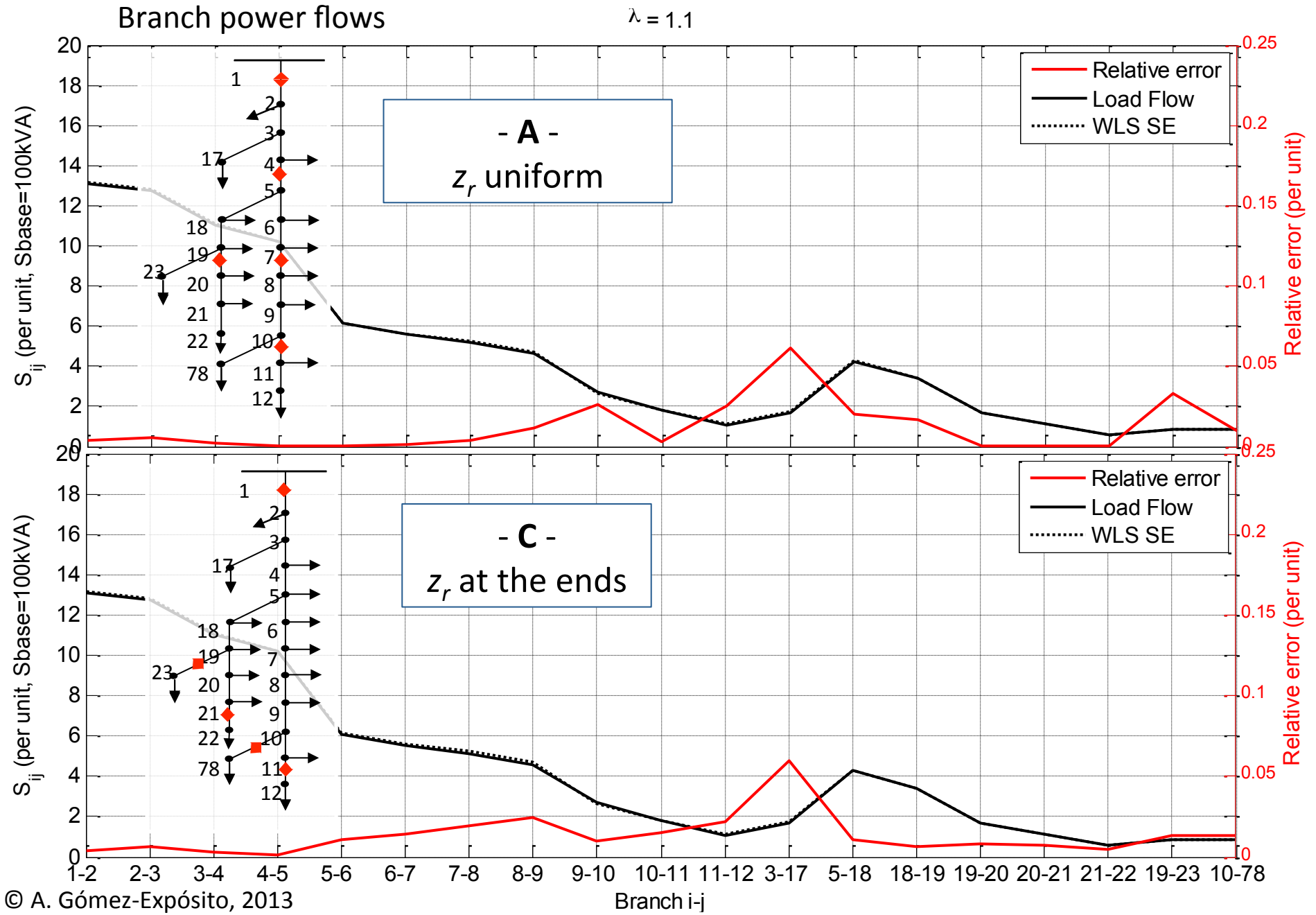

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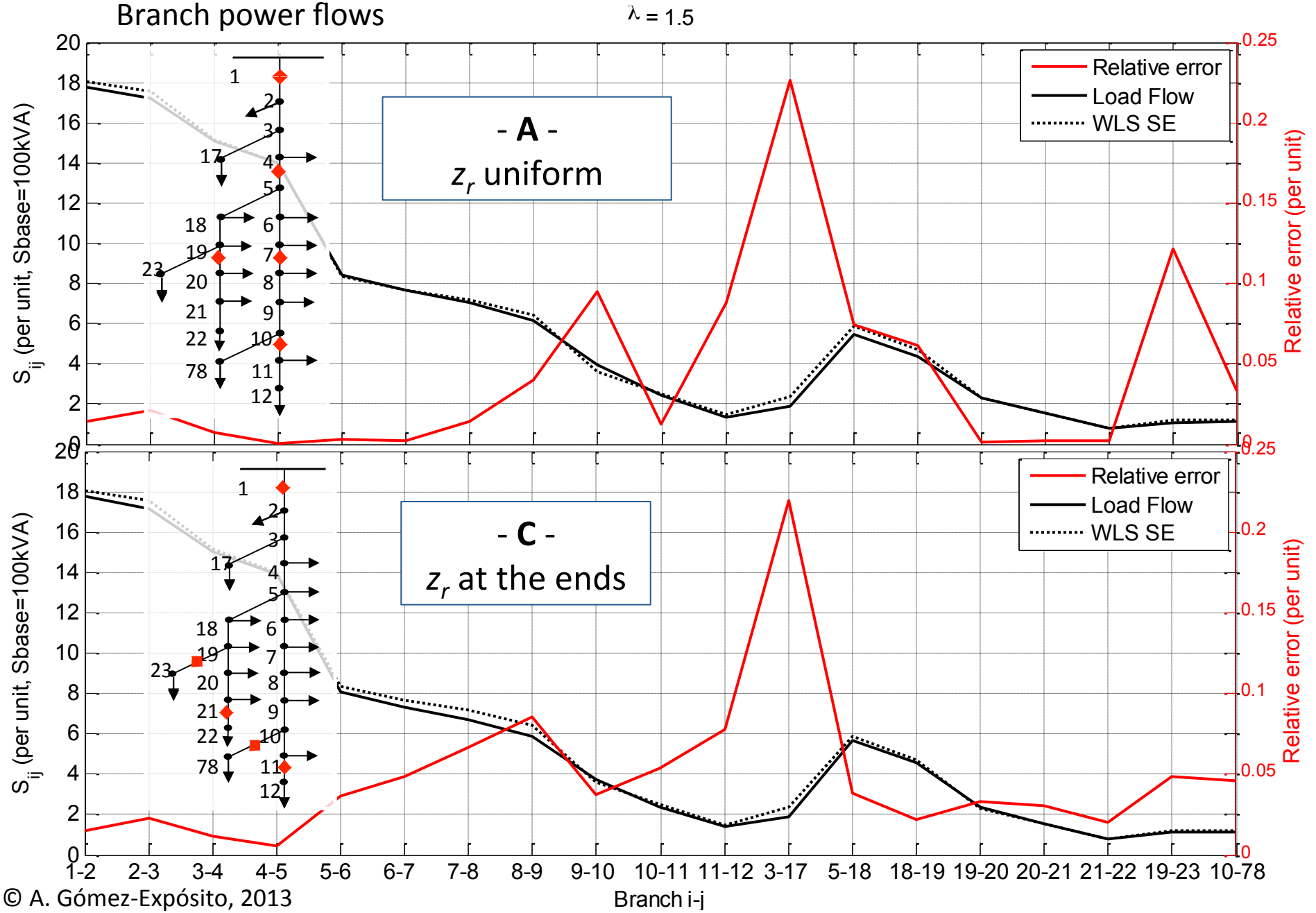
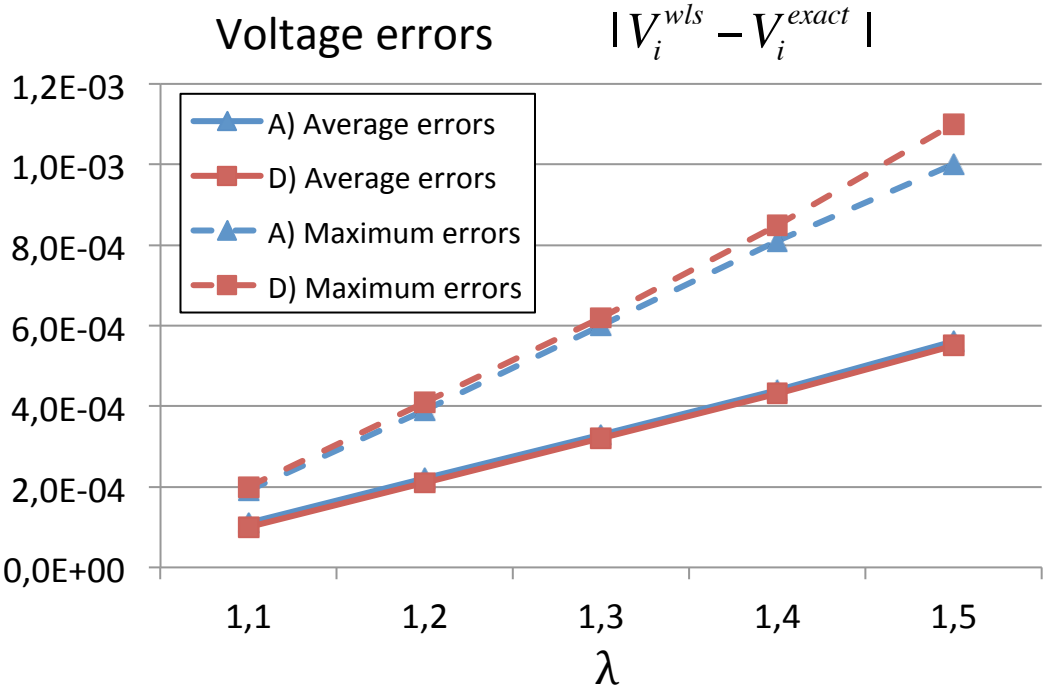


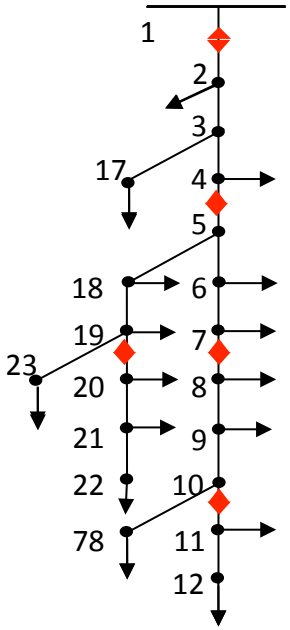
Test 3: Weighting coefficient influence

Set z_r: current measurements, uniformly distributed

- **A** - $\sigma_p = 0.1$, $\sigma_r = 0.1$

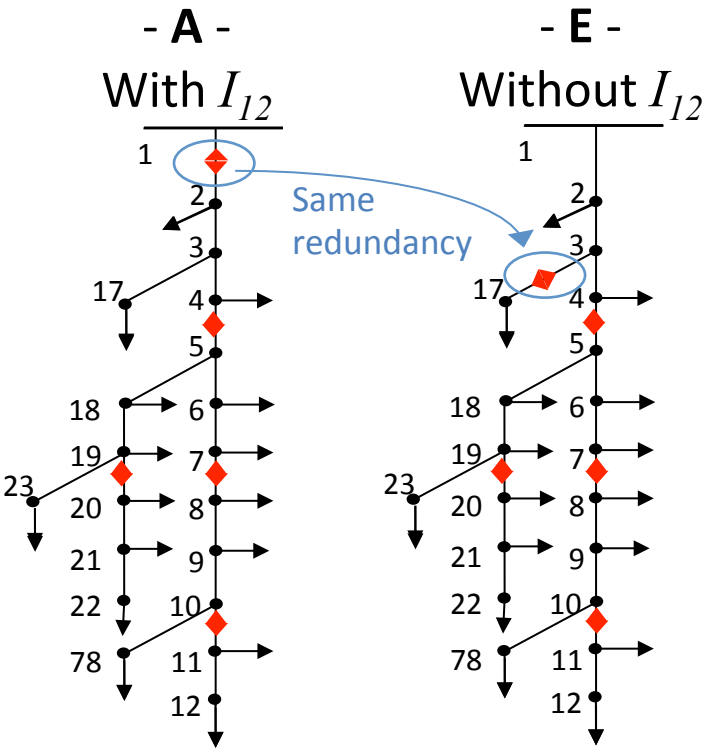
- **D** - $\sigma_p = 0.1$, $\sigma_r = 0.001$

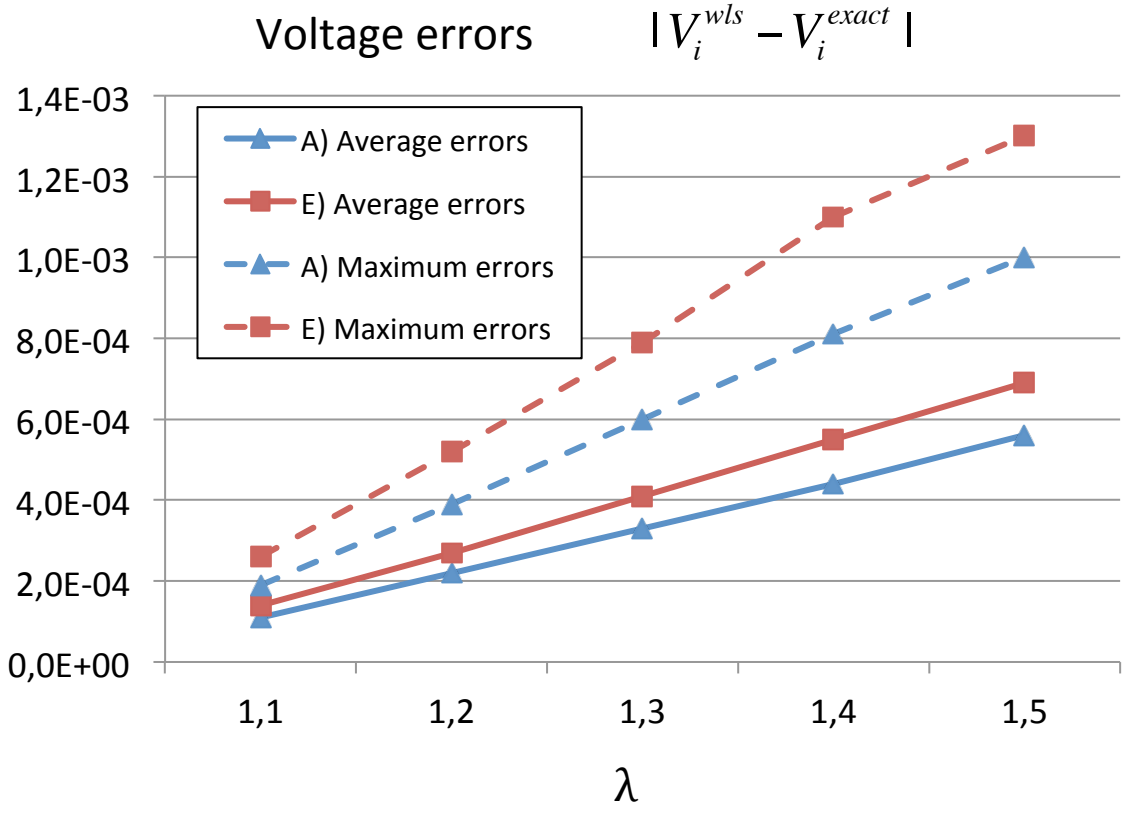




- Similar results with equal or different weights

Test 4: Influence of head current

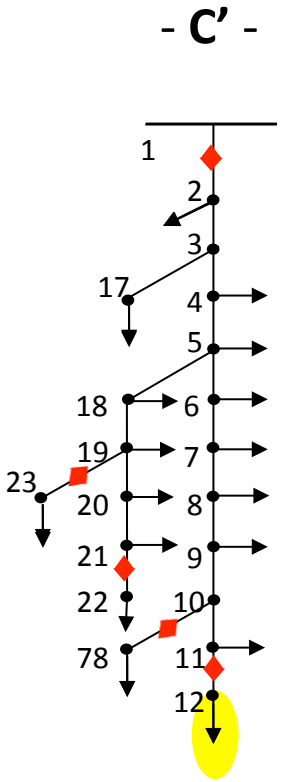




- Better results with head current measurement

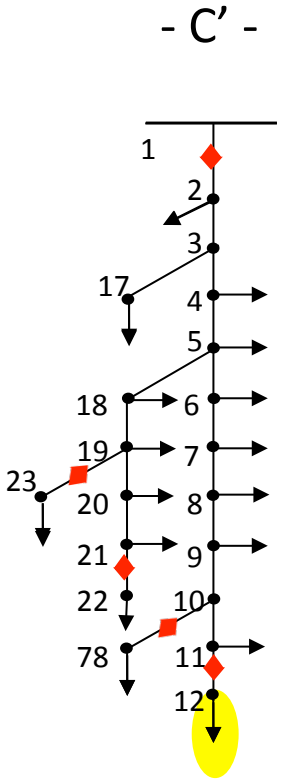
Test 5: Change in power flow direction (distributed generation)

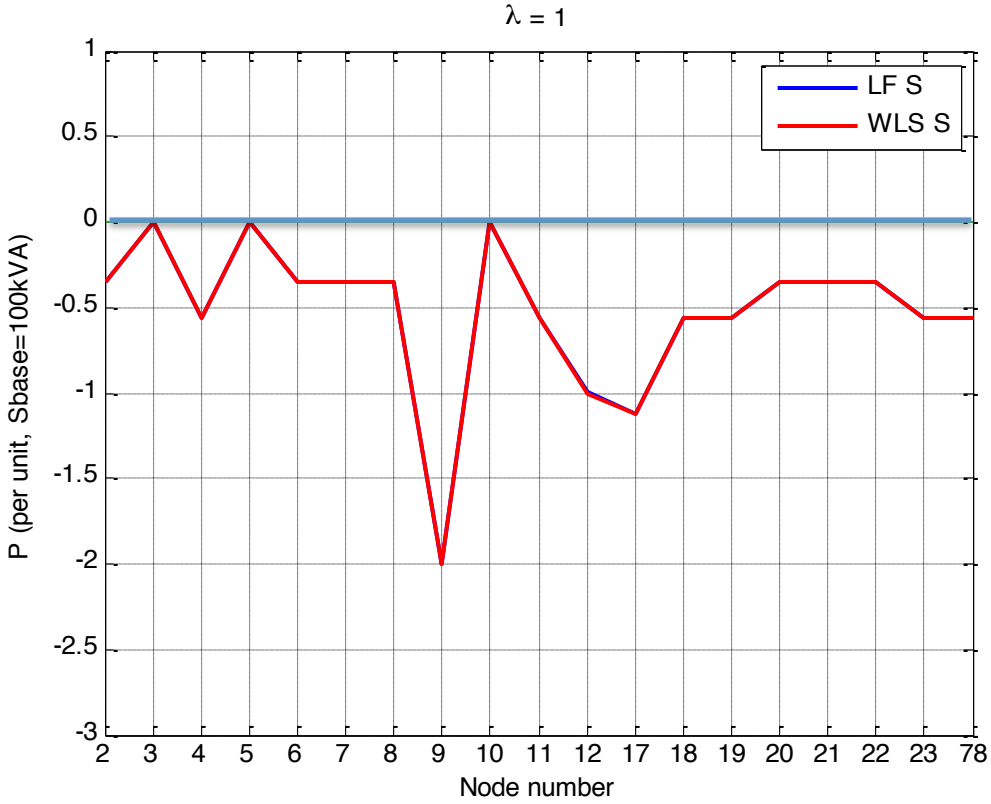
Set z_r: currents at the end of feeder laterals



Scenario: Power injection changes from P_{12} to $-P_{12}$ while rest of loads increase from λ=1 up to λ=1.5.

Test 5: Change in power flow direction (distributed generation)





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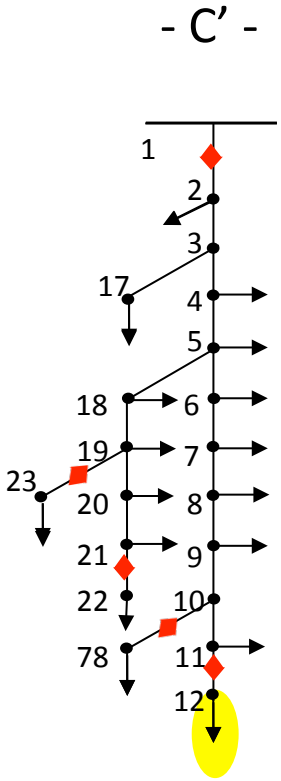

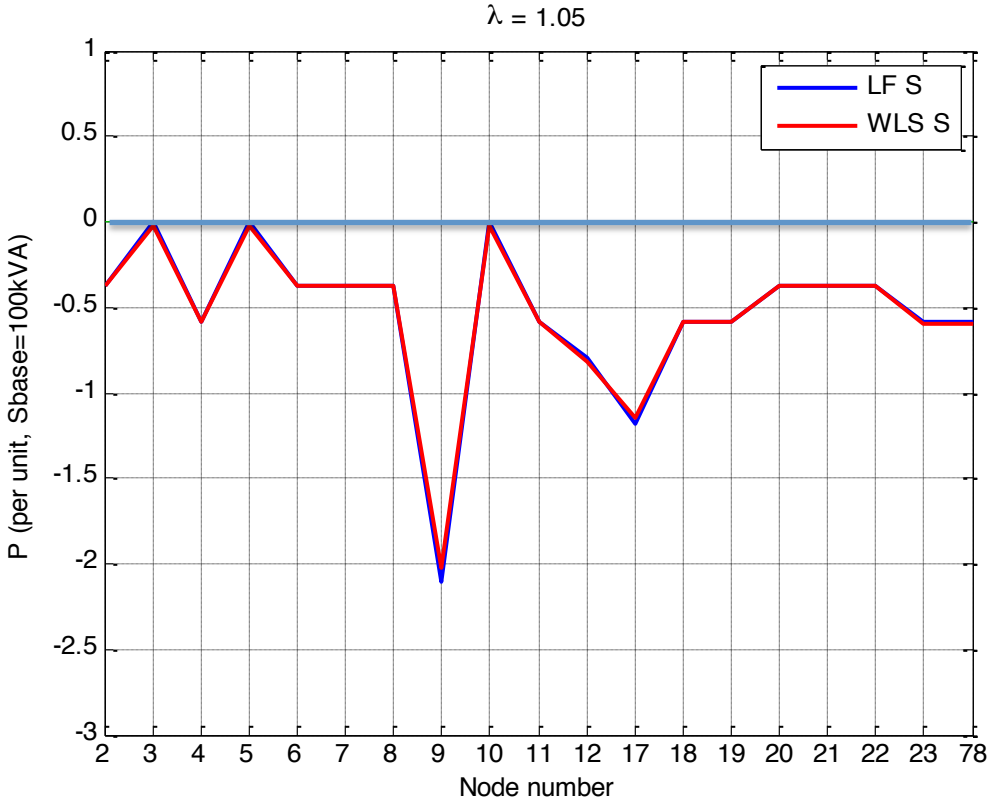

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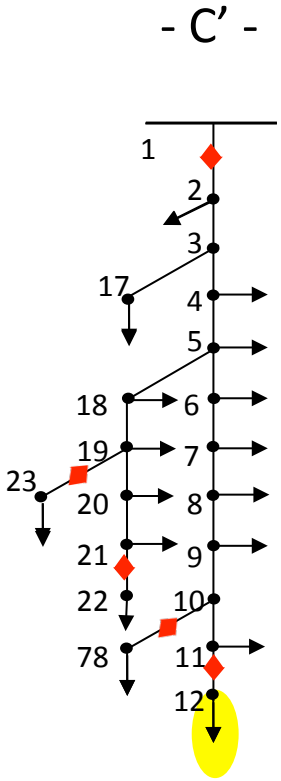

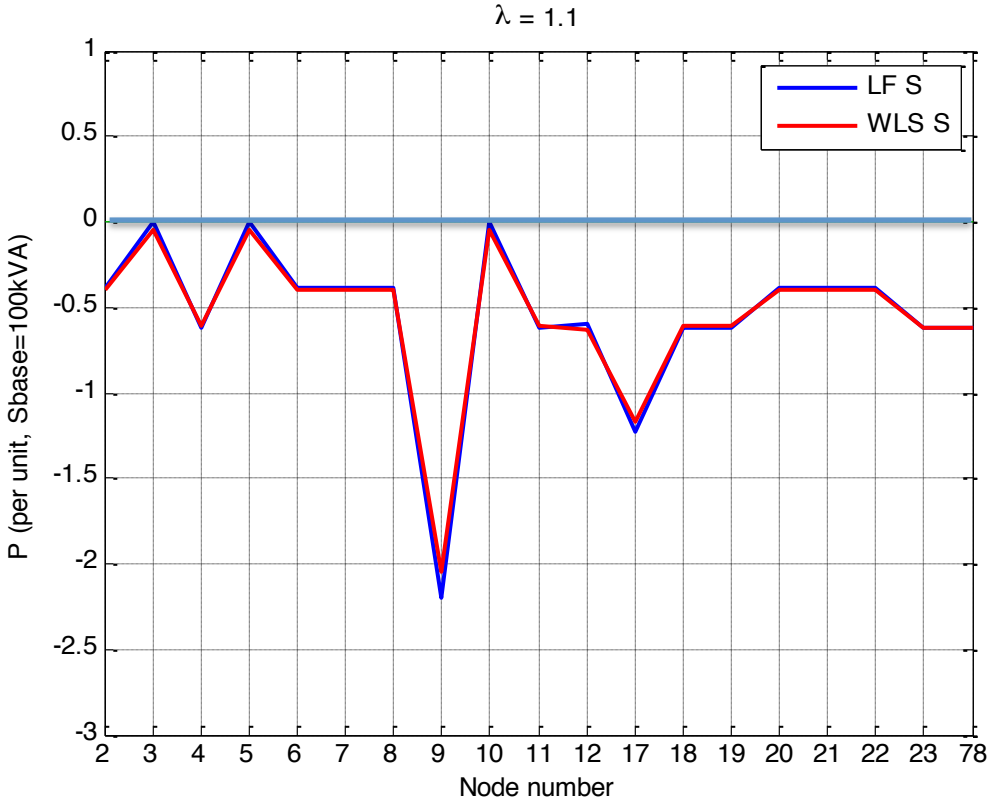

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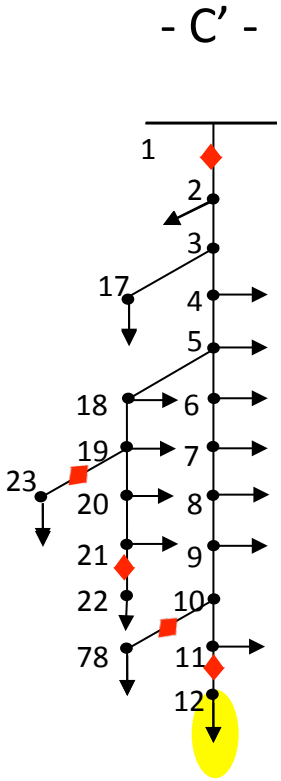

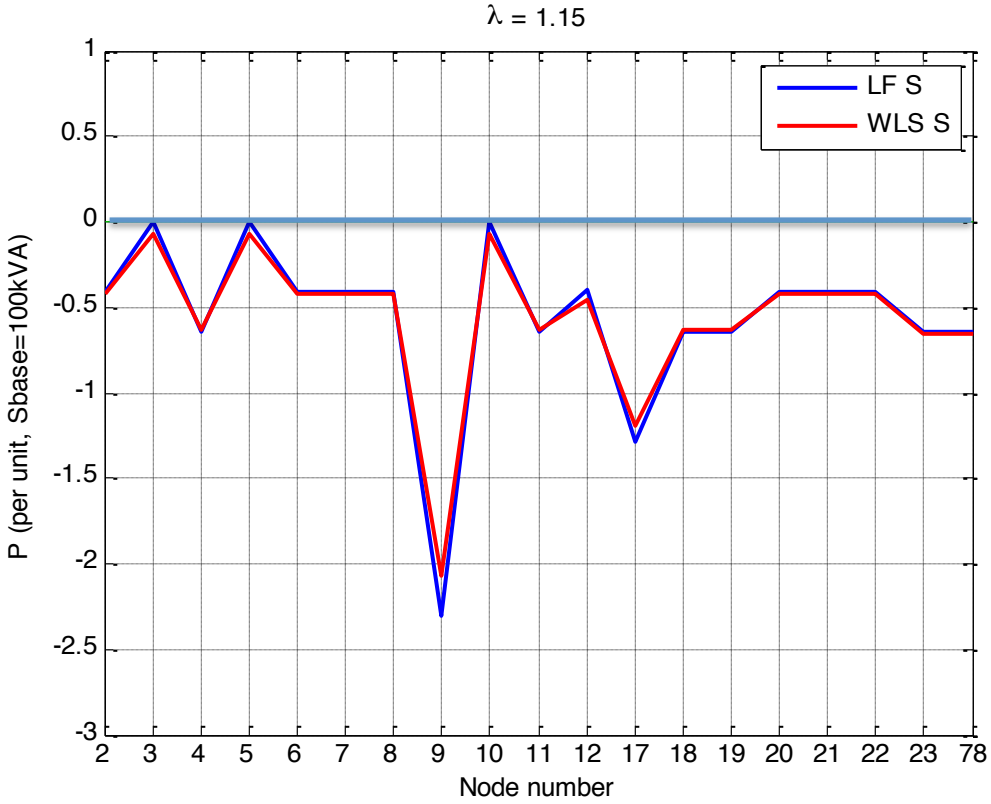

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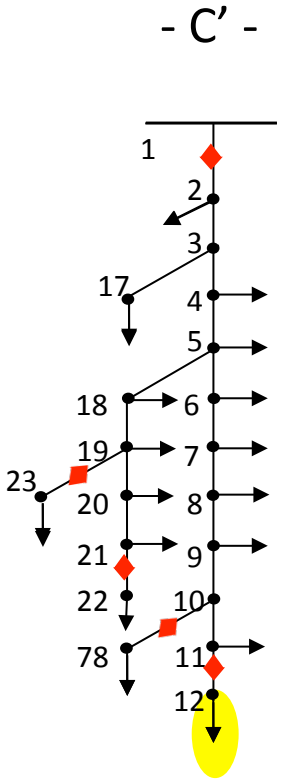
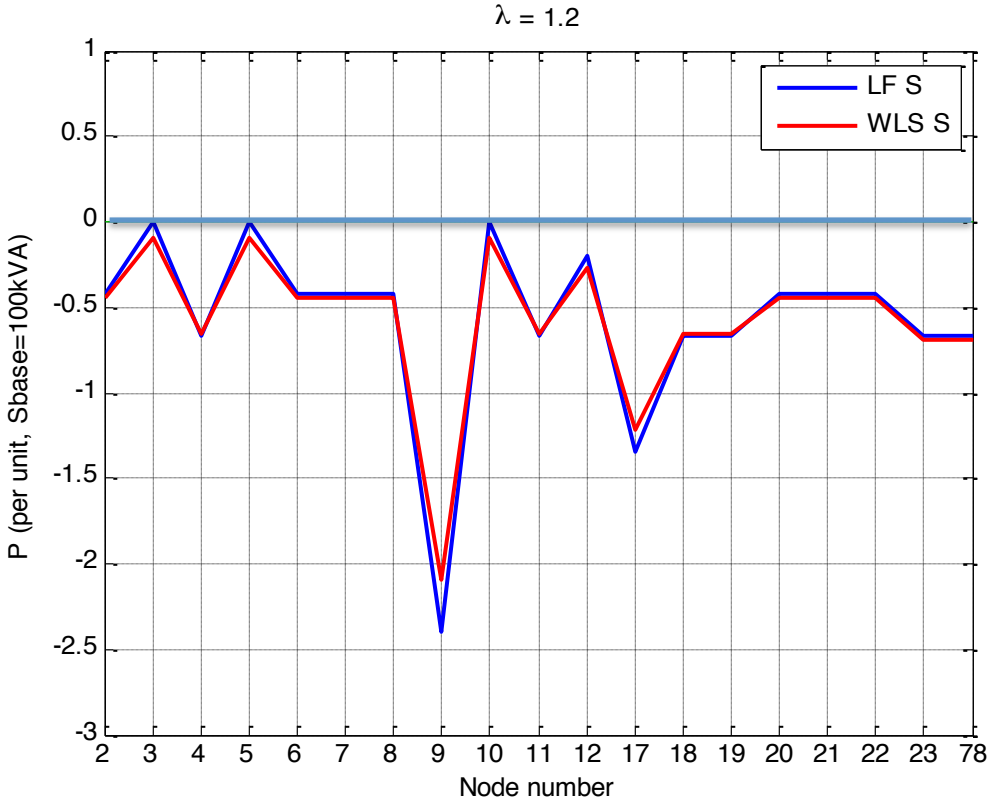
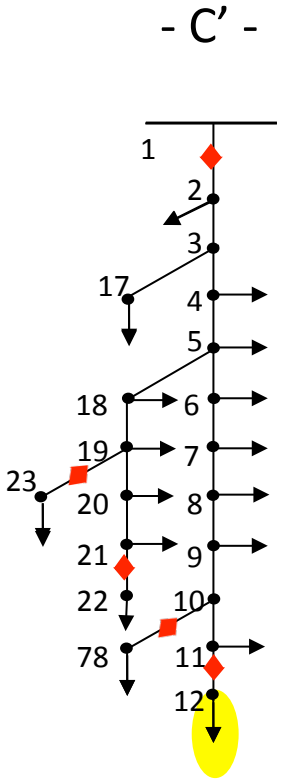
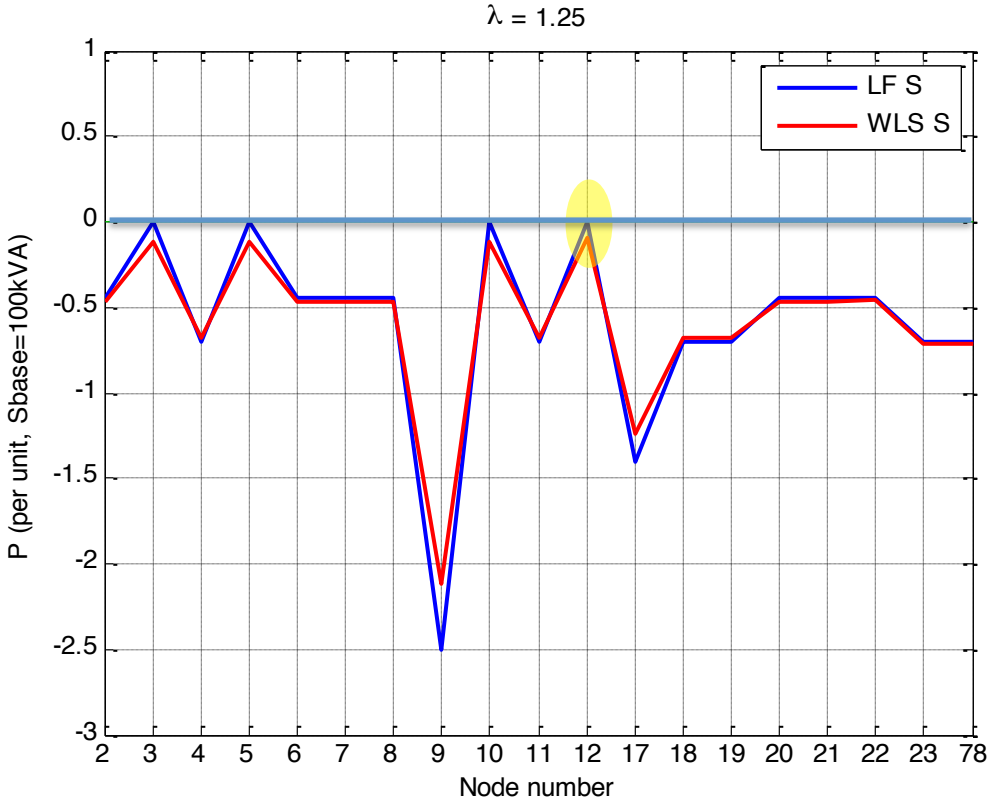


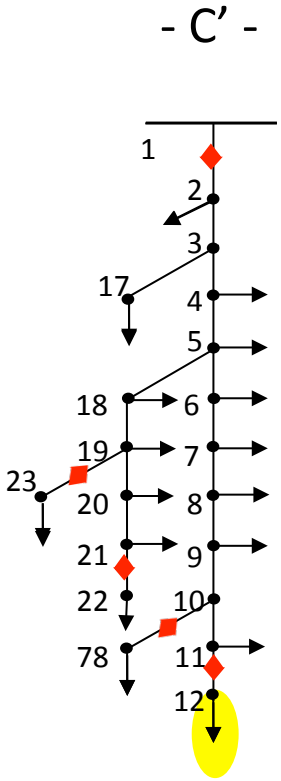


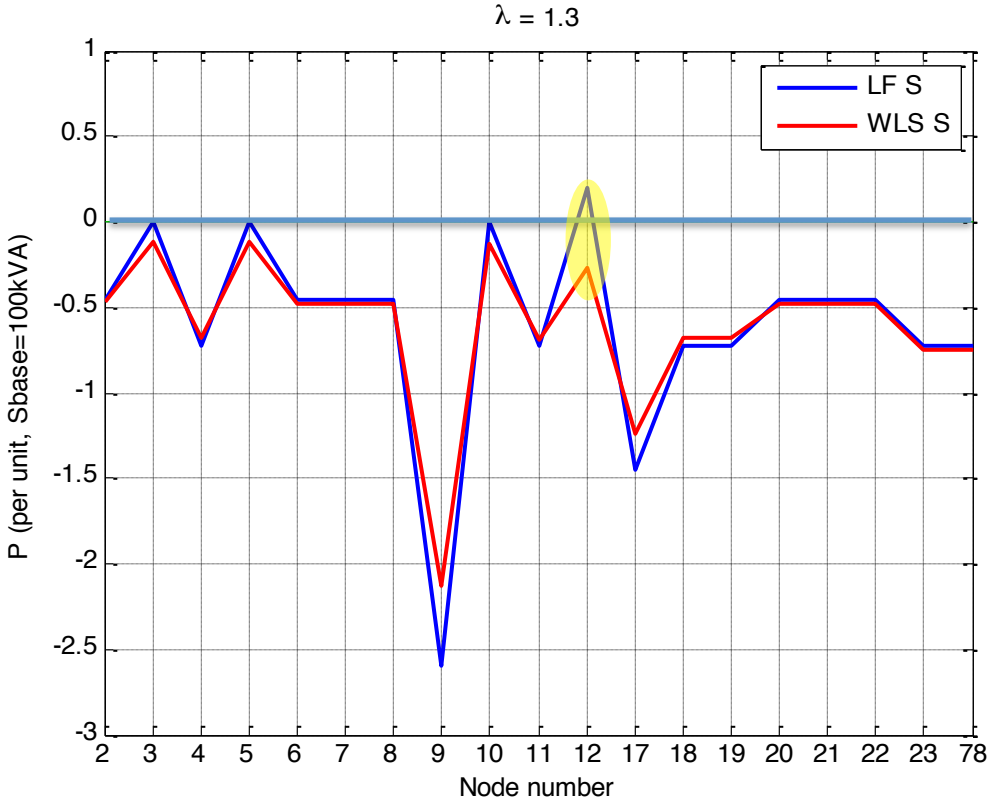
Test 5: Change in power flow direction (distributed generation)



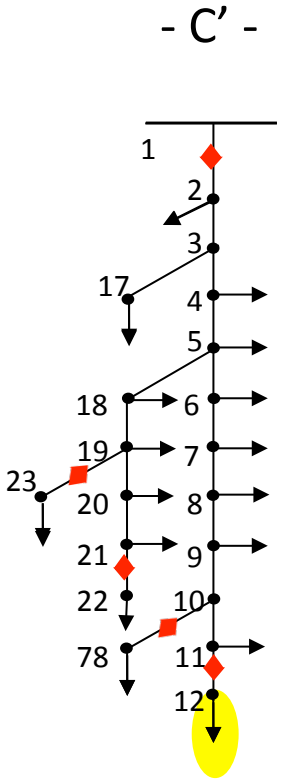


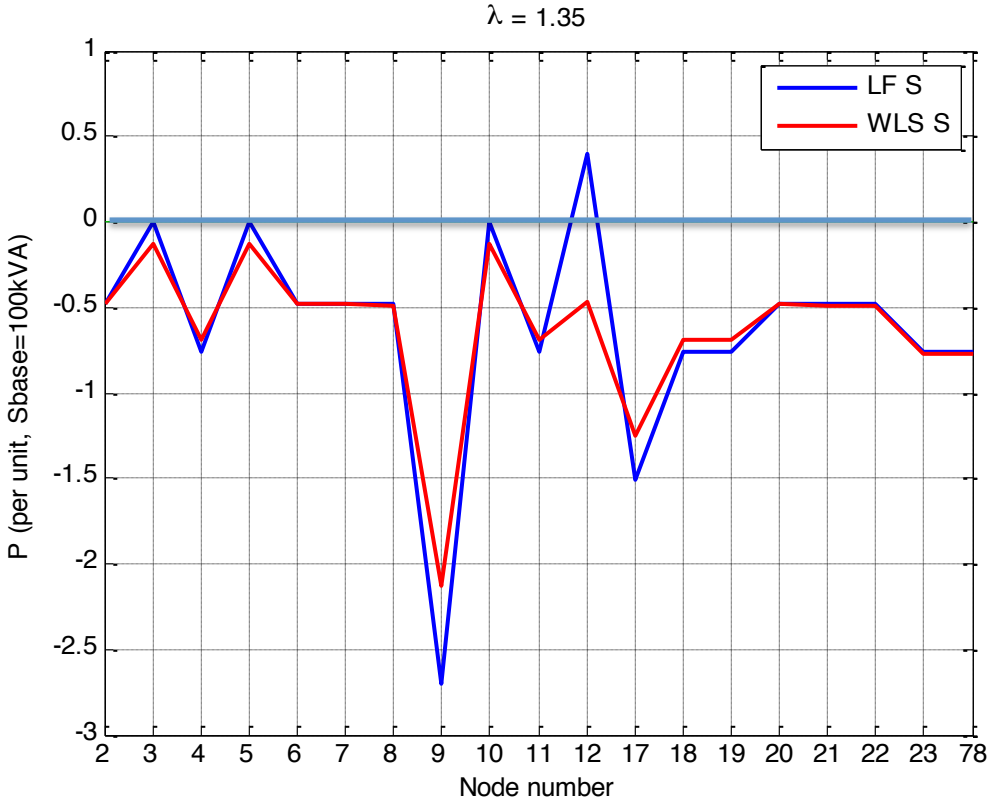
Test 5: Change in power flow direction (distributed generation)



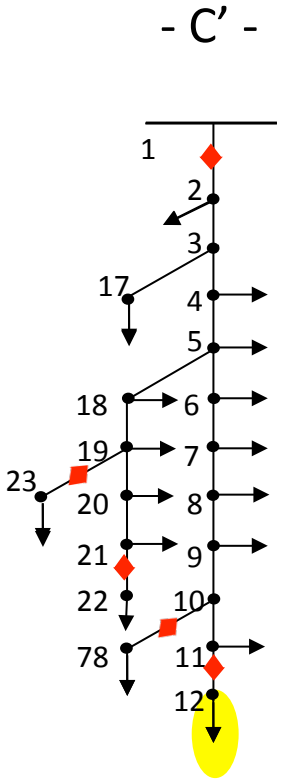


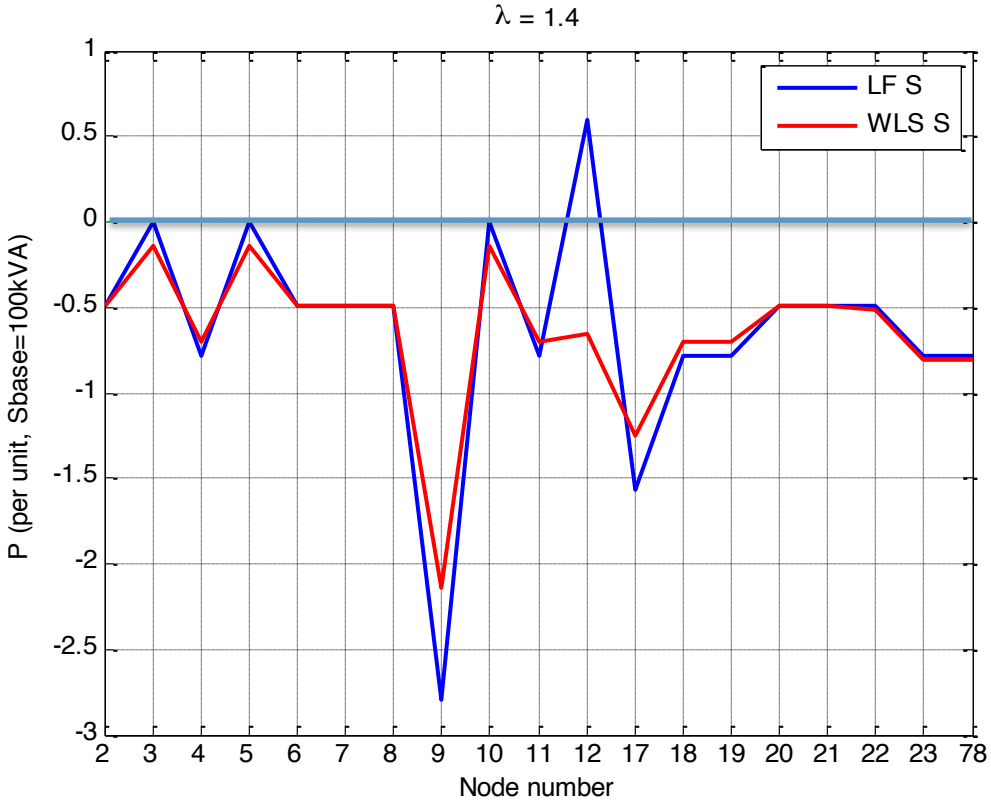
Test 5: Change in power flow direction (distributed generation)



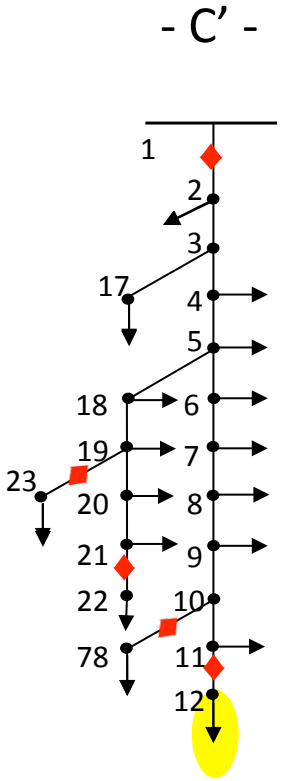


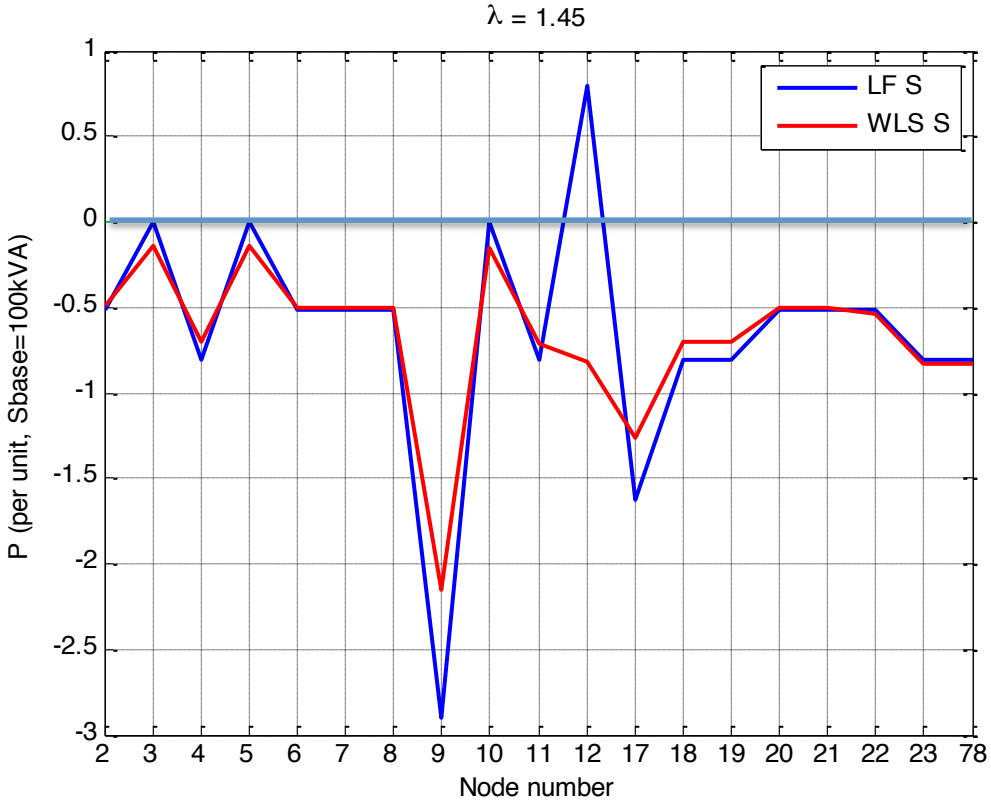
Test 5: Change in power flow direction (distributed generation)



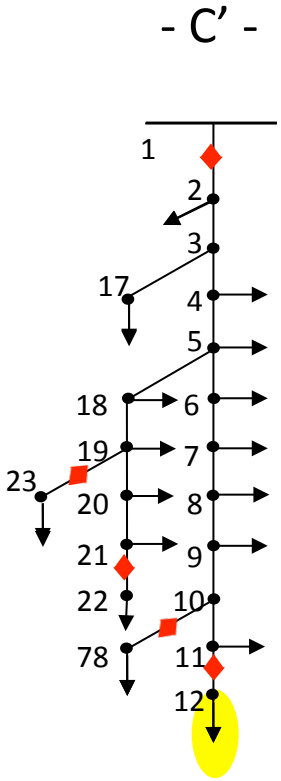


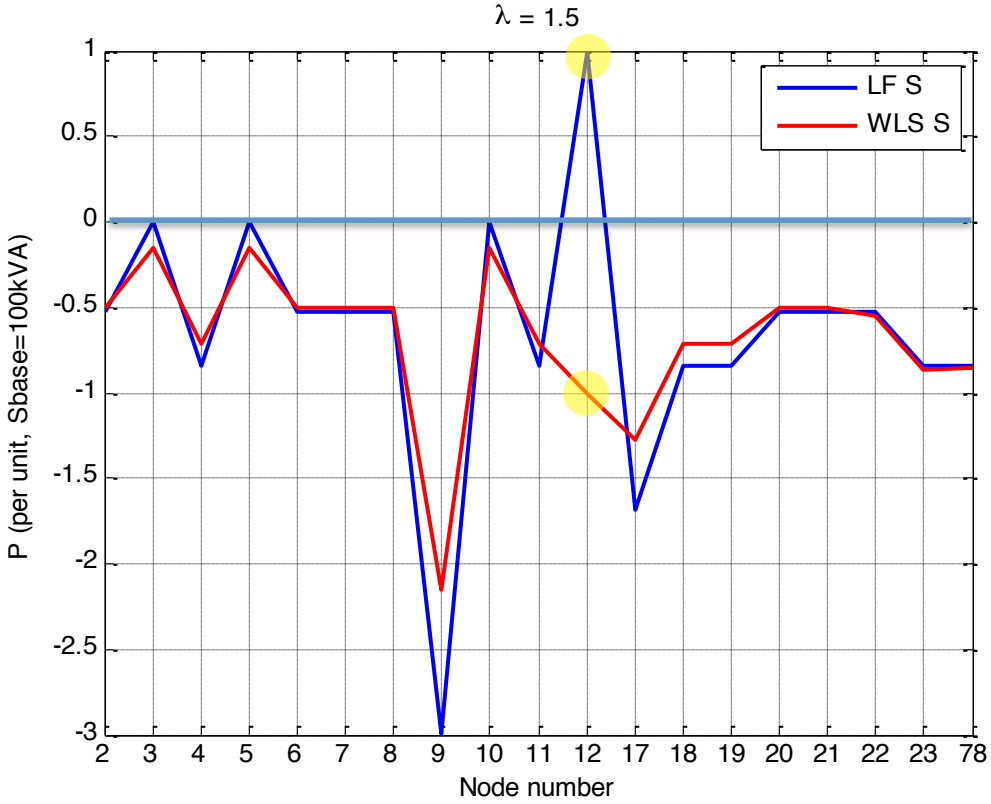
Test 5: Change in power flow direction (distributed generation)





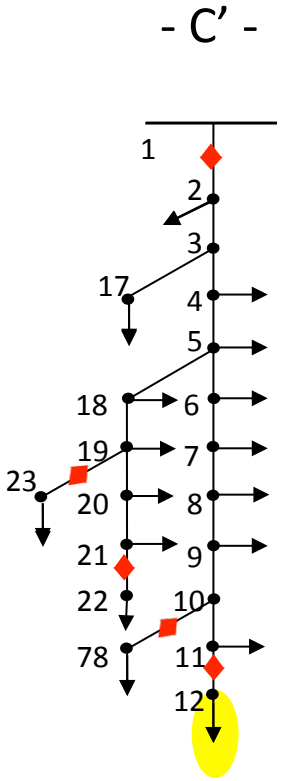
Test 5: Change in power flow direction (distributed generation)





- Inability of current measurements to track sign changes in *P*

Test 5: Change in power flow direction (distributed generation)

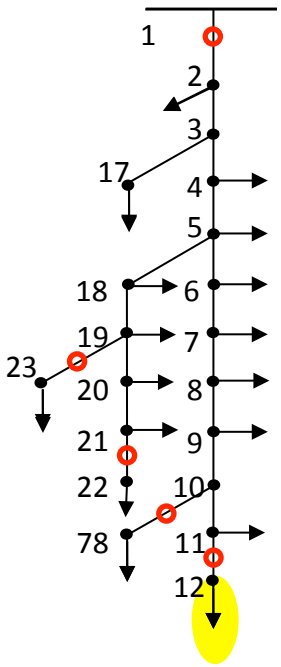


- Same happens when Q_{12} changes its sign

Test 5: Change in power flow direction (distributed generation)

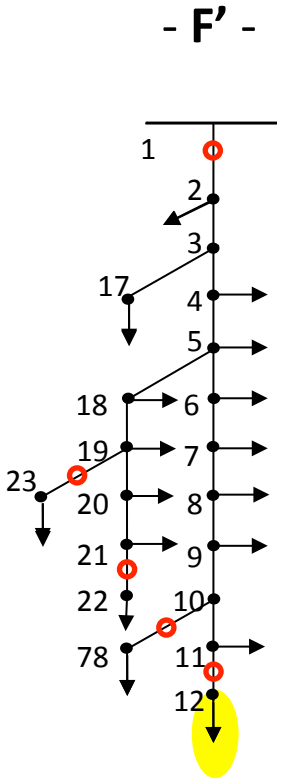
Set z_r: Active power flow measurements '⊙' instead of currents

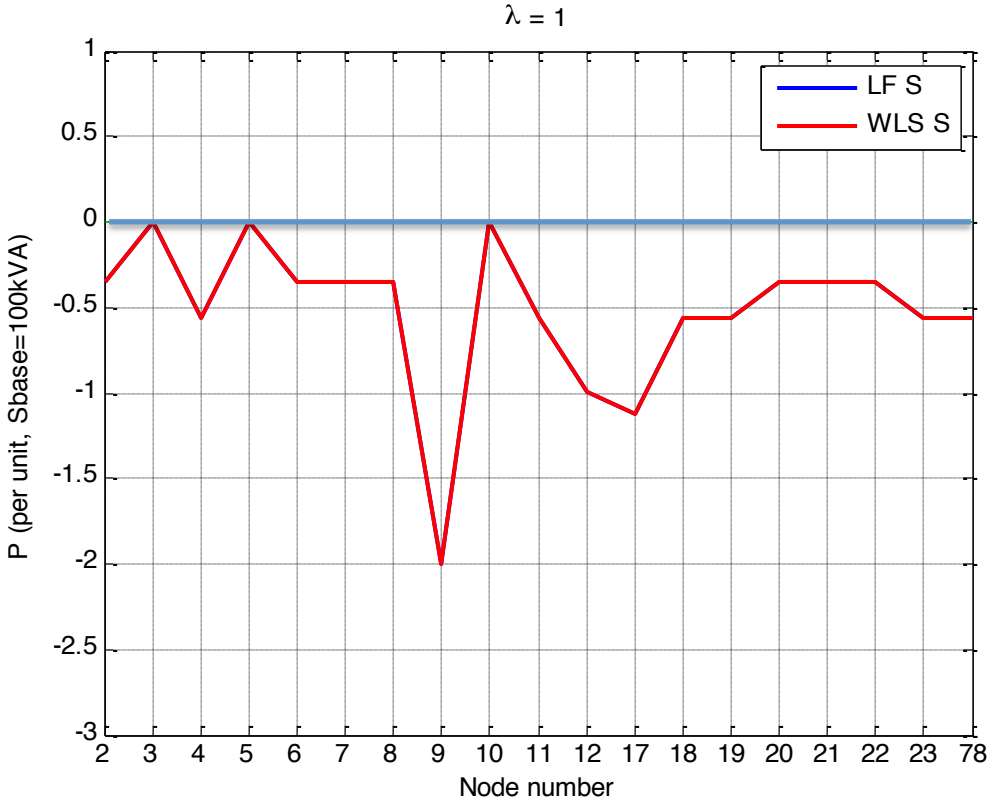
- F' -



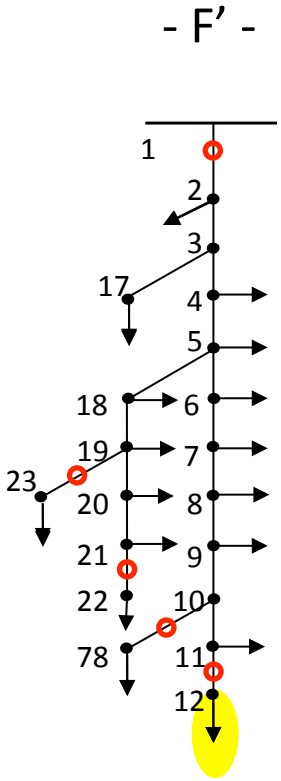
Scenario: Power injection changes from P_{12} to $-P_{12}$ while rest of loads increase from λ=1 up to λ=1.5.

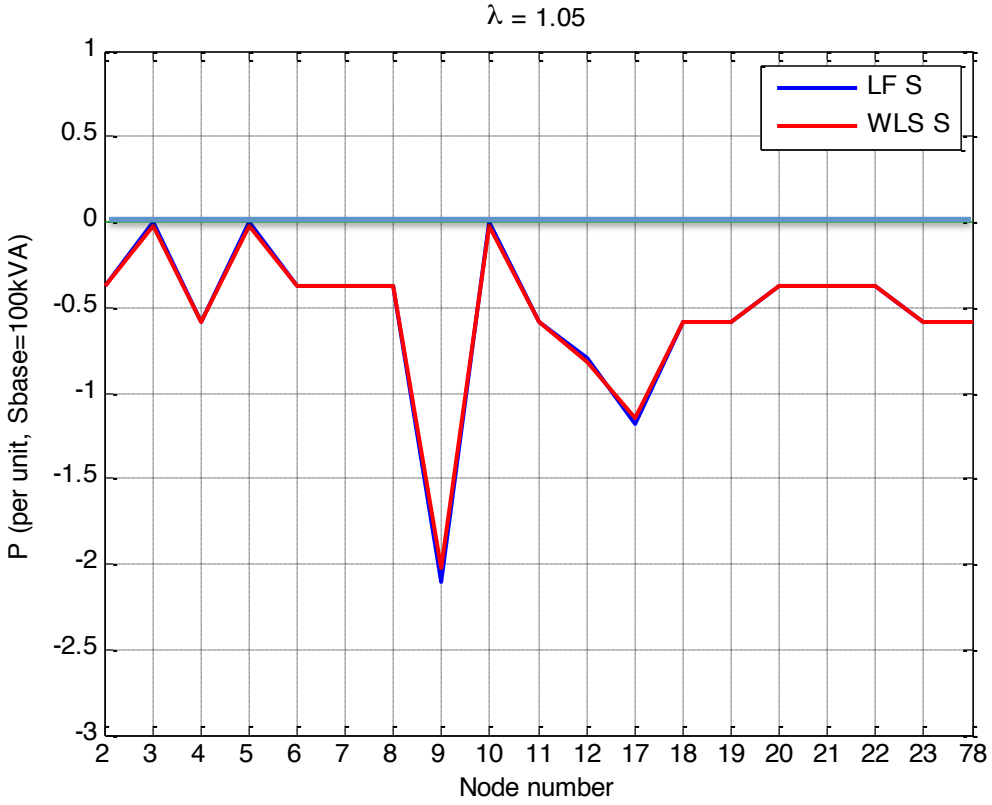
Test 5: Change in power flow direction (distributed generation)



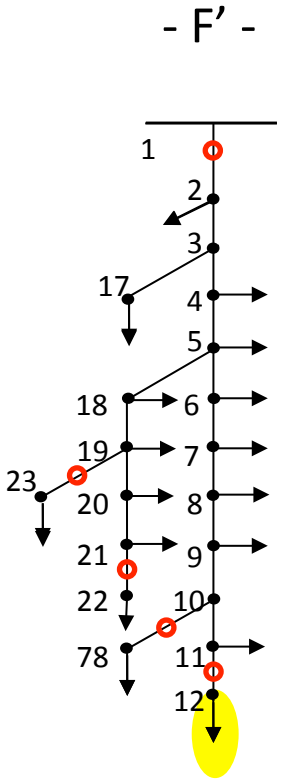


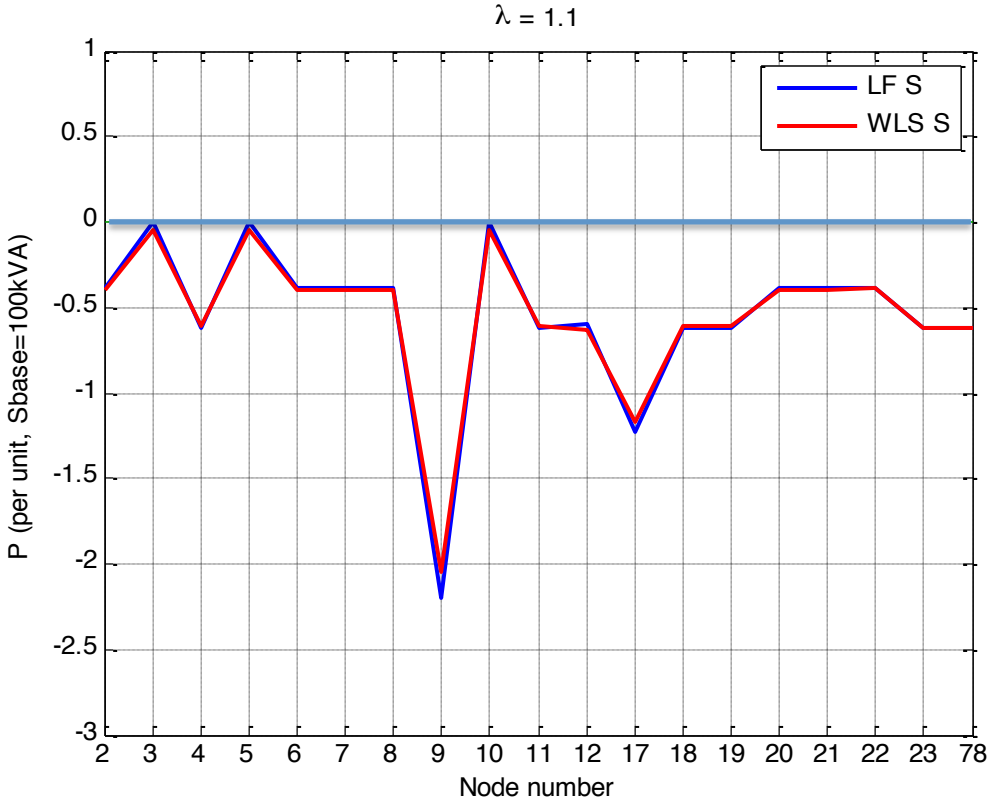
Test 5: Change in power flow direction (distributed generation)



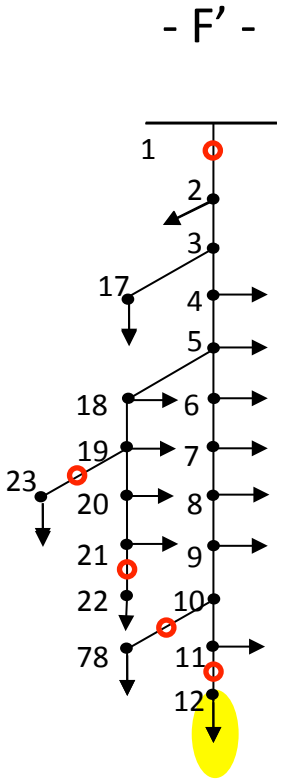


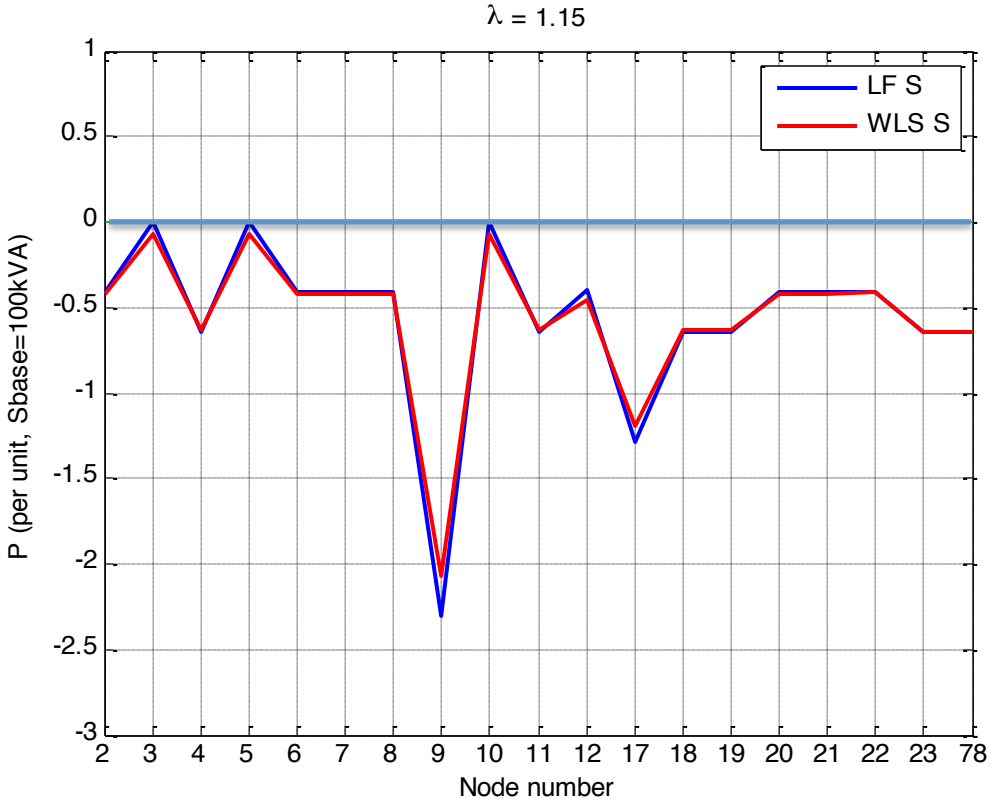
Test 5: Change in power flow direction (distributed generation)



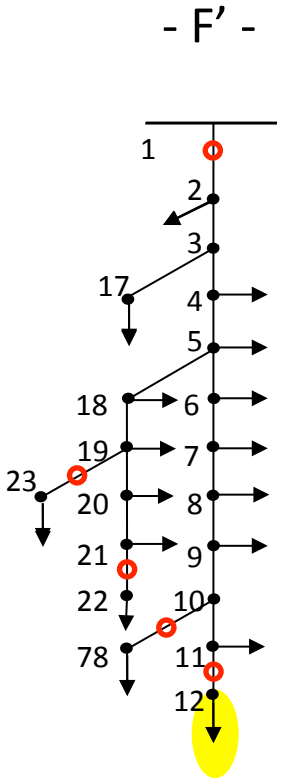


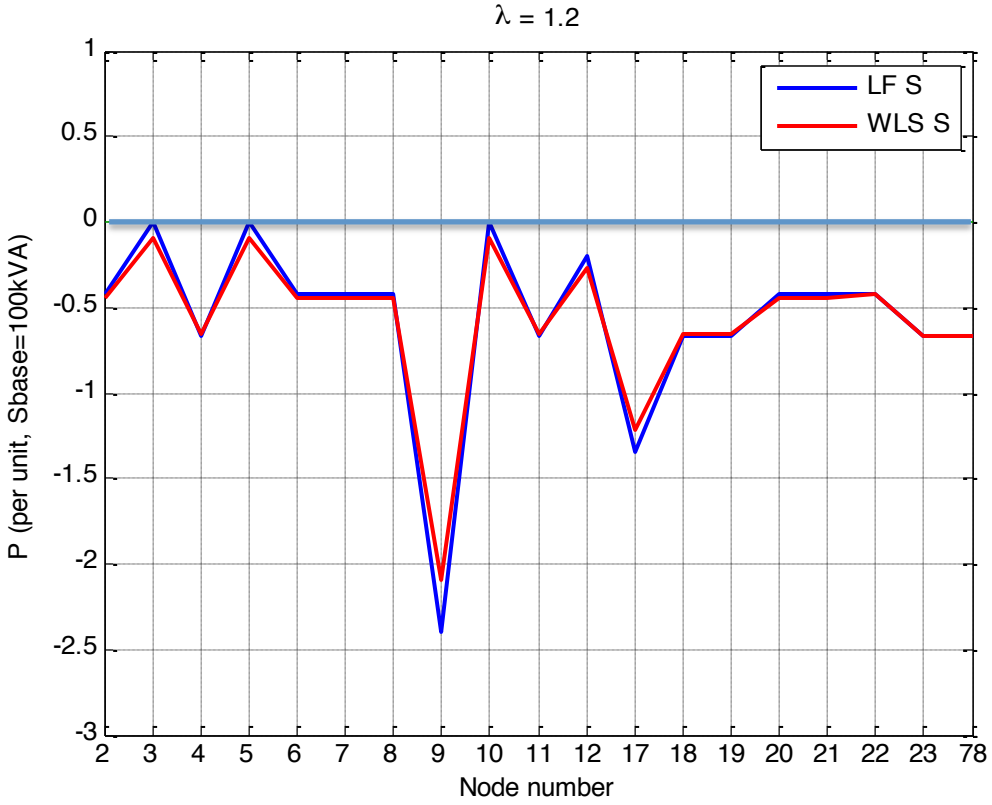
Test 5: Change in power flow direction (distributed generation)





Test 5: Change in power flow direction (distributed generation)





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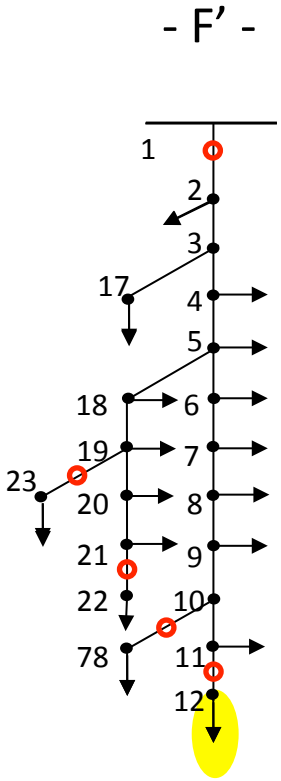
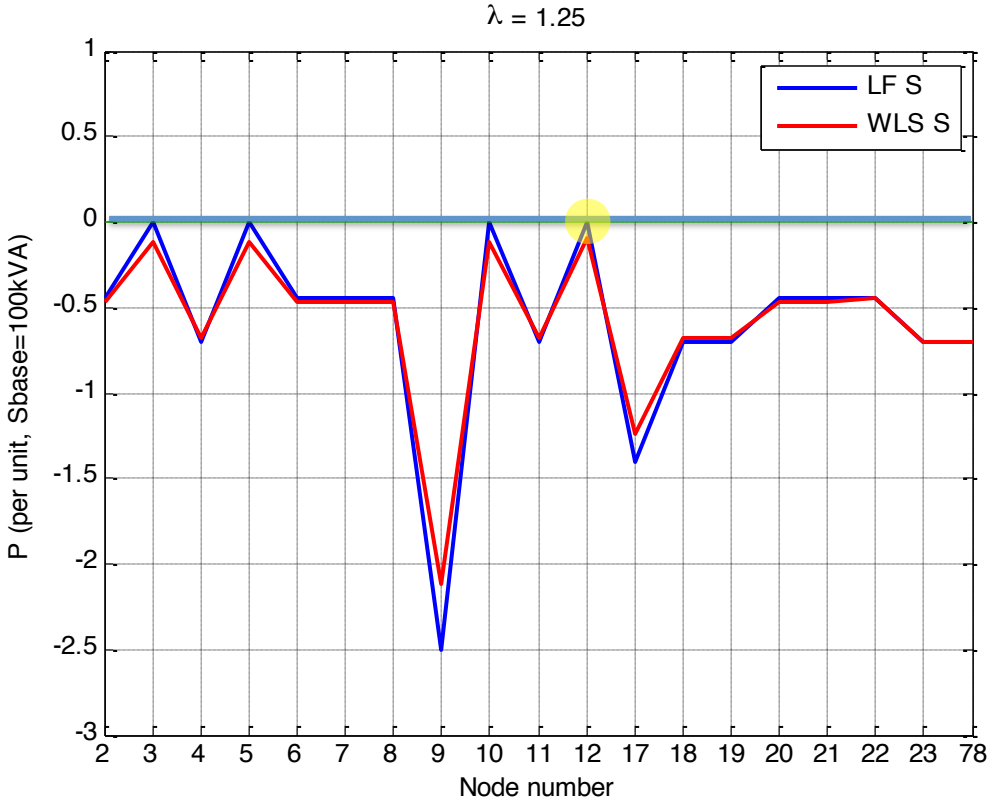
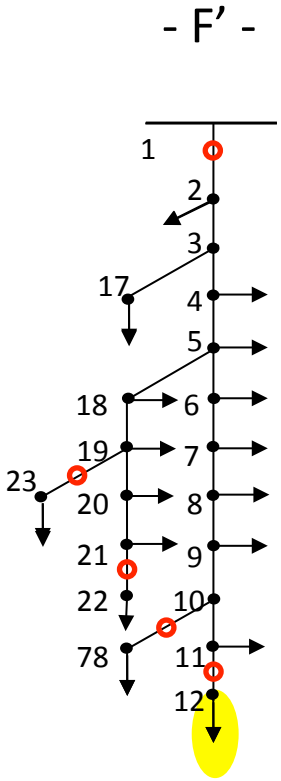
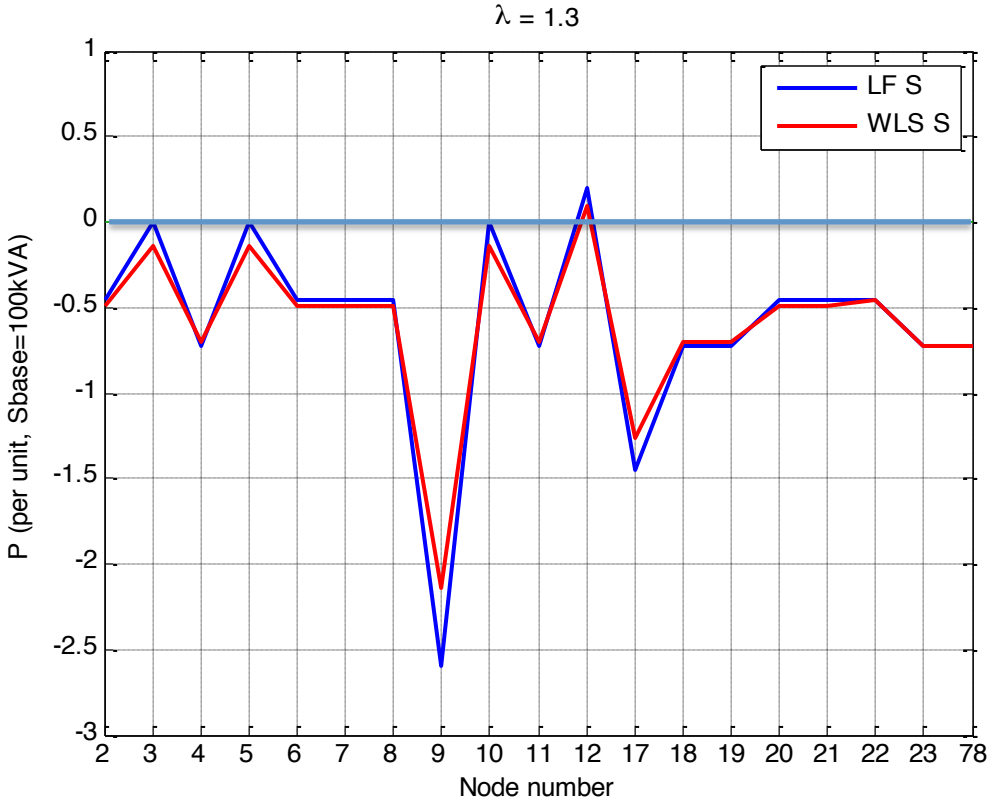




Test 5: Change in power flow direction (distributed generation)





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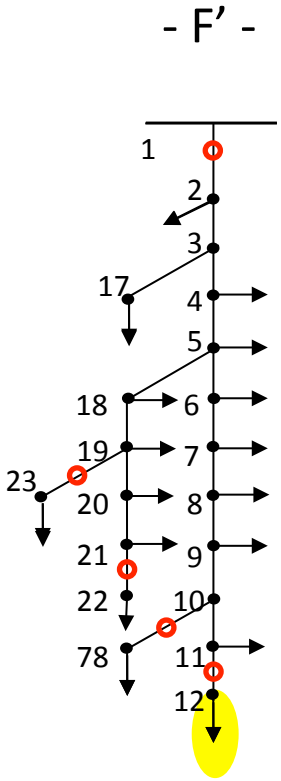

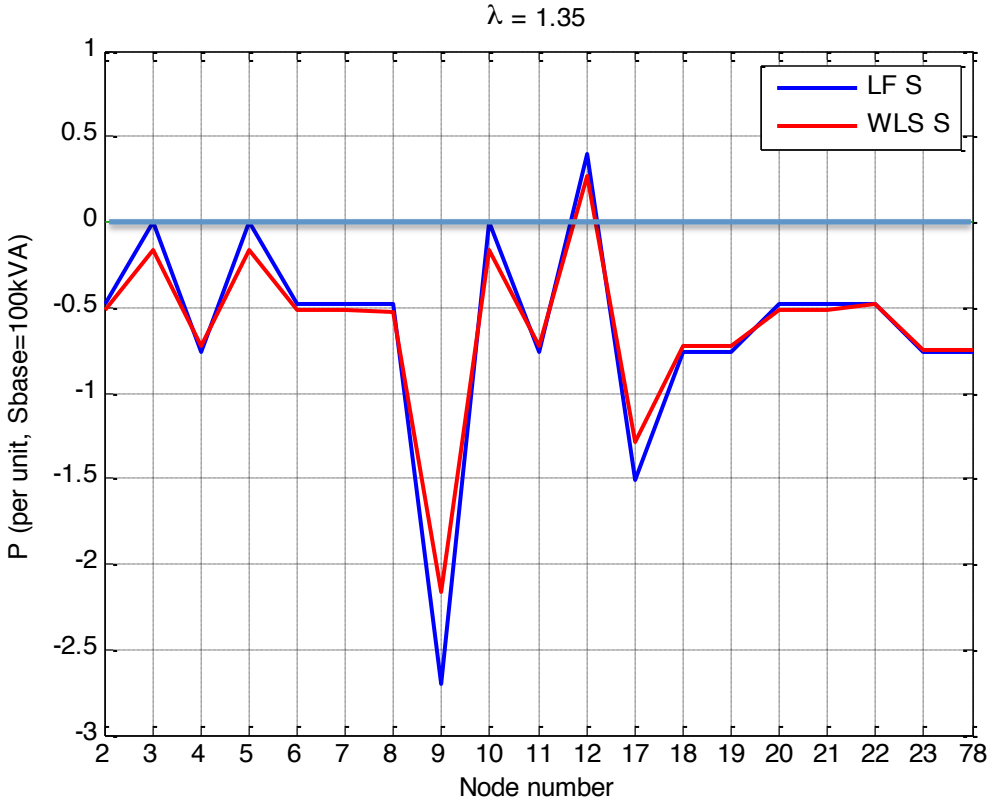

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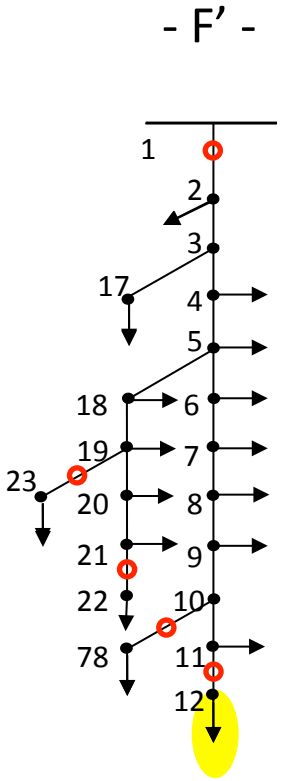
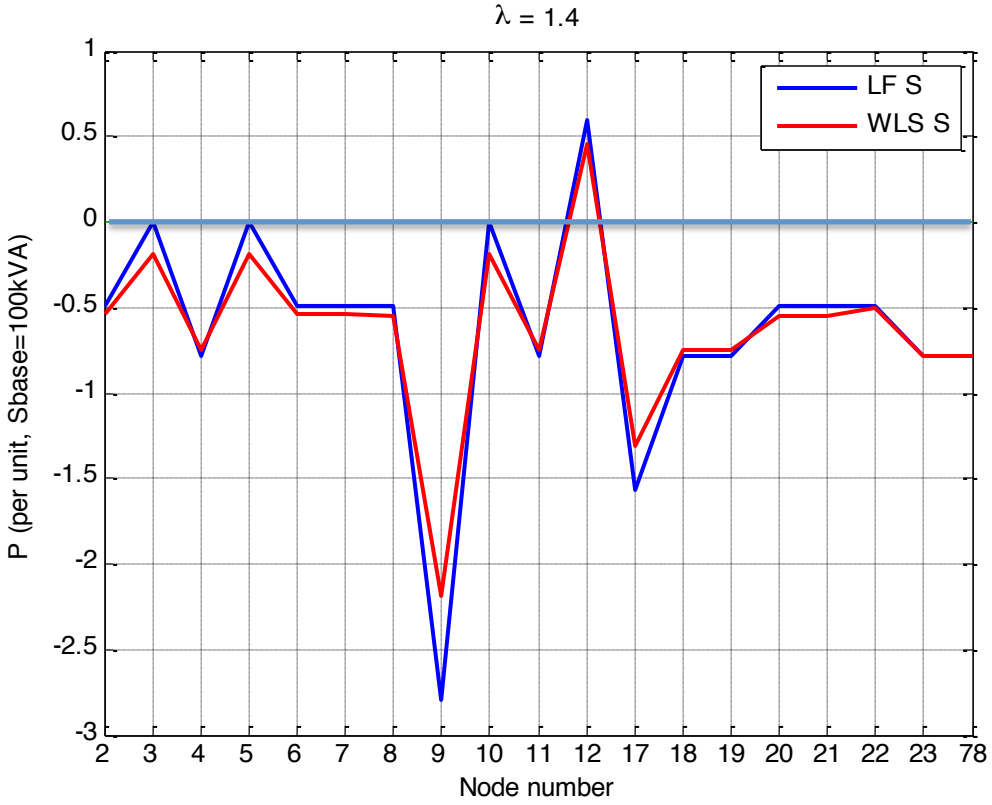
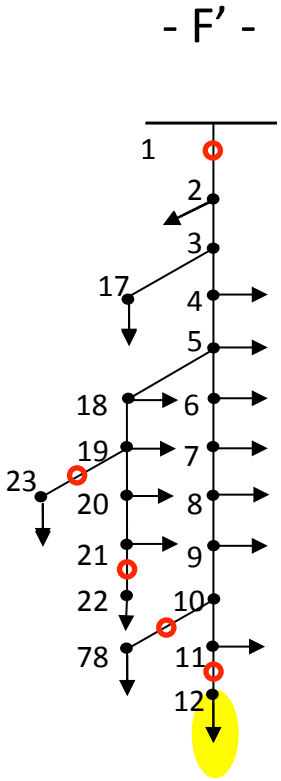
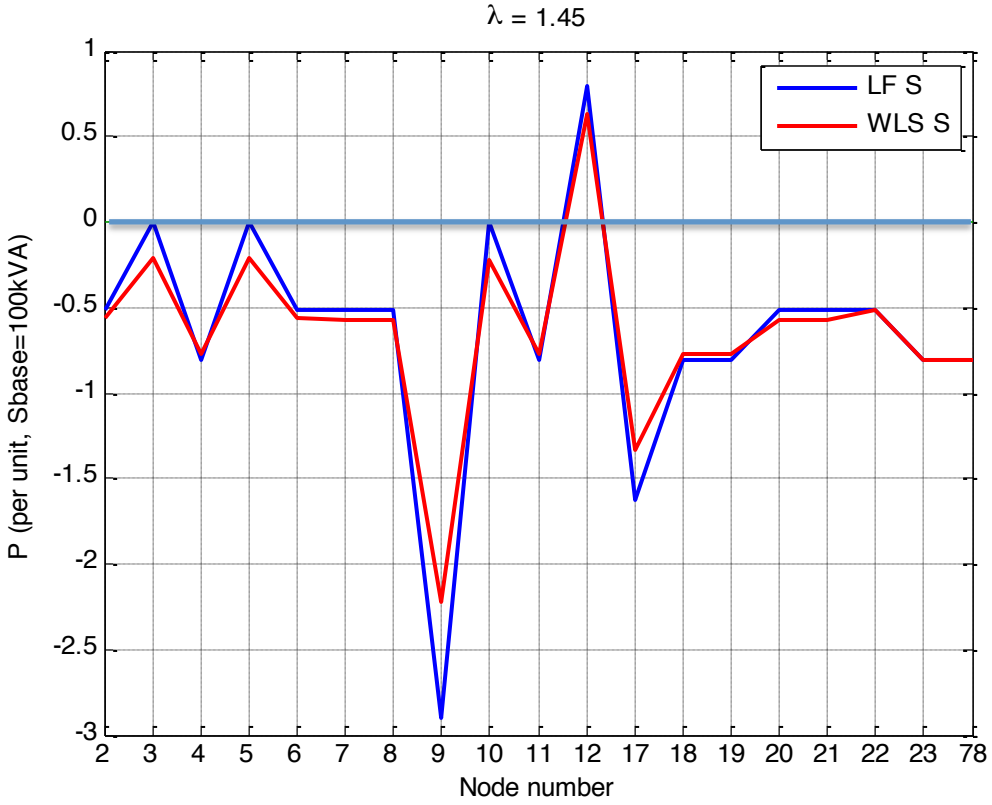




Test 5: Change in power flow direction (distributed generation)





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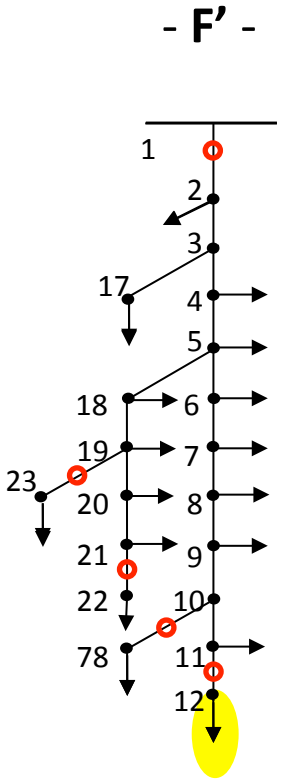
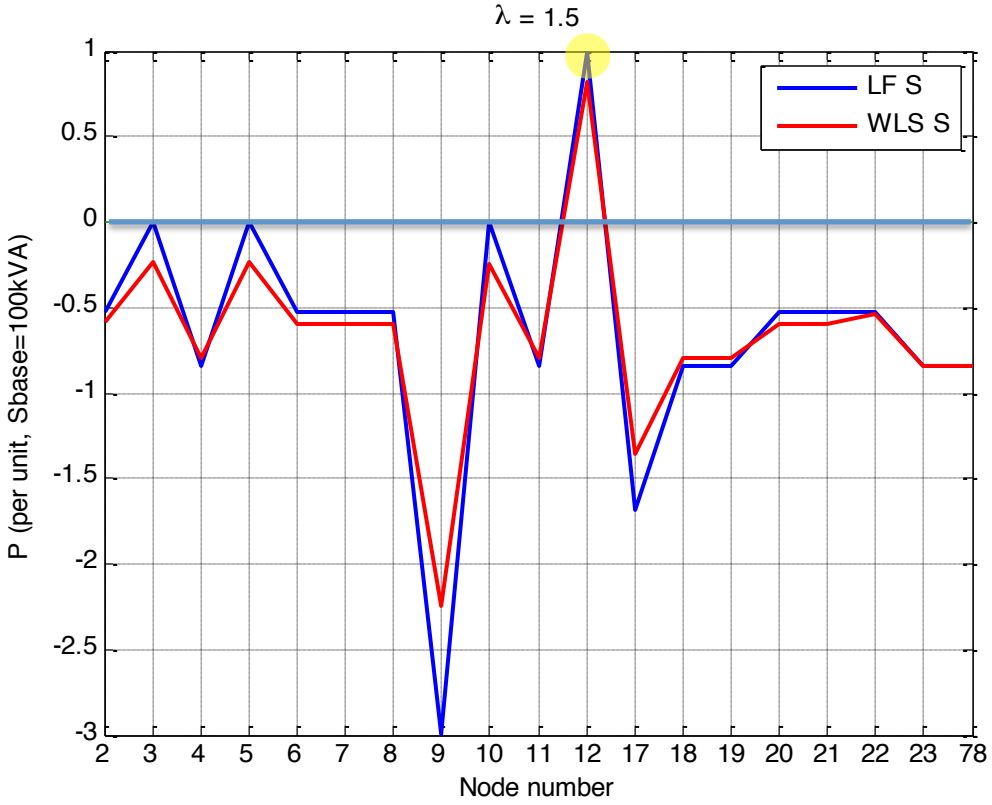




- Active power flow measurements detect power flow inversion

Conclusions

- *Smart grid* context: new "real-time" **feeder measurements** will become gradually available (fault detection & isolation).
- Insufficient to achieve observability: need to combine with **other information sources** (pseudomeasurements): AMI.
- **Two measurement latencies and accuracy levels**.
- Very **few Ampere measurements** may suffice to provide reasonable estimates, even for 50% load increase.
- Inability of Ampere measurements to track **counterflows**.
- Power rather than Ampere measurements encouraged in the presence of **distributed generation**.
- Future efforts: test larger realistic systems & practical implementation (computational saving).

IEEE/PES General Meeting, Vancouver
July 25, 2013

Panel session

State Estimation for Distribution Operations: sharing the experiences of implementation, usage and complexities

DEALING WITH TWO TIME SCALES IN DISTRIBUTION SYSTEM STATE ESTIMATORS

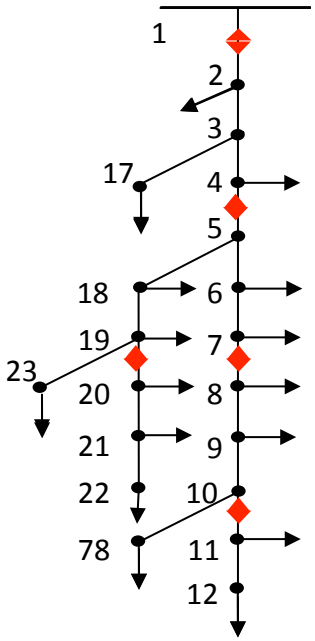
A. Gómez-Expósito **C. Gómez-Quiles**
University of Seville
Spain

I. Dzafic
Siemens AG
Germany

Test 7: current measurements versus active power measurements

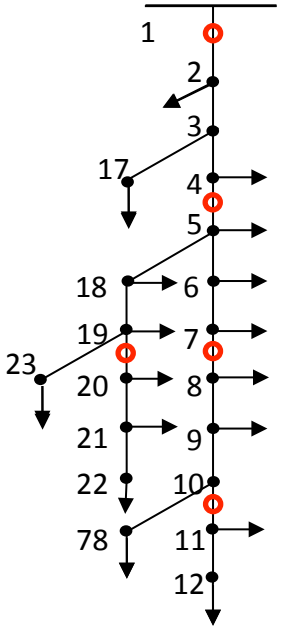
-A-

z_r current meas.



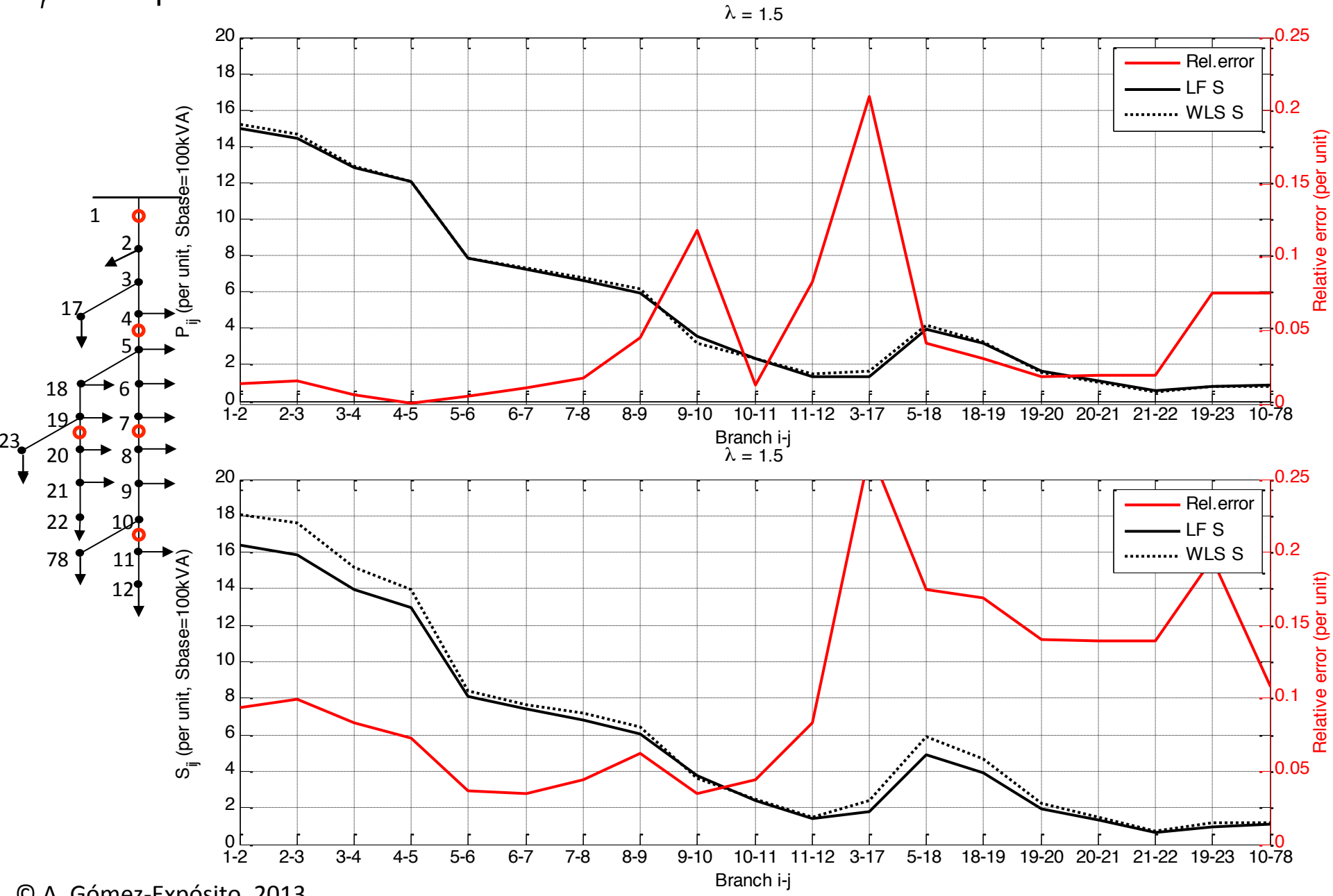
-G-

z_r active power meas.



-G-

z_r active power meas.



-A-

z_r current meas.