CIGRE US National Committee
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Initial Field Trials of Distributed Series Reactors and Implications for Future Applications

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Managing Overload and Congestion

Transmission Lines are becoming more overloaded and congested as loads and generation move or increase

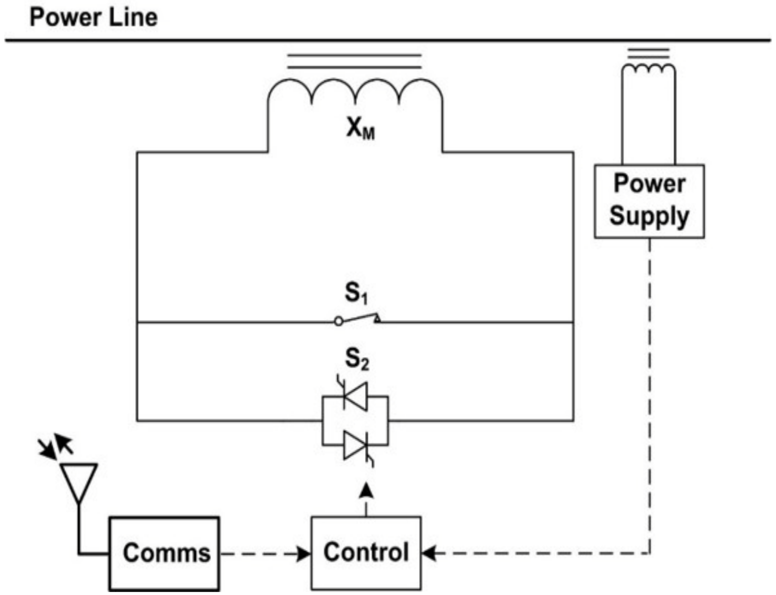
- Typical solutions
  - Switching (but this places increased burden on equipment)
  - Reconductoring
  - New Line Construction
- Other Lines are Underutilized
- Current Power Flow Methods
  - Expensive and/or need frequent operations
- Older Technologies such as air-core reactors or FACTS are:
  - Centralized
  - All or Nothing
  - Take up Substation Space

Background

- Rapidly deployable distributed power flow control for existing transmission lines
- Diverts current from the overloaded lines to underutilized ones
- Concept was first demonstrated in 2002-03 and has since been demonstrated in pilot installations on HV transmission lines.

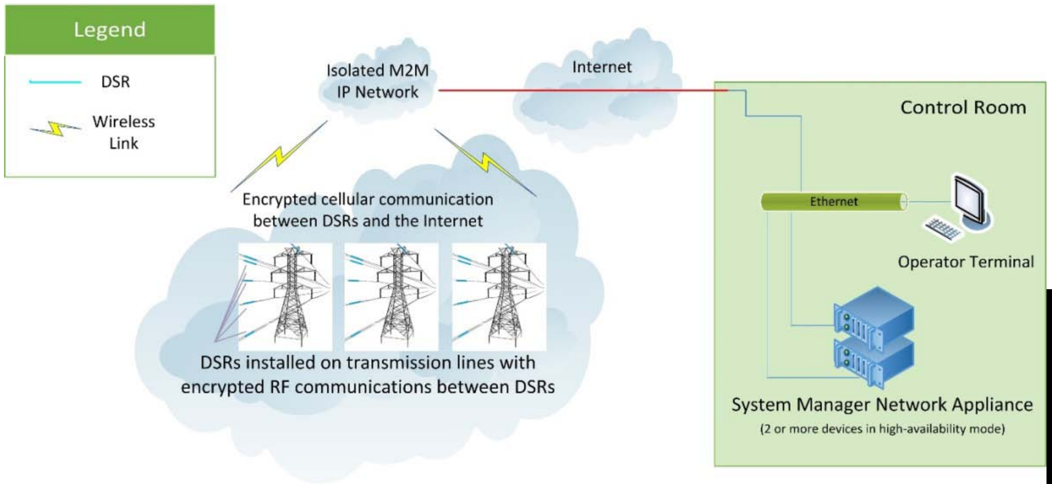
Distributed Series Reactor

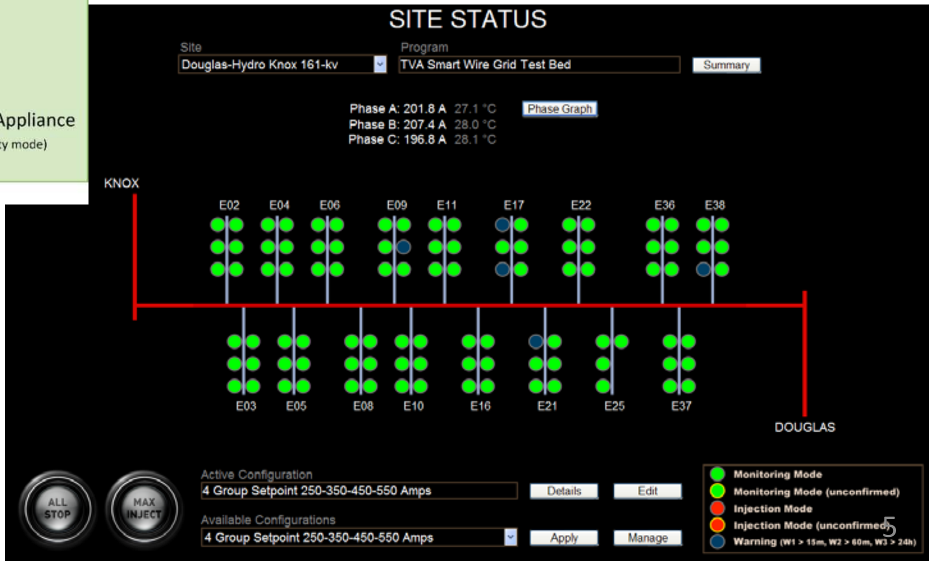
- Injects pre-tuned inductance value to increase line impedance
- Self contained device, powered by induction from a transmission line conductor
- Two methods of control
- With secondary winding shorted injection is negligible



Communication and Control

- Operate autonomously based on preset values (line current)
- Controlled remotely via Power Line Carrier, Cell phone
- DSR information display available in control center

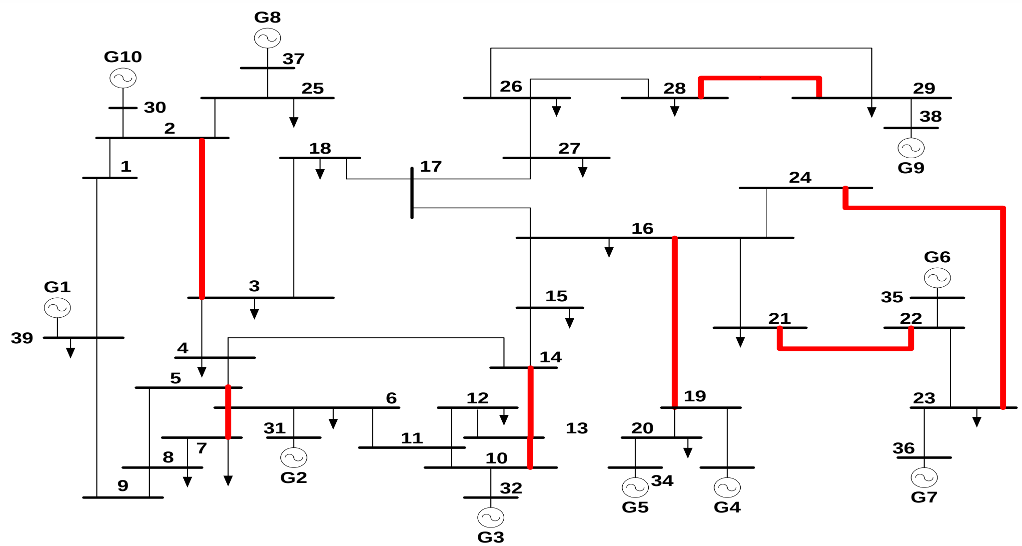


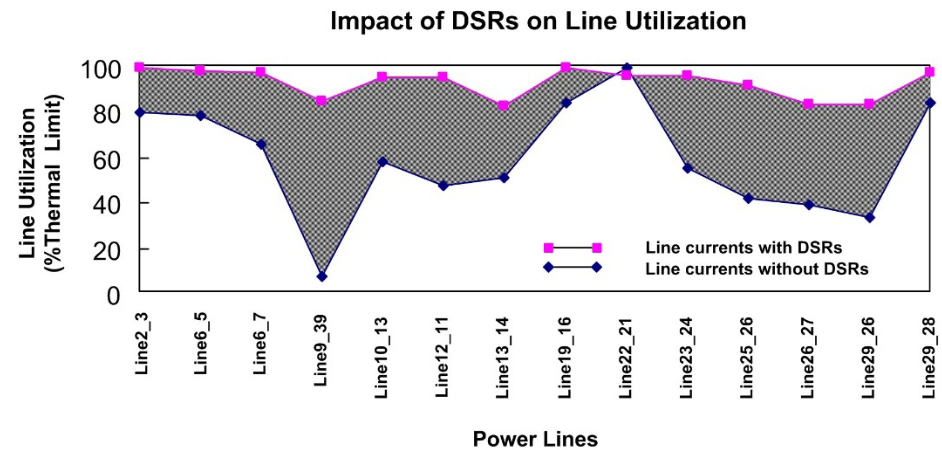


Example Application in Meshed Grid

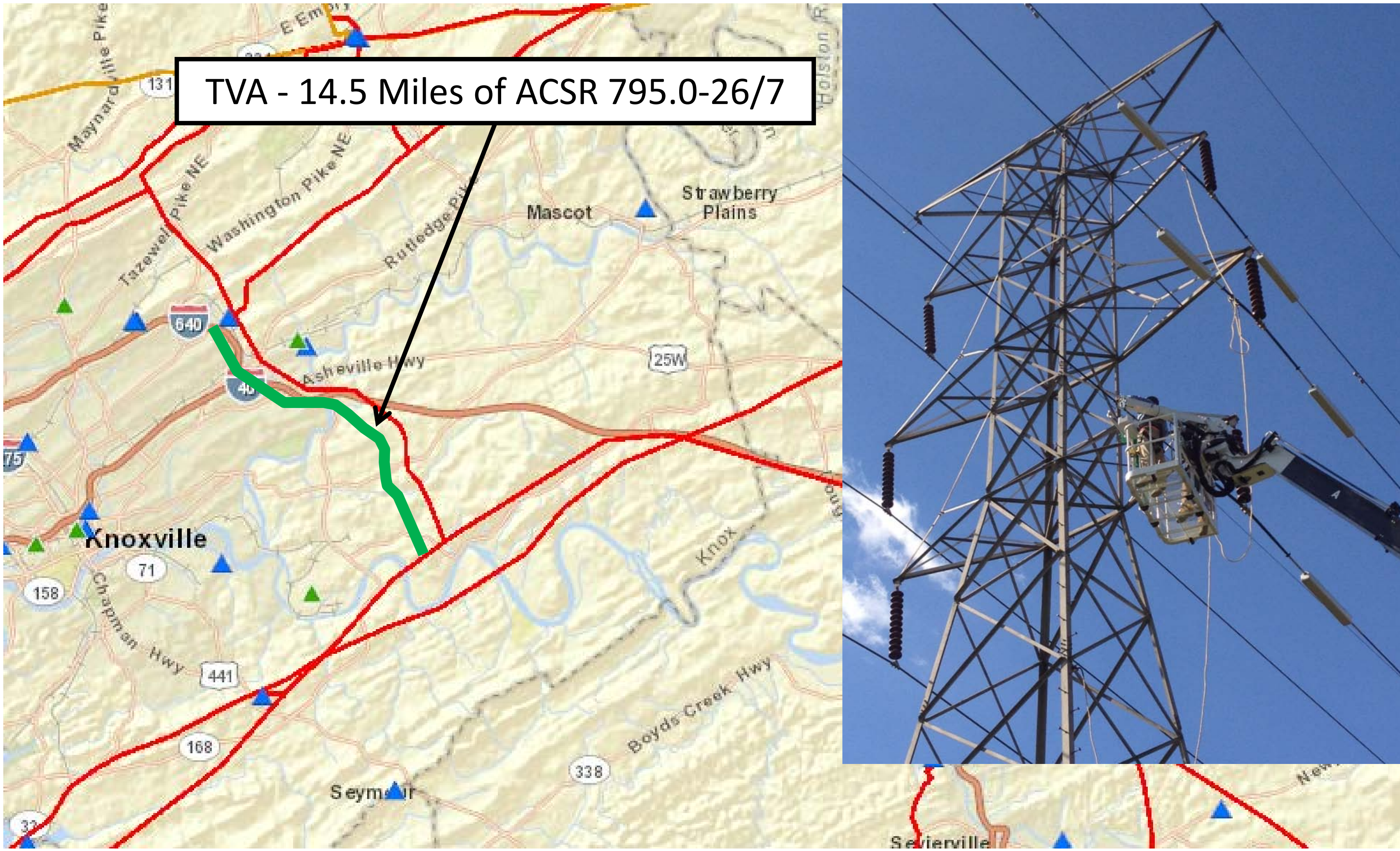
39 BUS SYSTEM

- Baseline MW: 1904 MW
- Increase in transfer capability of 638 MW (33.5%)
- Increase in line availability from 59% to 93%





Prototype DSR Installation at TVA



Installation Details

- 21 mile segment of 161 kV line
- 99 DSRs installed on 17 spans
- 33 DSRs per phase

- Clamshell construction
- Two halves secured together with a torque wrench
- Approximately 10 min to install each DSR
- Devices run self diagnostics and can be remotely tested

Pilot Test Results

- Total Impedance Increase (33 DSRs / Phase @ 47 µH / DSR): .226 % (control limited by number of available devices and a test line that was longer than optimal for the demonstration)
- Devices performed as expected over 4-step range (*see below*)
- Devices successfully adjusted phase imbalance
- Single point failure of communication system identified for necessary design upgrade
- DSRs presently considered unsuitable for bundled conductor use

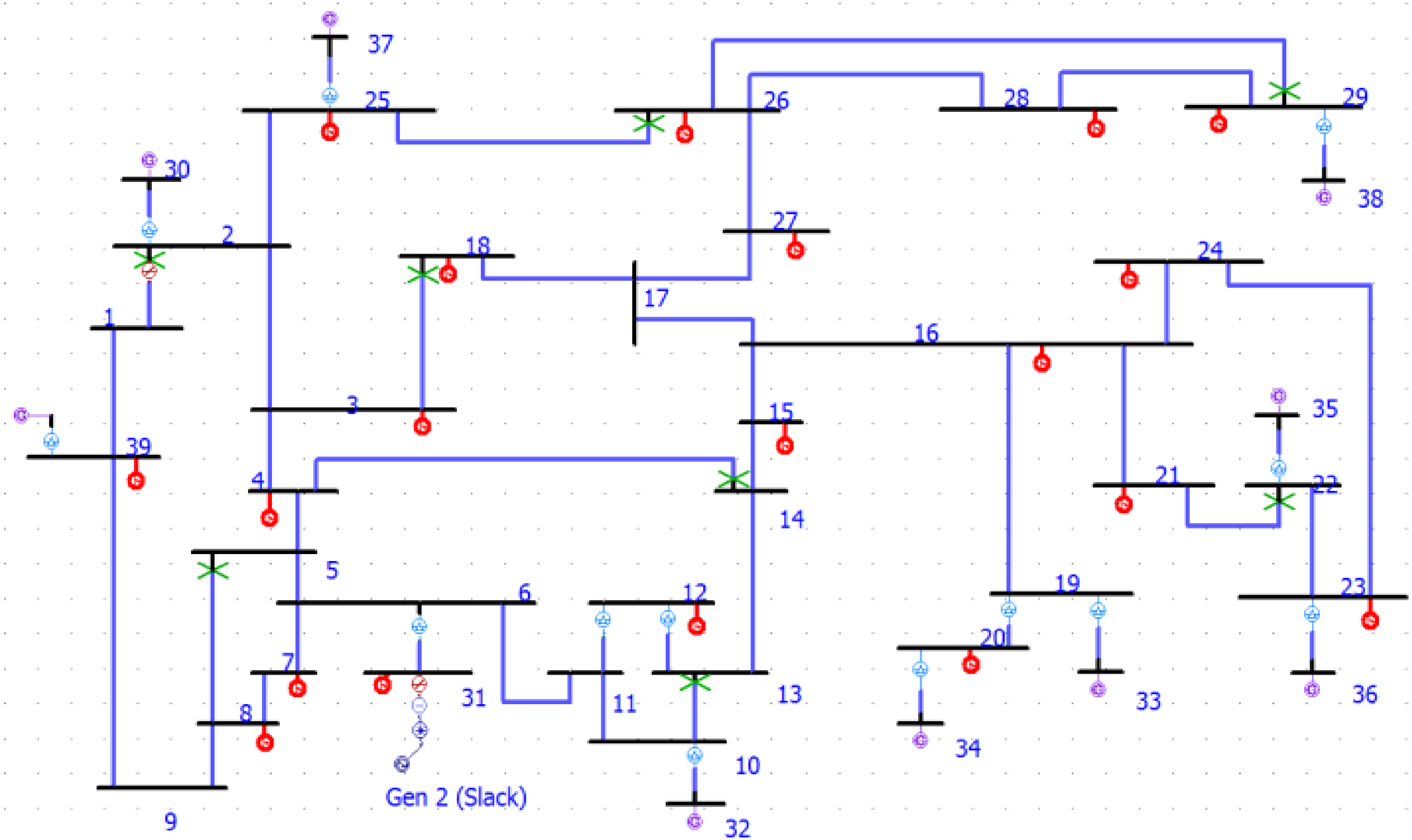
Time :	1:22 PM		1:28 PM	
	Pre Conditions		**Post Conditions**	
T	457.9	amp	462.0	amp
M	471.1	amp	464.7	amp
B	457.0	amp	463.1	amp
SCADA (Middle)	483.0	amp	469.0	amp

Information: 28 out of 33 DSRs ON Middle Phase

Future Applications

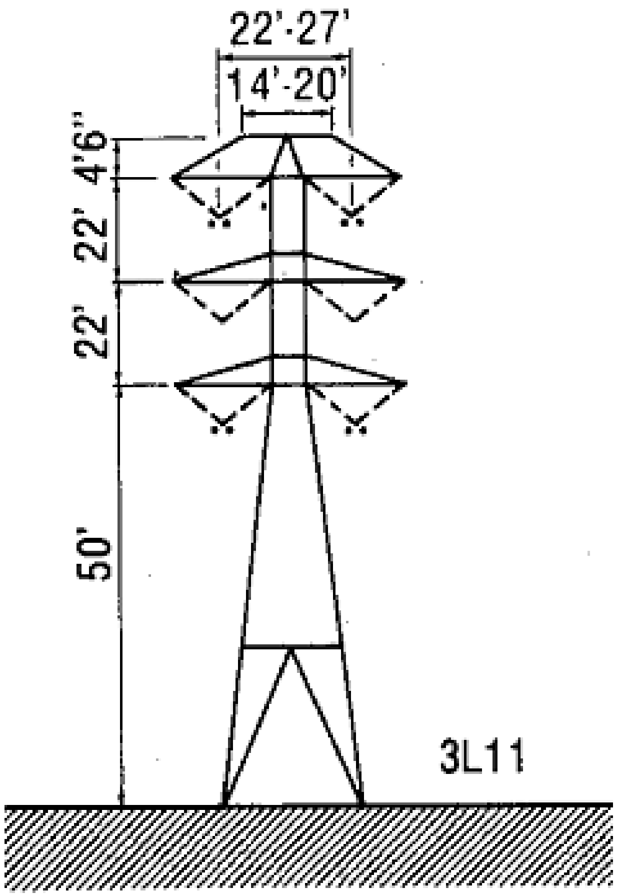
- Success of pilot opens path to more critical applications
- Simplest application is reduction of maximum contingency load for postponement of line uprate
- Ability to quickly relocate DSRs reduces cost to individual projects
- Extreme case for portion of HV grid to have dynamically assigned line loading for selected goals, e.g. minimize system losses
- Future designs may provide capacitive injection to reduce reactive impedance
- Future designs with high speed controls may be low cost alternative to FACTS

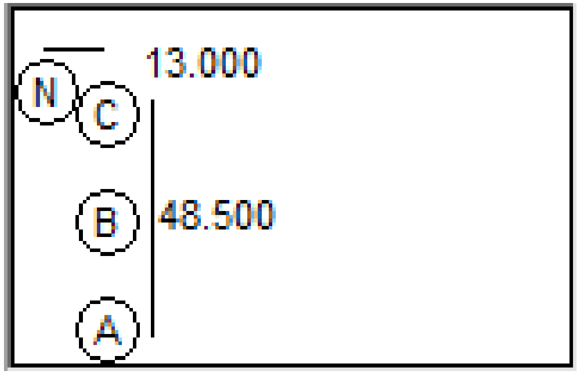
The IEEE 39 bus standard test system converted to a three phase system with 345kV lines



The 345kV Line Configuration

Structure Type: 3L11→Utility: Houston Lighting & Power Company





Reference: EPRI, Transmission Line Reference Book - 345kV and above

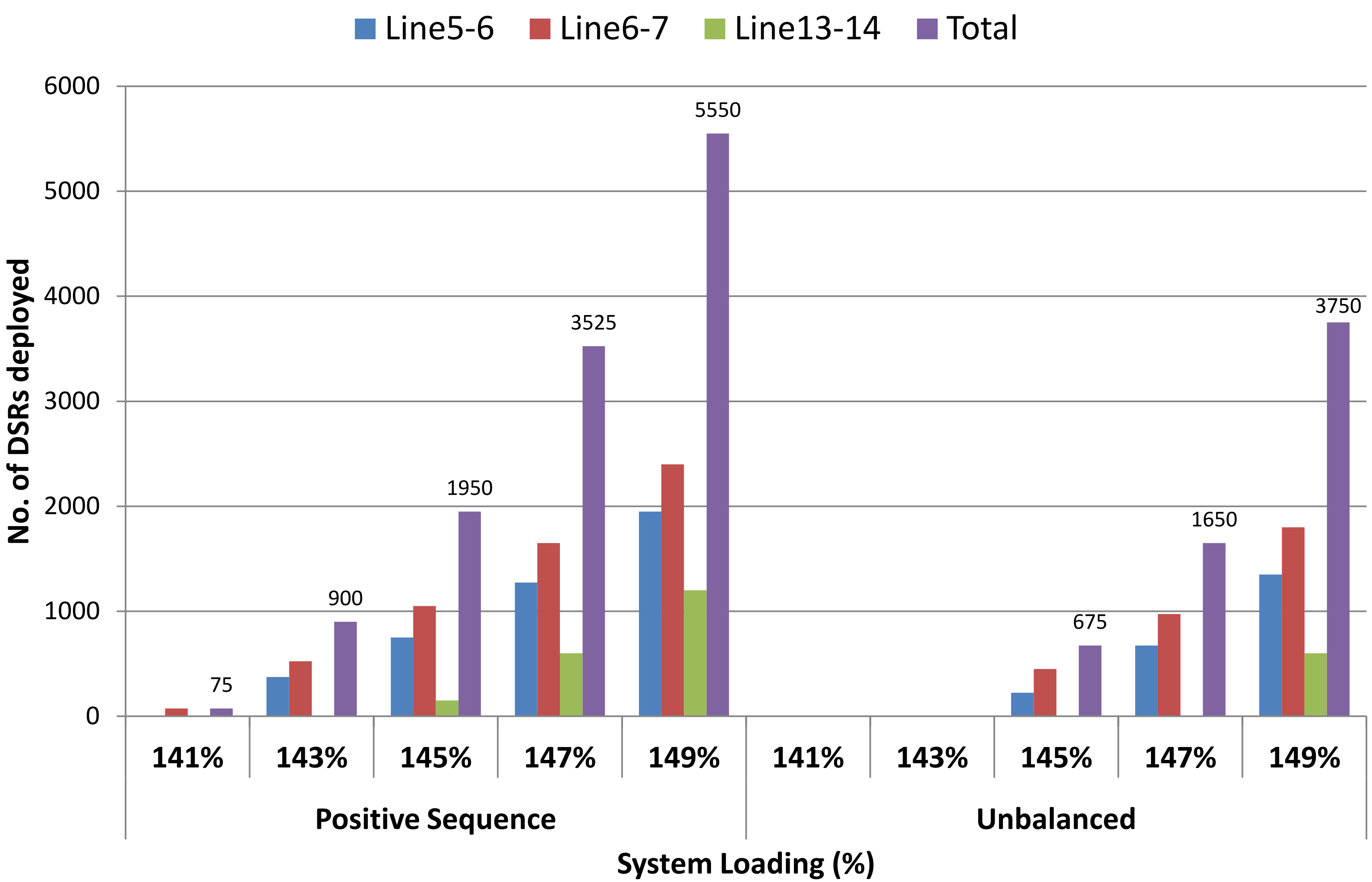
Line Impedance Models

Unbalanced: $$Z_{line} = \begin{bmatrix} z_{aa} & z_{ab} & z_{ac} \\ z_{ba} & z_{bb} & z_{bc} \\ z_{ca} & z_{cb} & z_{cc} \end{bmatrix}$$

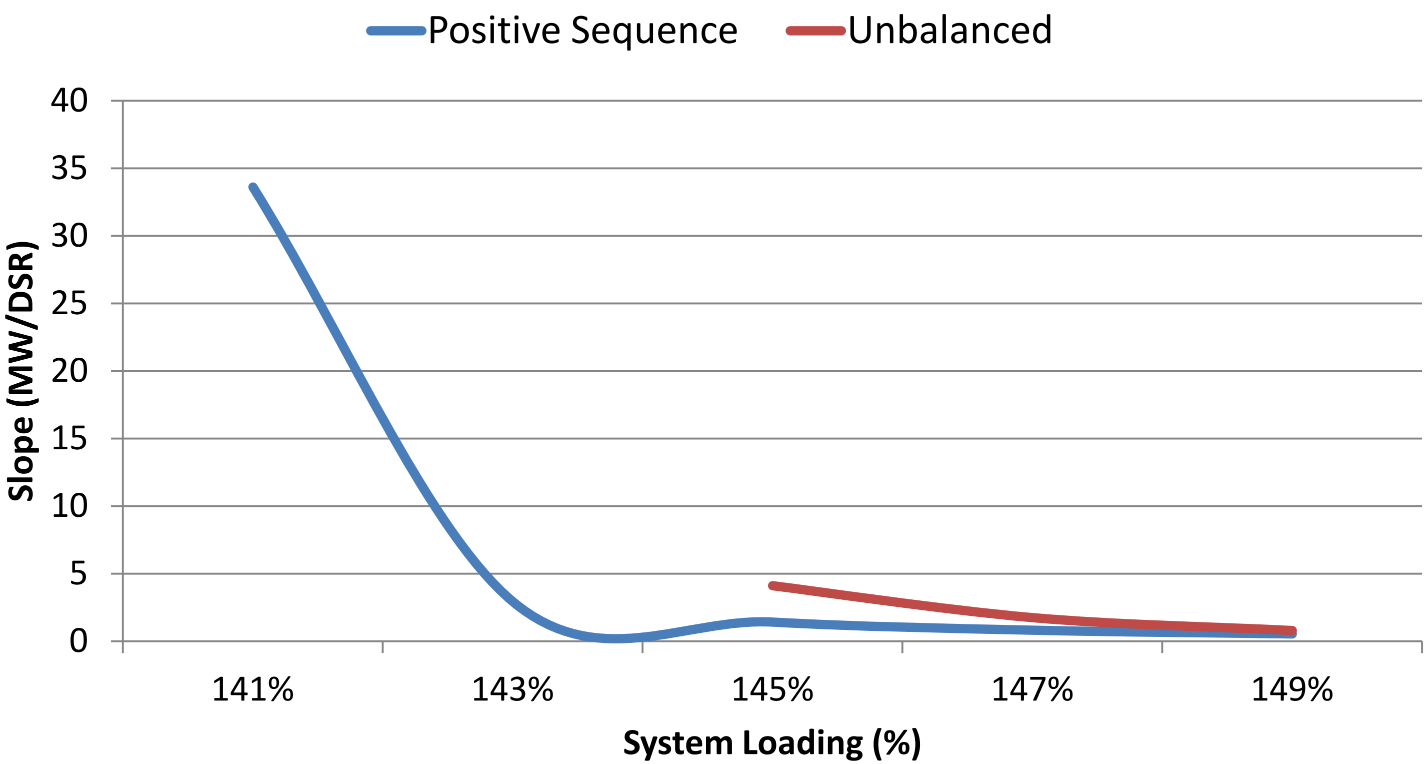
Positive Sequence: $$Z_{line} = \begin{bmatrix} Z^0 & 0 & 0 \\ 0 & Z^+ & 0 \\ 0 & 0 & Z^- \end{bmatrix}$$

Positive Sequence Z is derived from the Unbalanced Model Z using the symmetrical components transformation

DSR Design for Load Growth



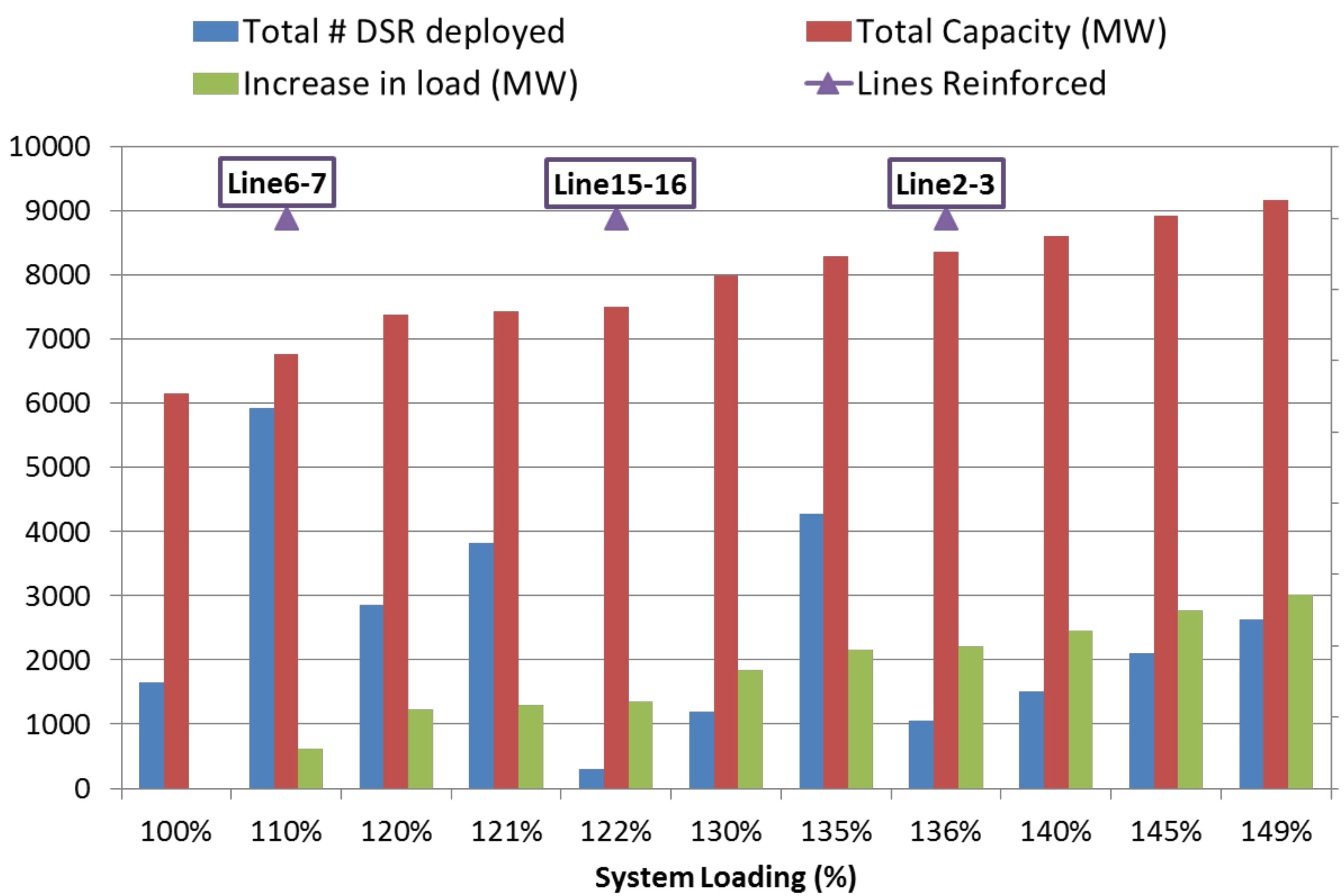
Unbalanced vs. Positive Sequence Impedance Model



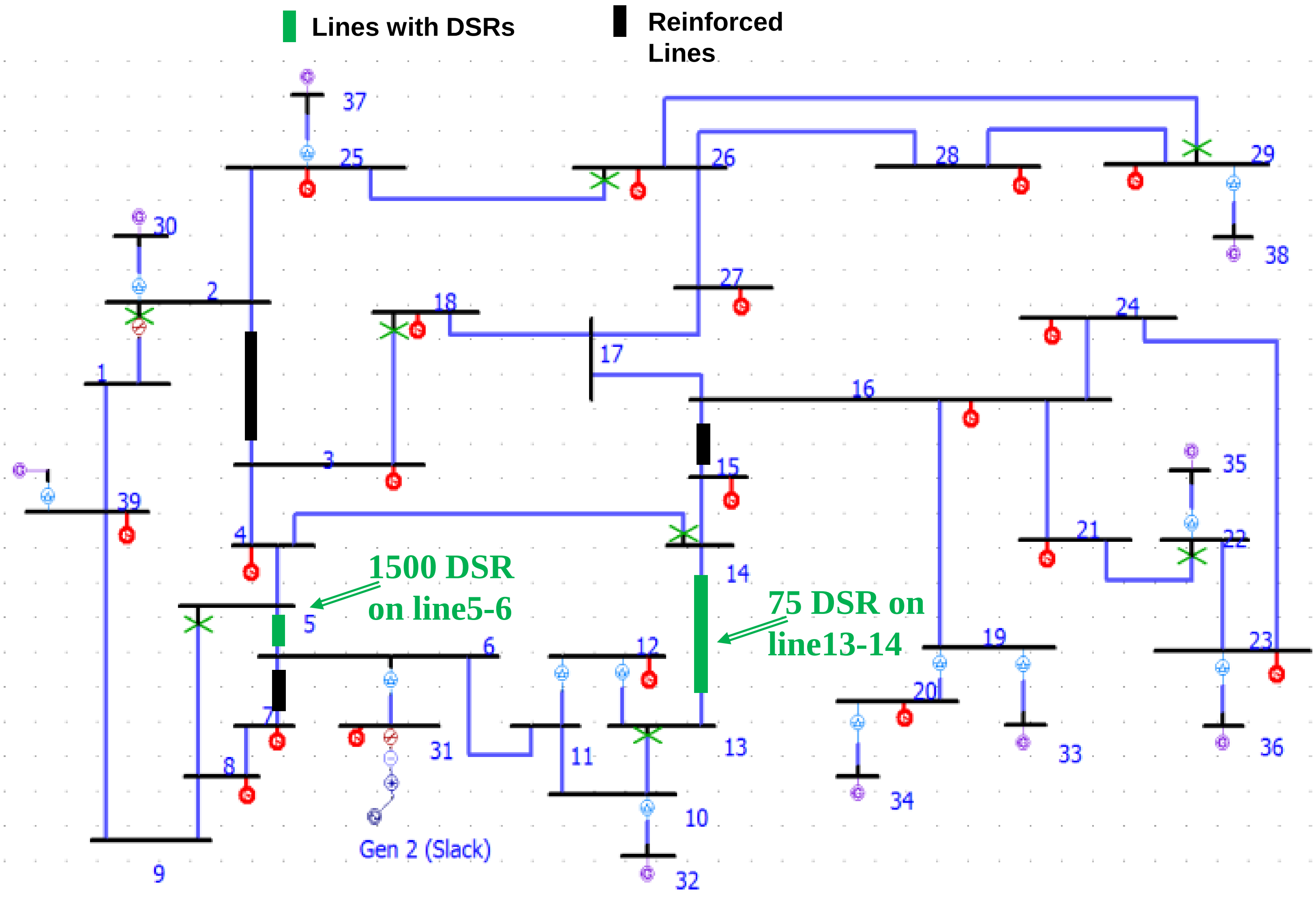
	Slope (MW/DSR) for different System Loading %				
	141%	143%	145%	147%	149%
Positive Sequence	33.60	2.93	1.41	0.81	0.54
Unbalanced			4.09	1.75	0.80

DSR Design for Single Contingency: Unbalanced Impedance Model

DSRs Deployed and Load Supplied



The Selected Design at 140% System Loading



DSR Design vs. Line Reinforcement for Single Contingency and Load Growth: Economic Evaluation

Economic Evaluation

- Determine the maximum MW supplied to load while handling all single contingencies
  - Case1: Three Lines Reinforced with No DSR
  - Case2: Three Lines Reinforced with DSR
- Economic assessment of both cases

Economic Evaluation Results

- Case1: With Three Lines Reinforced
  - 125% loading is reached

- Case2: With Three Lines Reinforced and DSRs Deployed
  - 140% loading is reached and selected as a desired DSR Design due to its technical merits
    - Fewer number of DSRs deployed.
    - Least % change in lines impedance.

Data for the Economic Study

- Max MW supplied at different % loading:

Case	% Loading	Max MW supplied	MW increase
Base	**100%**	6309.4	
Case1	**125%**	7886.6	1577.2
Case2	**140%**	8833.1	946.5

- Total length of the reinforced lines = 95 miles.

Reinforced Line	Length (miles)
Line2-3	37
Line6-7	29
Line15-16	29

- Cost of 345 kV, single circuit = 1298 $k /mile

Line Reinforcement Cost

- Cost of 95 miles of line =

  95 x 1298 k$ = 123.31 $M

- Cost for 1577.2 MW of load increase = 123.31 $M
- Cost per MW of load increase for reinforcing lines =

  123.31 $M/1577.2 MW = 78,182 $/MW

DSR Design Cost: Unbalanced Model

- For the selected DSR design, a loading of 140% is achieved using 1575 DSR modules.
- DSR worth in terms of transmission line value:
  - Cost of 946.5 MW of load increase =

    946.5 MW x 78,182.8 $/MW = 74 $M
  - Thus the equivalent value of 1 DSR =

    74 $M/1575 DSRs = 46,984 $/DSR

Questions