Distributed Power Flow Control using Smart Wires for Energy Routing

Joshua Hambrick

Electrical Distribution Design

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Project Objectives

- Develop models for Distributed Series Reactors (DSR)
  - Positive sequence and unbalanced models
- Develop tools and methodologies for design and operation of DSR on transmission systems
- Perform studies showing the impact of DSR on systems of increasing size and complexity

Simulation Overview

- Simulation environment:
  - Distributed Engineering Workstation (DEW)
  - Historically used primarily for distribution analysis but has been used more recently for transmission analysis
    - Bottom up approach
  - Primarily 3-phase, unbalanced models
  - Highly detailed models with large component counts

Test Systems

- Small systems
  - IEEE 39 Bus Test Feeder (positive sequence)
  - Small unbalanced utility system
- Medium system
  - Unbalanced transmission system from utility partner
- Large system
  - Increase import into area allowing high cost generation to backed down
  - Positive sequence import
  - Tiered approach to gain insight on system size

Medium test system

- Medium model description:
  - Roughly 150 transmission buses
  - Approximately 4,000 3-phase components
  - Contains 345, 138, 34.5 and 13.2 kV components
  - Max overload: 117%
  - Max voltage unbalance: 2.27%
  - 167 lines considered for DSR placement

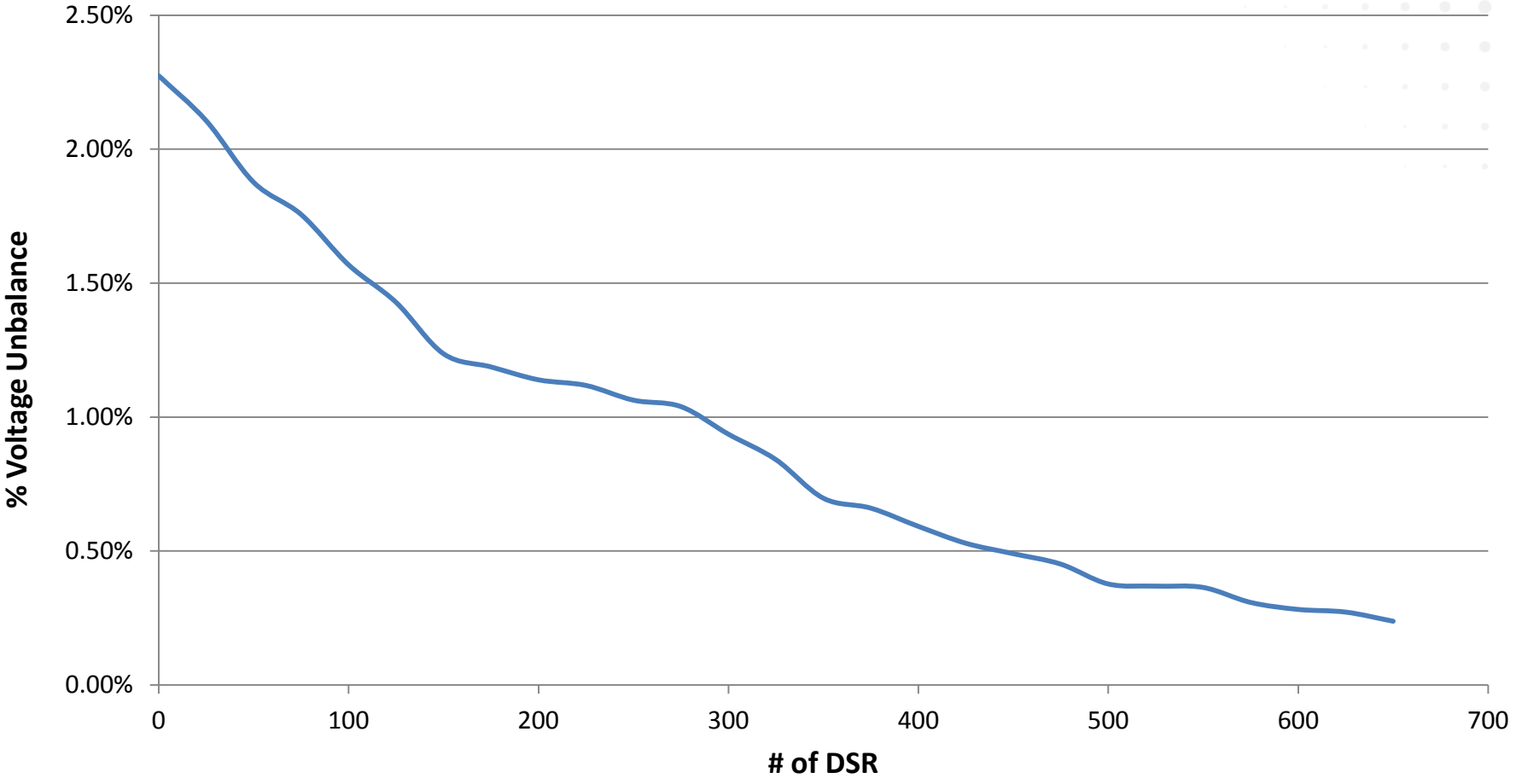
DSR Allocation Overview

- Determine lines available for DSR allocation
  - Filter based on voltage level, area/zone, impedance, etc.
- Specify design criteria:
  - Number of DSR on a line, % reactance, etc.
- Specify stopping criteria:
  - Loading level, max DSR allocation, etc.
- Algorithm overview:
  - Increment step size at each available line
  - Choose location that improves the most
  - Repeat until stopping criteria reached or no improvement is measured

Medium test system – constraint relief

Component Type	Loading Before (%)	MVA Before	DSR Deployed	Loading After (%)	MVA After
69 kV Transmission Line	117.39	127.98	300	95.73	104.45
69 kV Transmission Line	108.59	116.81	300	86.92	93.00
69 kV Transmission Line	80.04	84.07	300	64.45	68.45
69 kV Transmission Line	70.18	73.24	300	54.26	57.08
35 kV Transmission Line	111.47	63.30	300	77.84	44.07
138 kV Transmission Line	43.29	86.52	300	47.04	93.80

Medium test system – unbalance correction



Large test system

- Study overview:
  - Select a test area
  - Reduce generation within an area (5% increments)
  - Monitor for overloads and voltage violations
  - Deploy DSR to alleviate overloads
  - Continue reducing generation until DSR can’t alleviate overloads
  - Repeated for all equipment in service case as well as N-1 contingencies

Large test system

- Design parameters:
  - Step size of DSR allocated: 50 / phase
  - % Reactance limit of a branch: 30%
  - Total DSR allocation: 3,000 (relaxed in some cases)
  - All lines in the test area and Tie lines into the test area are available for DSR allocation
  - Stopping criteria: all overloads alleviated or DSR allocation reached

Large test system

- Study area overview:
  - Summer loading case evaluated
  - Base case generation: 8.5 GW
  - Base load in study area: 11.4 GW
  - Tie lines: 15
  - System size:
    - Tier 1: ~700 buses
    - Tier 2: ~2,500 buses
    - Tier 3: ~7,000 buses

Large test system

- Results:

  Import increase: 5% (390 MW)

  DSR Allocation: 1,710 DSR on 9 branches

  4 failed contingencies alleviated using DSR

  Import increase: 10% (775 MW)

  DSR allocation: 6,831 DSR on 20 branches

  4 failed contingencies alleviated using DSR

Large test system

	Contingency 1	Contingency 2	Contingency 3	Contingency 4	Max DSRs
Branch 1	600				600
Branch 2	300				300
Branch 3	54			54	54
Branch 4			111		111
Branch 5			117		117
Branch 6			282		282
Branch 7			90		90
Branch 8			1806		1806
Branch 9			93		93
Branch 10			96	96	96
Branch 11			96	96	96
Branch 12			105	105	105
Branch 13			204		204
Branch 14				282	282
Branch 15				225	225
Branch 16				468	468
Branch 17		468		468	468
Branch 18		288		288	288
Branch 19				918	918
Branch 20		228			228
				Total:	6,831

Conclusions

- DSR can be very instrumental / cost effective in relieving capacity constraints
- Unbalance, load type, line models can all significantly impact DSR allocation calculation
- DSR on lines that were not overloaded were routinely selected over overloaded lines
- If modeled appropriately, DSR are an option to address unbalance problems