UNIVERSITY OF MANITOBA

Optimization-enabled Electromagnetic Transients Simulation for the Design of HVDC System

S. Filizadeh*, A. M. Gole*
D.A. Woodford† and G.D. Irwin†

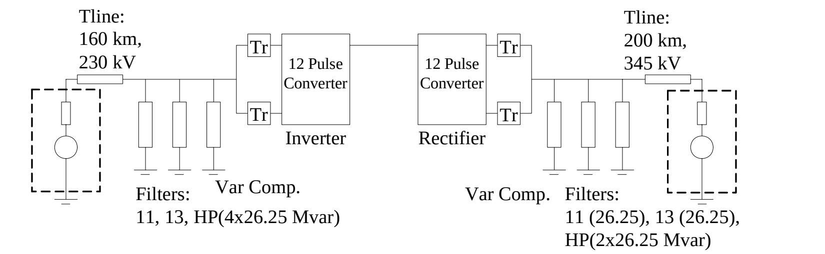
* Dept. of Electrical and Computer Engineering, University of Manitoba, CANADA

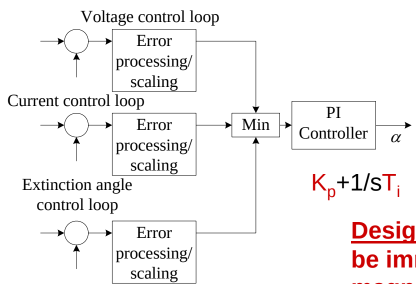
† Electranix Corporation, CANADA

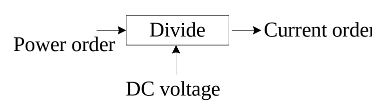
Outline

- Optimization-enabled transient simulation – A Powerful design tool
- Application to the controller design of a 200 MW HVDC Transmission System
  - Incorporating multiple objectives
  - Selection of Objective function

HVDC Controller Optimization (200 MW B-B Scheme)

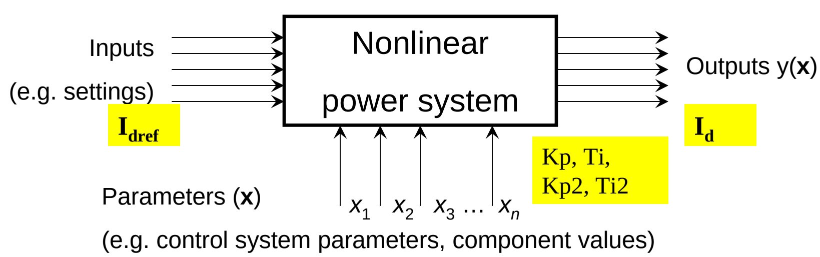




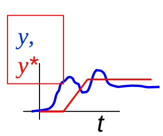


<u>Design Objective:</u> System response to be immune against ac voltage magnitude and phase changes.

Design, Optimization and Simulation



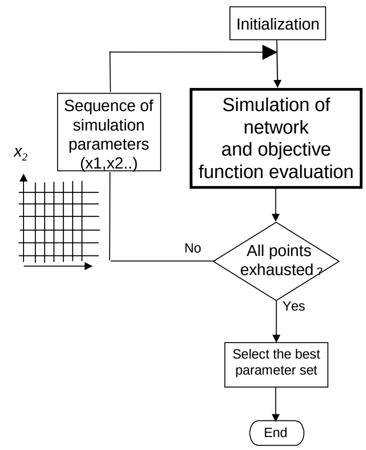
<u>Design objectives</u> → f(**x**) - smallest f(**x**) indicates "best" performance



$$f(x_1, x_2, \dots x_n) = \int_0^T (y - y^*)^2 \, dt$$

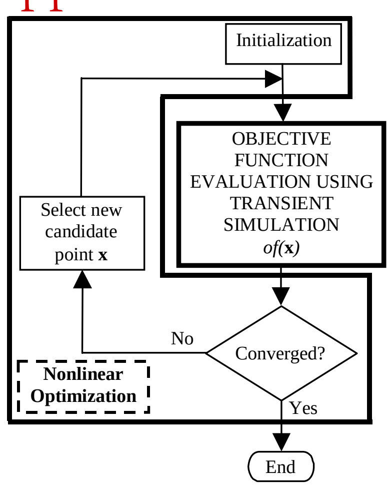
Design Using Simulation – Multiple Run
(brute force approach)

- Multiple simulations for several sequentially- or randomly-generated points;
- The best-performing point is singled-out.



Optimization-Enabled Transient Simulation – smart approach

- A mathematical optimization algorithm strategically selects the trial points
- Result- orders of magnitude less runs than with brute force approach
- Non-linear Simplex Method of Nelder and Mead used in paper

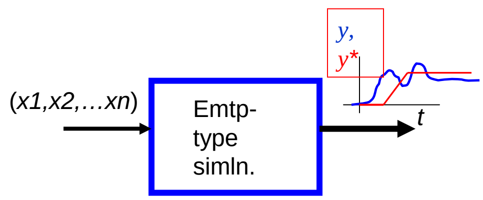


How is this different from conventional optimization ?

- Conventional Optimization: Find ($x_1, x_2, \ldots x_n$) which minimizes an explicit OF: $f(x_1, x_2, \ldots x_n)$

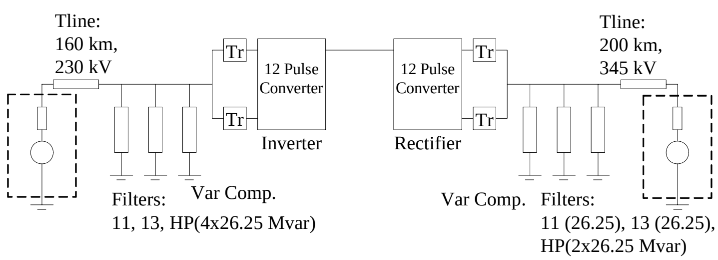
$$f(x_1, x_2, \ldots x_n) = \frac{x_1^2 + \sin(x_3 + x_4)}{\sqrt[n]{e^{1/\sum_{1}^{n} x_j}}}$$

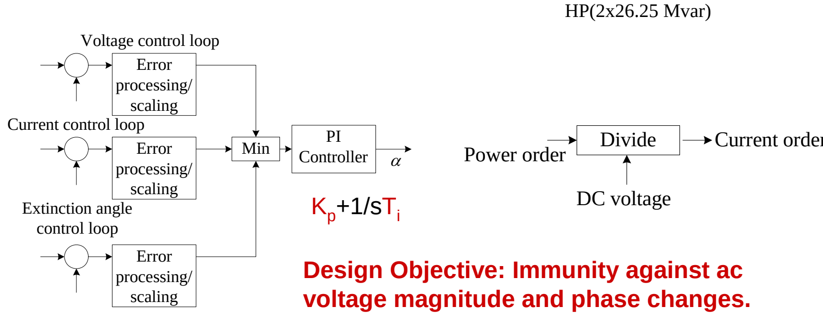
- Simulation based optimization: The mathematical form of the OF is unknown- it is determined from the simulation



$$f(x_1, x_2, \ldots x_n) = \int_0^T (y - y^*)^2 \, dt$$

HVDC Controller Optimization (200 MW B-B Scheme)





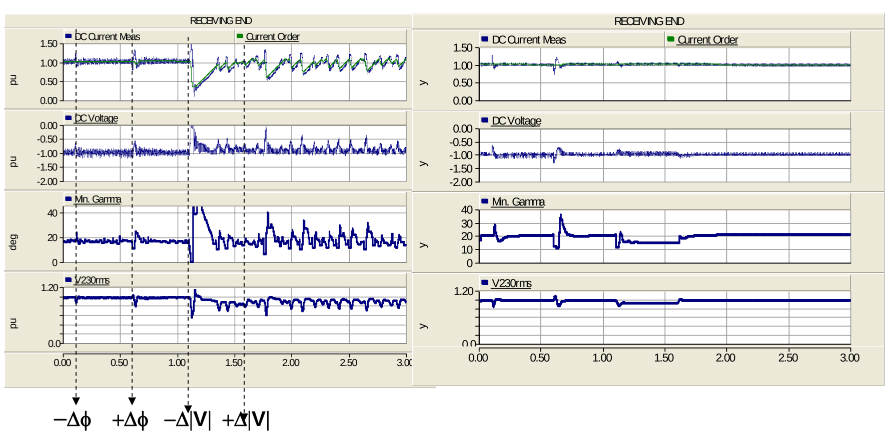
$K_p + 1/sT_i$

Design Objective: Immunity against ac voltage magnitude and phase changes.

Design Sequence

- HVDC model is run to steady state with initial parameters and a “snapshot” is taken.
- Optimization sequence of simulations is initiated starting from the “snapshot” (t=0) with applied disturbances:
  - t= 0.1 s: phase of the inverter side ac source reduced by 15^{o}
  - t= 0.6 s: phase increased by 15^{o}.
  - t= 1.1 s: magnitude of the ac source voltage reduced by 7%
  - t= 1.6s: the magnitude restored to its original value.
- Optimal parameter set emerges when the convergence criterion is satisfied.

Pre- and post- optimization HVDC Response



a) Initial Parameter Set b) Optimized Parameters

HVDC Response to AC Voltage Phase and Magnitude Changes

Selection of Objective Function

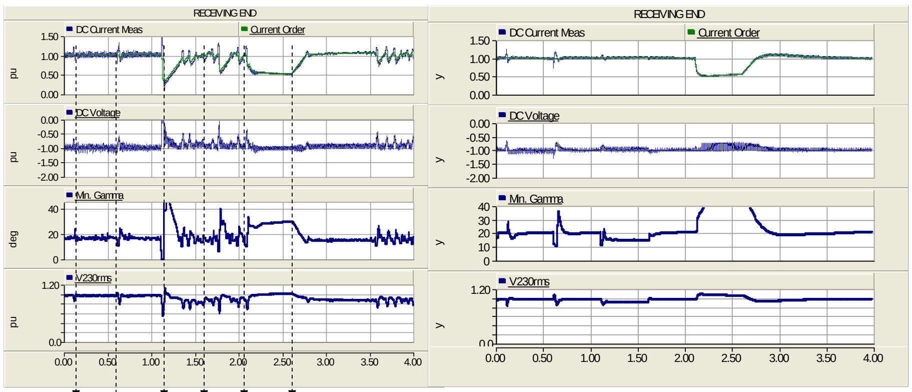
- Simulation with initial parameter set shows poorest response between 1.1s and 1.65s.
- Selected OF penalizes current deviation from reference, and particularly targets the [1.1 s, 1.65 s] interval.

$$OF = \int_{0}^{1.1} (I_{dref} - I_d)^2 dt + \int_{1.1}^{1.65} 2(I_{dref} - I_d)^2 dt + \int_{1.65}^{4.0} (I_{dref} - I_d)^2 dt$$

Other optimization refinements

- Optimization with objective to de-sensetize against voltage changes gave poor performance for set-point changes
- Hence the system was re-optimized with an additional current order set-point change in the simulation

Optimization to de-sensitize against ac voltage variations and give good dynamic response



−Δϕ +Δϕ −Δ|V| +Δ|V| −ΔId + ΔId

a) Pre-optimization OF=62.5

b) Post-optimization OF=27.5

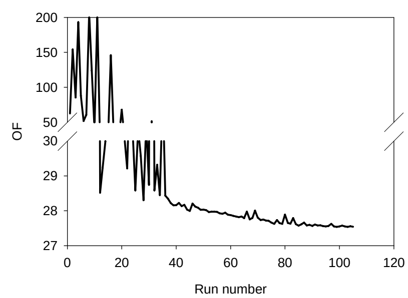
Presentation at IEEE PES T&D Subcommittee Meeting, Montreal, June 21, 2006 13/17

Optimization Performance

Table 1. Initial and Optimized Parameters

	Initial Parameters	Optimized Parameters
Gain (rectifier)	1	1.04
Time constant (rectifier)	0.3	0.007
Gain (inverter)	1.44	0.3
Time constant (inverter)	0.0083	0.033

- •OF reduced from 62.5 to 27.5 in 108 runs.
- •With 10 steps in each of 4 variables, traditional multiple-run techniques would require 104=10,000 simulation runs.
- •2 Orders of Magnitude time savings!

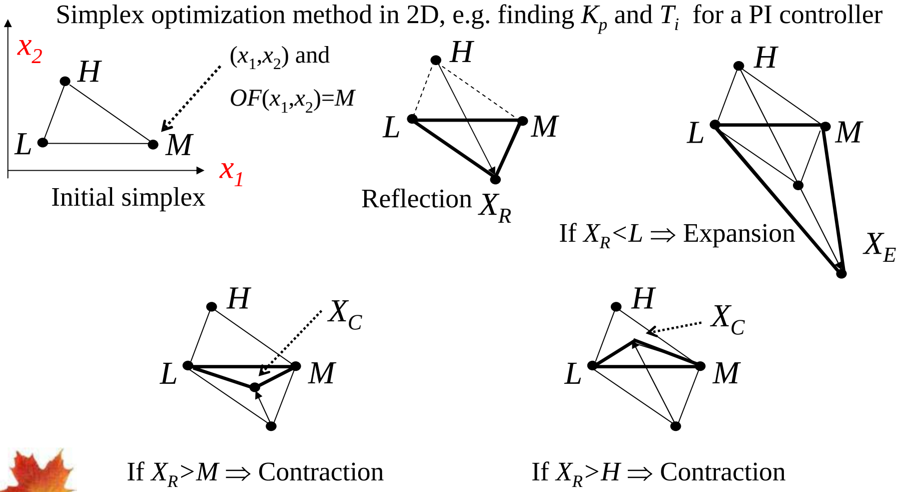


Presentation at IEEE PES T&D Subcommittee Meeting, Montreal, June 21, 2006 14/17

•An Example of an Optimization Algorithm

–Gradient-like algorithm → Simplex Method of Nelder and Mead

Simplex optimization method in 2D, e.g. finding K_p and T_i for a PI controller



Conclusions

- Optimization-enabled simulation → design where no explicit OF is available
- The method can succesfully be applied to the design of HVDC Controllers to satisfy multiple objetives
- Objective Function must be carefully chosen with appropriate weights to different objectives
- Potentially results in orders of magnitudes in computer time in design applications

Thank You

Contact

Ani Gole

Email: gole@ee.umanitoba.ca

References:

1. Filizadeh, S. and Gole, A.M., "Inclusion of Robustness into Design Using Optimization-Enabled Transient Simulation", EEE Trans. on Power Delivery, v 20, Issue 3, July 2005, pp 1991-97
2. Gole,A.M., Filizadeh,S., Menzies, R.W. and Wilson, P.L, "Optimization-Enabled Electromagnetic Transient Simulation"IEEE Transactions on Power Delivery, v 20, Issue 1, January 2005, pp 286-293
3. S. Filizadeh, A.M. Gole, D.A. Woodford and G.D. Irwin, "Optimization-enabled Electromagnetic Transients Simulation for the Design of Hvdc Systems" CIGRE SC B4 Colloquium on "Role of HVDC FACTS and Emerging Technologies in Evolving Power Systems" Bangalore, India, Sept. 23-24 2005
4. Filizadeh, S.; Gole, A.M.; Woodford, D.A.; Irwin, G.D.;"Control system design for HVDC systems using optimization-enabled electromagnetic transient simulation", The 8th IEE International Conference on AC and DC Power Transmission, 2006. ACDC 2006. 2006 Page(s):46 - 49