Optimal Adaptive Control of Cascading Power Grid Failures

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Based on: Daniel Bienstock. "Optimal adaptive control of cascading power grid failures"

Introduction

- Major blackouts caused by cascading power grid failures have renewed interest in problems related to grid vulnerabilities
- Control actions must be taken in order to prevent the collapse of an entire grid
- Optimization can lead to a solution to terminate cascading behaviour while maximizing demand satisfied

Cascading Power Grid Failures

- Cascading behaviour is the process by which components of the grid sequentially become inoperative
- Components of the grid which are especially vulnerable are power lines
- The simultaneous outage of a set of power lines and buses can lead to cascading behaviour
- In catastrophic events these cascades ”snowball” until the entire grid collapses

Optimization Problem

- The optimization problem is to stop the cascade after a fixed number of rounds of outages while maximizing the total demand satisfied
- The goal is to compute an optimal control which redistributes demand as a function of variables of the state of the grid
- It is also important for the control to be computed in real time (ideally less than 1 hour)
- In this paper the majority of algorithms used to compute optimal control implemented first-order methods

Data

- Simulations were run using data acquired from a segment of the U.S. Eastern Interconnect
  - 15000 buses
  - 23000 lines
  - 2000 generators
  - 6000 load buses
- **Important point 5000 of the line flow limits were 0 indicating data errors or missing data**

Simulation Results

- Simulations were conducted to illustrate the comparison between the cases
  - No control implemented
  - Simple control methods implemented

Simulation Results

Table 1: *Cascade evolutions*

r	No control				c20			
	κ	O	I	Y	κ	O	I	Y
1	40.96	86	1	100	40.96	86	1	100
2	8.60	187	8	99	8.60	165	8	96
3	55.51	365	20	98	61.74	303	17	96
4	67.14	481	70	95	66.63	408	44	94
5	94.61	692	149	93	131.08	492	94	93
6	115.53	403	220	91	112.58	416	146	90
7	66.12	336	333	89	99.62	326	191	78
8	47.83	247	414	87	60.95	227	248	77
9	7.16	160	457	85	32.50	72	279	76
10	7.06	245	542	84	9.50	43	292	76
11	37.55	195	606	83	45.28	35	303	76
12	13.04	98	646	82	11.60	10	306	76
13	22.61	128	688	82	3.88	6	310	75
14	10.64	107	715	81	1.46	4	312	75
15	5.03	64	721	81	1.34	1	312	75
16	84.67	72	743	80	1.13	1	312	75
17	32.15	52	756	80	1.38	2	312	75
18	6.50	43	763	80	1.26	1	312	75
19	9.97	85	812	80	0.99	0	312	75
20	32.34	39	812	2	0.99	0	312	75

Optimization Methods

- The general method uses first-order algorithms (steepest ascent)
- Algorithms used were based on the following template
- This procedure should be viewed as a local search method

Procedure 6.1 *First-order algorithm*

Input: a control vector (c, b, s).
For $k = 1, 2, \dots$ **do**

1. Estimate $g = \nabla\tilde{\Theta}^R(c, b, s)$.
2. Choose "step-size" $\mu \geq 0$ and update control to $(c, b, s) + \mu(g_c, g_b, g_s)$.
3. If μ is small enough, stop.

Things to Consider

- The control vector is not differentiable so it should be considered an approximate
- The control vector is not convex so the steepest ascent method may not converge to a global optima
- This procedure is too slow

Grid Search

- Standard enumerative two-dimensional search
- Carried out one parameter at a time
- Can produce good control vectors
- Room for improvement by widening the search

Gradient/Segmented Search

- The control vector computed by the grid search can be used to start the general gradient search
- In high dimensional cases the general gradient search can be slow
- Segmented search is used in place of gradient search since it is much faster and can be extended to full gradient search without much difficulty
- Segmented search groups buses together based on demand (highest demand buses grouped together, then next highest demand grouped together etc.)

Grid Search vs. Gradient/Segmented Search

- In several cases the gradient search solution shows significant improvement over the grid search solution
- Gradient search control allows more outages in initial rounds but these outages are monotonically decreasing
- By round 5 the gradient search has less outages than the grid search
- The gradient search control maintains a high demand yield while still allowing outages to occur

Grid Search vs. Gradient/Segmented Search

Table 7: *Controlled cascade evolutions*

	Grid-search				Gradient-search			
Round	κ	faults	comps	yield	κ	faults	comps	yield
1	3.79	126	1	45.37	172.22	1629	32	60.72
2	33.49	32	1	45.37	97.44	1079	293	54.26
3	7.44	26	2	45.27	59.97	282	401	49.87
4	6.69	82	4	45.27	21.88	89	459	48.67
5	4.95	72	9	45.23	2.74	55	468	47.74
6	1.99	28	13	45.23	13.27	10	471	47.72
7	1.54	16	13	45.23	1.01	14	478	47.41
8	1.00	16	13	29.27	1.00	1	478	46.97

Future Work

- Derivative-free optimization and methods that incorporate second-order information can potentially be adapted to this problem
- Stochastic optimization
  - Specifically using stochastic gradients

Summary

- What is the application?
  - Calculating a control vector which effectively terminates cascading power grid failures while maximizing the demand supply yield
- Why is optimization desired?
  - During a power grid failure it is important to not only stop the collapse of the grid but to also maintain supply to as many users as possible
- What optimization algorithm was used?
  - Modified first-order (steepest-ascent) method
  - Using grid and gradient search

Summary

- Did it work?
  - To a certain extent
  - Control vectors that were computed prevented collapse of the power grid while maintaining high demand yields
- Are you sure?
  - No
  - Alternative optimization methods may produce better solutions
  - Further research using other methods should be conducted on this problem

Thank you!