Improving the robustness of Newton-based power flow methods to cope with poor initial points

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Acknowledgments

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Outline

Introduction

The issue

What is the issue?

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- difficult task of trying to get a case to converge

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Solving power flow problems is crucial

but current solvers have questionable reliability

- can fail due to purely algorithmic reasons

Failures can leave system operators/planners with

- difficult task of trying to get a case to converge
- limited or incorrect knowledge about the system

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2. absence of key information in problem formulation

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Widely used solution method

- Newton-Raphson (NR) combined with switching heuristics

suffers from many weaknesses

1. performance dependency on initial point x_0
2. absence of key information in problem formulation
3. conflicts introduced by switching heuristics (cycles, jumps)

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Our work

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We try to overcome these weaknesses using techniques based on

- homotopy
- optimization

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This presentation focuses on handling poor initial points

Methods and results

A homotopy approach

A homotopy approach

Instead of solving power flow equations $f(x) = 0$,
solve sequence of subproblems $h(x, t_k) = 0$, $k \in \mathbb{N}$,

where

- first subproblem is easy to solve
- last subproblem is original problem
- consecutive subproblems are similar

Methods and results

Based on system transformations

We first tried transforming the system

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- Injection Homotopy (IH)
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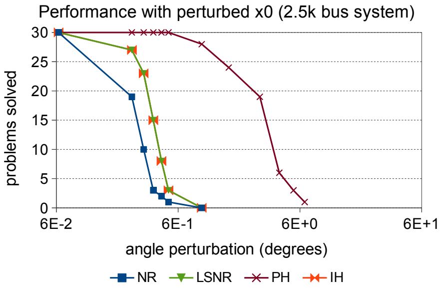
solved each subproblem with

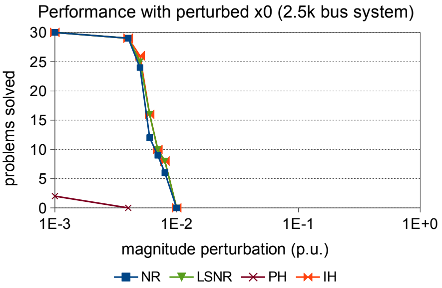
- Line Search Newton-Raphson (LSNR)

Methods and results

Based on system transformations (performance)

Constructed 30 initial points by perturbing good x_0





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Need to encourage algorithms to search in “good” regions

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Before even solving, we know that generally $v \approx 1$, hence use

Penalty function

$$\varphi(x) = \frac{1}{2} \sum_{i \in \mathcal{U}} (v_i - 1)^2$$

$\mathcal{U}$ is set of unregulated buses

Methods and results

Based on prior information

Magnitude Homotopy (MH)

Solve sequence of subproblems

$$\underset{x}{\text{minimize}} \quad (1 - t_k)\varphi(x) + t_k \frac{1}{2}\|f(x)\|_2^2$$

for $t_1 = 0$, $t_k \to 1$ as $k \to \infty$

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for $t_1 = 0$, $t_k \to 1$ as $k \to \infty$

Can think of it as homotopy approach with

$$h(x, t_k) = (1 - t_k)\nabla\varphi(x) + t_k J(x)^T f(x), \;\; J = \frac{df}{dx}$$

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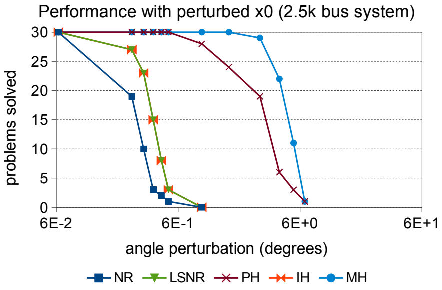

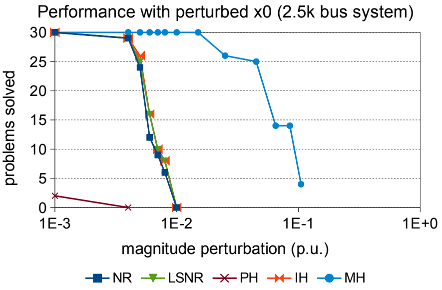

Methods and results

Based on prior information (reformulation)

MH is just penalty function method applied to

New formulation

$$\begin{aligned} \underset{x}{\text{minimize}} \quad & \varphi(x) \\ \text{subject to} \quad & f(x) = 0, \end{aligned}$$

x consists of $\{v_i\}_{i \in \mathcal{U}}$ and $\{\theta_i\}_{i \in [n] \setminus \{s\}}$

θ is voltage angle, n is number of buses, s is slack bus

Methods and results

Extension of prior information approach

Extend approach to handle Q limits and voltage control

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New formulation (extended)

$$\begin{aligned} \underset{x}{\text{minimize}} \quad & \varphi(x) \\ \text{subject to} \quad & f(x) = 0 \\ & (v_i, Q_i) \in \mathcal{G}_i, \; i \in \mathcal{R}, \end{aligned}$$

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$\mathcal{R}$ is set of regulated buses

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Extension of prior information approach

Extend approach to handle Q limits and voltage control

New formulation (extended)

$$\begin{aligned} \underset{x}{\text{minimize}} \quad & \varphi(x) \quad \text{(strongly convex)} \\ \text{subject to} \quad & f(x) = 0 \\ & (v_i, Q_i) \in \mathcal{G}_i,\ i \in \mathcal{R}, \end{aligned}$$

x consists of $\{v_i\}_{i\in[n]\setminus\{s\}}$, $\{\theta_i\}_{i\in[n]\setminus\{s\}}$ and $\{Q_i\}_{i\in\mathcal{R}}$

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based on augmented Lagrangian method

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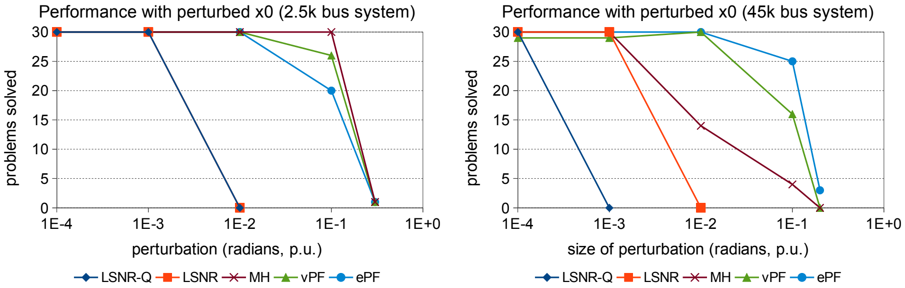

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  - helped significantly to cope with poor x_0
  - penalty function method applied to constrained problem
  - can be extended to consider Q limits and voltage control

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What we have done and learned ...

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  - did not help to cope with poor x_0
  - same weaknesses as NR/LSNR
- homotopy based on prior information
  - helped significantly to cope with poor x_0
  - penalty function method applied to constrained problem
  - can be extended to consider Q limits and voltage control
    - ePF and vPF
    - based on augmented Lagrangian method
    - inherit robustness to poor x_0

Questions

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