Reactive Power Considerations in Automatic Contingency Selection
Outline

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What is Contingency Analysis?

- Analysis to ensure reliable operation of the power grid in the event of failures
- Analysis is typically done n-1 or n-2
- Failures might include
  - Line loss
  - Generator loss
  - Equipment loss
- A list of failures the could potentially have a large system impact are identified
- The failure list is the contingency list
Computing Technology in the 1980s

- Cyber 170 Series Computers
- 262k 60 bit words memory
- Operate at one million floating point operations a second
- Computational efficiency very important
- Computers cost over a million dollars
Fast Decoupled Load Flow (FDLF)

- By making reasonable engineering assumptions, amount of calculation were reduced
- Able to eliminate two parts of the Jacobian

\[
\begin{bmatrix}
\Delta P \\
\Delta Q
\end{bmatrix}
= 
\begin{bmatrix}
J_1 & 0 \\
0 & J_2
\end{bmatrix}
\begin{bmatrix}
\Delta \theta \\
\Delta V
\end{bmatrix}
\]
Fast Decoupled Load Flow (cont.)

- The impedance of transmission lines is mostly reactive
- Conductances are significantly less than susceptance ($G_{ij} \ll B_{ij}$)
- Under normal steady state operation, the angular difference among bus voltages are small ($\Theta_i - \Theta_j \approx 0$)
- Injected reactive power at a bus is much less than reactive power consumed by the connecting elements when shorted to ground ($Q_i \ll B_{ii} V_i^2$)
- Using this information we are able to eliminate $J_2$ of the Jacobian
Similarly we are able to eliminate $J_3$ of the Jacobian.

\[
\frac{\partial Q_i}{\partial \theta_j} = \sum_{k=1}^{n} V_i V_k \left[ G_{ik} \cos(\theta_i - \theta_k) + B_{ik} \sin(\theta_i - \theta_k) \right]; \quad j = i \\
\frac{\partial Q_i}{\partial \theta_j} = -V_i V_j \left[ G_{ij} \cos(\theta_i - \theta_j) + B_{ij} \sin(\theta_i - \theta_j) \right]; \quad j \neq i \\
\frac{\partial Q_i}{\partial \theta_i} \approx 0 \quad \text{and} \quad \frac{\partial Q_i}{\partial \theta_j} \approx 0 \quad \implies J_3 \approx 0
\]
Motivation to Create New Contingency Method

- Need to study contingencies on the power system
- Testing all contingencies takes a long time
- This paper describes a method to select the important contingencies to study
- Other methods focus on line loading and overlook contingencies that affect voltage
- Need to study voltage to prevent voltage limit violation
Fast Decoupled Contingency Method

- Extension of a DC Flow method
- Uses a performance index which includes voltage limit violations and reactive power deviations
- Normally a Fast Decoupled power flow converges to a solution in 3-4 iterations
- The solution from the first iteration is considered within “engineering” tolerance and from there we calculate a performance index for every outage
- Outages ranked based on index
Performance Indices: Real Power

Index to measure line MW overloads.

\[ PI_{MW} = \sum_{\alpha} W_p \left( \frac{P_\ell}{P_{\ell}^{max}} \right)^2 \]

Where

- \( W_p = \) Real power weighting factor
- \( P_\ell = \) MW flow in line \( \ell \)
- \( P_{\ell}^{max} = \) MW capacity of limit
- \( \alpha = \) Set of overloaded lines
Performance Indices: Voltage – Reactive Power

Index to measure if either the voltage or reactive power is outside of a specified range.

\[ PI_{VQ} = \sum_{\beta} W_V \left| \frac{V_i - V_{lim}}{V_{lim}} \right| + \sum_{\gamma} W_Q \left| \frac{Q_i - Q_{lim}}{Q_{lim}} \right| \]

Where
- \( V_i = \) Voltage magnitude at bus i
- \( V_{lim} = \) Voltage magnitude limit at bus i
- \( W_V = \) Voltage weighting factor
- \( Q_i = \) Reactive power injection at bus i
- \( Q_{lim} = \) Reactive power limit at bus i
- \( W_Q = \) Reactive power weighting factor
- \( \beta = \) Set of buses at which the voltage magnitude is either below a min or above a max
- \( \gamma = \) Set of buses at which the reactive power is either below a min or above a max
Contingency Ranking

1. Iteration one calculates the performance indices for every outage
2. Outage ranking created using real power index
3. Separate outage ranking created using voltage – reactive index
Contingency Selection – Stopping Criteria

- Ranking of contingencies in order of severity
- Starting with the most severe, run a full AC analysis
- Run AC analysis for the next most severe case
- Stop when
  - Desired number of contingencies have been studied
  - No overloads or limit violation over the last N amount of cases analyzed
Computational Efficiency of the Method

- Problem required solving many power flows, one for each contingency
- To reduce the number of iterations required for each power flow solution, the power flow for each contingency used the results from the first iteration as a base case
- No need to create a new admittance matrix for each contingency

Table IV from the paper shows the CP time saved using the ranking method

<table>
<thead>
<tr>
<th></th>
<th>Ranking</th>
<th>Full</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average CP Time per outage case (seconds)</td>
<td>.3626</td>
<td>.6732</td>
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References


Questions?