Modelling of a Large Mining Network

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Background

• Large mine development in North-West of W.A
• 500MW on-site power plant (not grid connected)
  – Gas Turbines
  – Steam Turbines (Heat Recovery Steam Turbine)
• Network consisting of 220kV, 33kV, 11kV, 6.6kV and 415V
• Loads
  – 15MW Ball Mill
  – 28MW AG Mill (Cyclo-converter)
Motivation

- Islanded industrial networks present many unique challenges
- Finding the right solution(s) requires a good understanding of the problem
- In-depth analysis can be achieved with powerful computer simulation packages;
  - Load flow/short circuit
  - Dynamics (voltage frequency)
  - Power Quality (harmonics, flicker)
  - Transients
  - Protection
# Problems in Large Industrial Networks

<table>
<thead>
<tr>
<th>Classification</th>
<th>Risks</th>
<th>Cause</th>
<th>Control Measures</th>
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<tr>
<td>Frequency instability</td>
<td>Cascading tripping of;</td>
<td>• Loss of Generation</td>
<td>• Load Shedding</td>
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<td>• Load: motors, VSDs</td>
<td>• Tripping of large motors of VSDs</td>
<td>• Adequate control of generator reserves</td>
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<tr>
<td></td>
<td>• Generation</td>
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<td>• Adequately tuned frequency control system</td>
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<tr>
<td>Voltage instability</td>
<td>Loss of load</td>
<td>• Motor Dynamics (start-up)</td>
<td>• Reactive Compensation (dynamic/static)</td>
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<td>• Voltage control schemes</td>
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<tr>
<td>Harmonic distortion</td>
<td>• Thermal stress</td>
<td>• VVVF drives</td>
<td>• Passive/Active harmonic filters</td>
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<td></td>
<td>• Control problems</td>
<td>• Resonance</td>
<td>• 12, 18 pulse front end converter VVVF drives</td>
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<tr>
<td>Protection</td>
<td>• Spurious tripping</td>
<td>• Poor/incorrect setting of protection relays</td>
<td>• Appropriate setting of protection devices</td>
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<tr>
<td></td>
<td>• Long tripping times</td>
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## Benefits of Computer Simulations

<table>
<thead>
<tr>
<th>Solution</th>
<th>Type of Simulation</th>
<th>Outcomes</th>
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<tbody>
<tr>
<td>Load shedding</td>
<td>Dynamic (Frequency)</td>
<td>Optimised setting of U/F, ROCOF load shedding elements</td>
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<tr>
<td>Frequency control</td>
<td>Dynamic (Frequency)</td>
<td>Tuning of frequency controllers/governors</td>
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<tr>
<td>Reactive Compensation</td>
<td>Dynamic (voltage)</td>
<td>Optimised sizing and placement of capacitor banks, SVCs</td>
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<td>-Load flow</td>
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<tr>
<td>Harmonic Filters</td>
<td>Harmonic load flow,</td>
<td>• Appropriate specification of harmonic filter banks</td>
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<td>frequency sweep</td>
<td>• Assessment of different options (Active/Passive)</td>
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<tr>
<td>Setting of protection</td>
<td>Protection coordination</td>
<td>• Appropriate setting of protection relays</td>
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<tr>
<td>devices</td>
<td></td>
<td>• Management of network protection settings</td>
</tr>
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</table>
Developing the Network Model

- The development of any model requires correct and accurate information. Sources of information for this project included:
  - Cable schedules (Cable lengths, size, type)
  - Overhead lines (conductor, geometric arrangement)
  - Transformer datasheets/nameplate (rating, vector group, impedance)
  - Load lists
  - Single Line Diagrams (CT ratios, VTs)
  - Generator datasheets (impedances, time constants)
  - Motor datasheets
  - Protection (relay models and settings)
  - Manufacturer AVR and governor control block diagrams
  - Power station control philosophy (frequency, voltage control)

- Due to the large size of the network, careful control and management of information sources was critical in ensuring an accurate model
Dynamic Models

**Generation**
- Governors
- AVR\(\text{s}\) and exciters
- Secondary frequency and voltage controllers
- Automatic tap changing controllers

**Load**
- Ball Mill
- Variable speed drives
- Direct On-Line (DOL) drives
Power Station Frequency Controller

\[ \sum_{i=1}^{10} P_i = 1 \]

\[ P_{Gc_i} = P_i \times GCE \]
Power Station Frequency Controller
Power Station Voltage Controller
Ball Mill Motor Model
Variable Speed Drive Model

- Dynamic loads using the PowerFactory *ElmLod element has been used to model the VSDs:
  
  \[ P = k \times P_0 \left( \frac{V}{V_0} \right)^\alpha \]
  
  \[ Q = k \times Q_0 \left( \frac{V}{V_0} \right)^\beta \]

- Exponents have been set to 0 to represent a constant power load.

- Large VSDs and the cyclo-converter have been modelled with a user defined PQ starting characteristic to represent the actual starting characteristic as measured on site.
Variable Speed Drive Model

• VSD controllers have voltage and frequency set-points that disconnect the drive on a voltage/freq event
Protection Model

- Total of 600 protection relays associated with the HV distribution system
- 25 different relay models/type
- DPL scripting enabled protection relay settings to be managed in an excel spread sheet and imported into the respective PowerFactory relay model
- Protection elements models included;
  - Direction and non-directional over-current/earth fault
  - Differential, Restricted Earth Fault
  - Frequency (U/F, O/F), Voltage (U/V,O/V, negative phase sequence)
  - Motor protection (Thermal overload)
Model Validation

- Accuracy of dynamic models needs to be confirmed against actual site test measurements
- Parameters from manufacturers, or typical parameters, do not always accurately represent the true performance of the system
- Models that require validation include;
  - Exciter
  - Governor
  - Automatic voltage regulator
  - Power station controllers (voltage, frequency)
  - Ball Mill start-up characteristic (ramp time, peak inrush current)
  - Cyclo-converter start-up characteristic (Active/reactive power)
- Models are verified by undertaking a series of site tests (generator voltage/frequency step, motor start-up) and simulating the same test in the PowerFactory model
Model Validation

Generator unsynchronised voltage step test

Original Exciter Model Parameters

Revised Exciter Model Parameters

![Graph showing comparison between original and revised exciter model parameters for generator unsynchronised voltage step test](image-url)
Conclusion

• A power system model has been developed for a large mine that can facilitate the following types of studies;
  – Load flow: Equipment loading, voltage regulation
  – Short-circuit: Equipment fault ratings
  – Dynamic simulations: Start-up of Mills/large motors, frequency and voltage stability following loss of generation or load
  – Protection coordination: Grading of over-current and earth fault protection elements

• The dynamic performance of the generators and the loads models have been verified against site tests (ongoing process)

• The model will serve as a useful tool for;
  – Future planning
  – Diagnosing problems before they occur