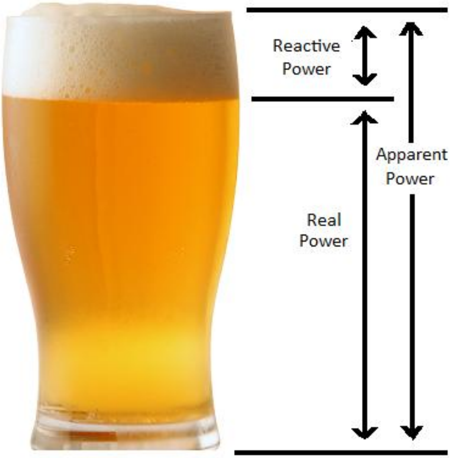
Power factor, reactive power and voltage stability in the New Zealand power system

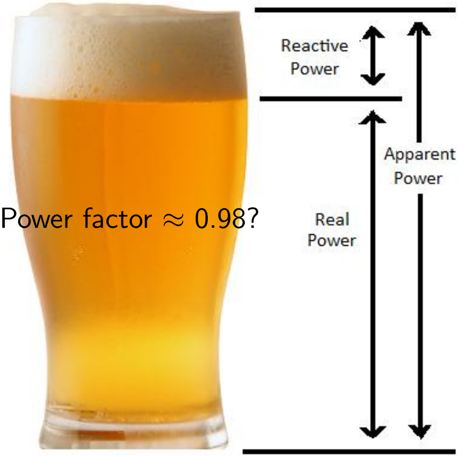
EA Board meeting - 14th September, 2011

David Hume
david.hume@ea.govt.nz
Electricity Authority of New Zealand

Introduction



Introduction



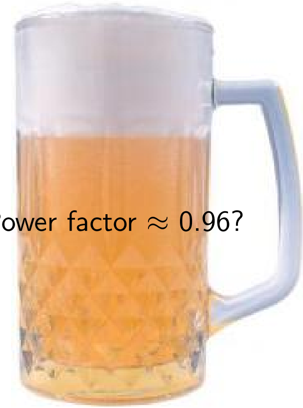
Power factor ≈ 0.98?

Effect of power factor on power transfer – thermal limits

Effect of power factor on power transfer – thermal limits

Power factor ≈ 0.96?

Effect of power factor on power transfer – thermal limits

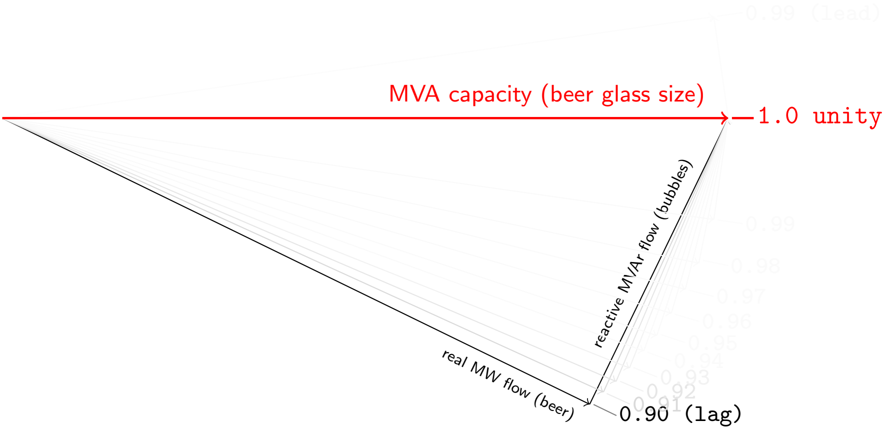


Power factor $\approx$ 0.96?

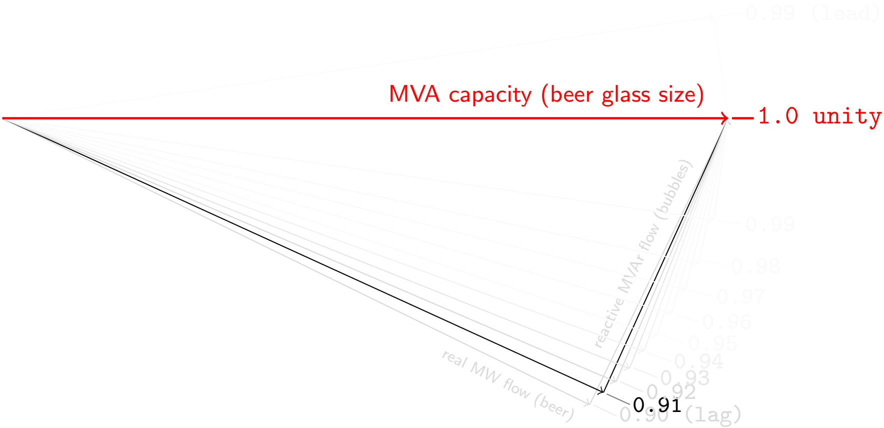
is better than

Power factor $\approx$ 0.3?

Effect of power factor on real power transfer



Effect of power factor on real power transfer



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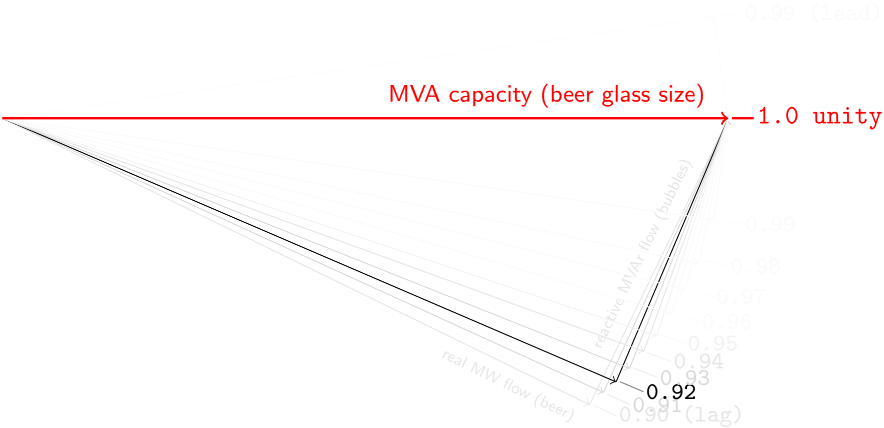

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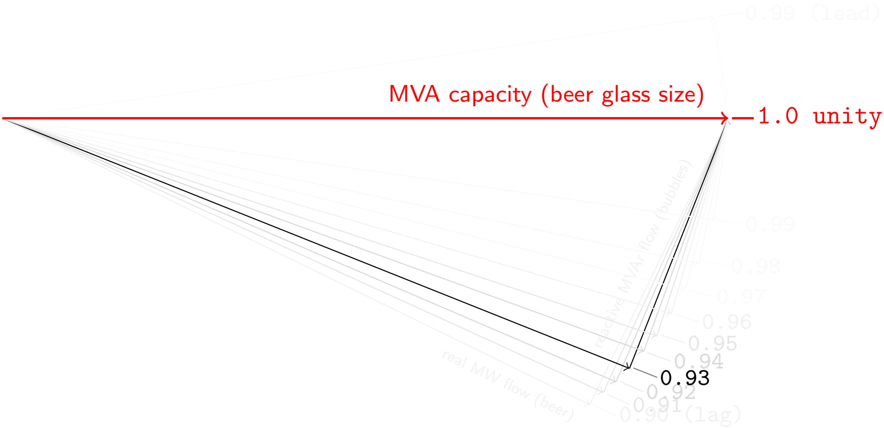

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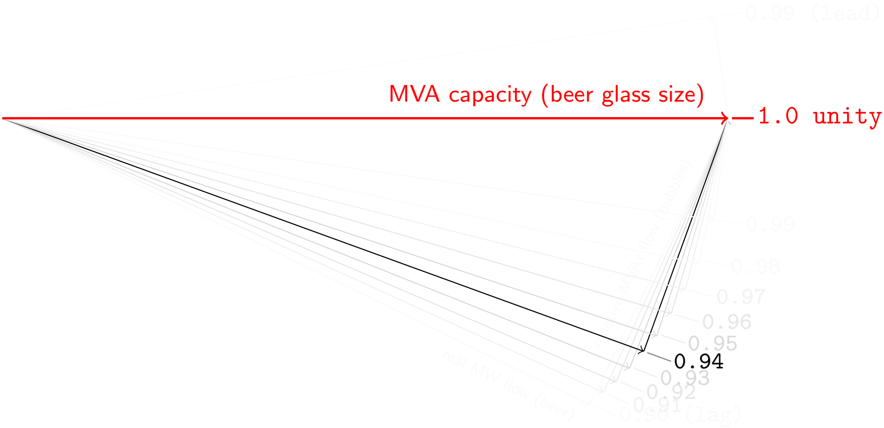

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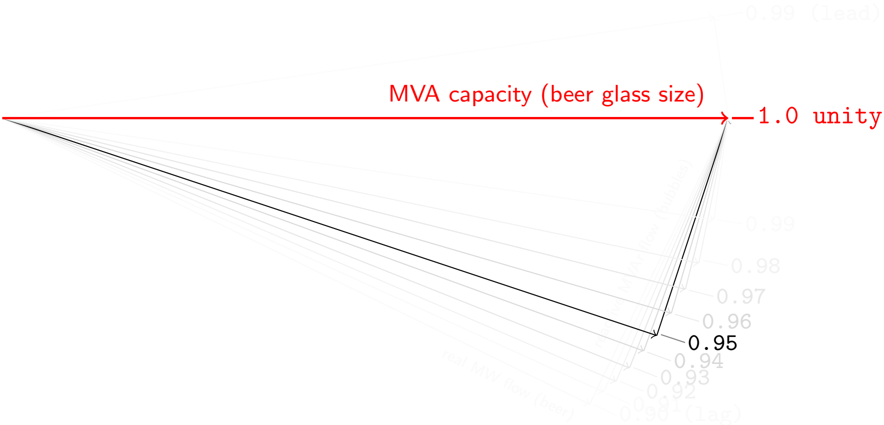
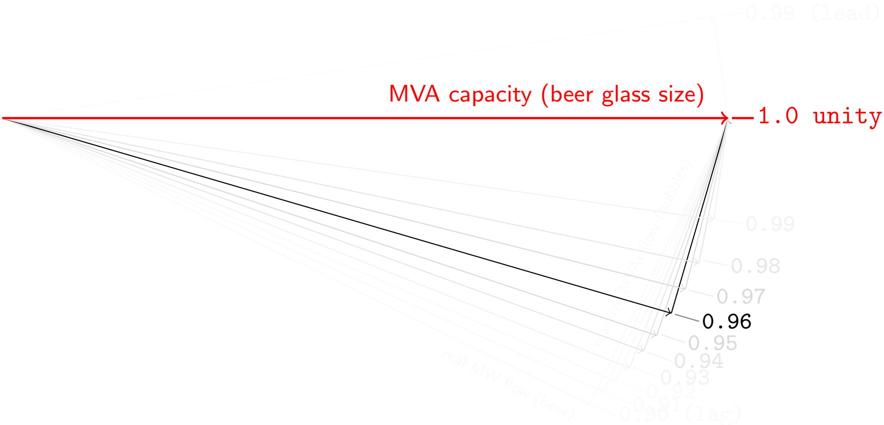
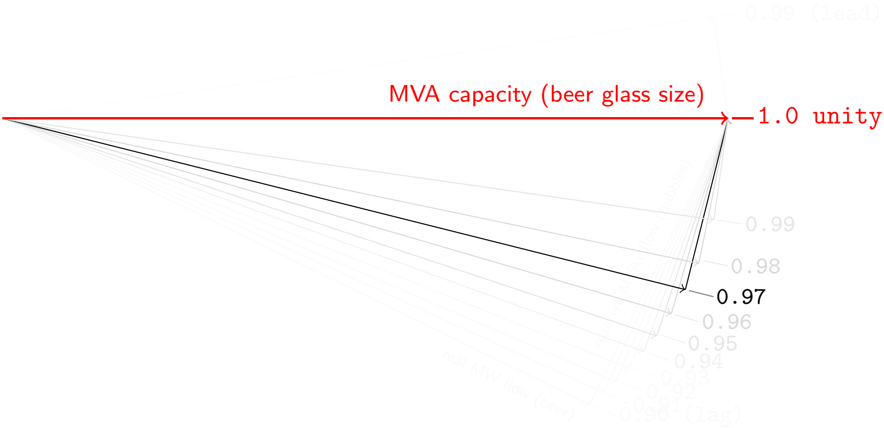


Effect of power factor on real power transfer



Effect of power factor on real power transfer



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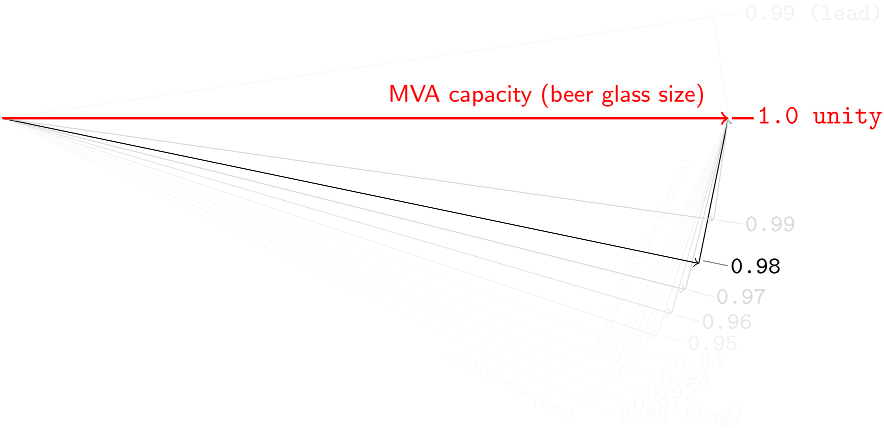

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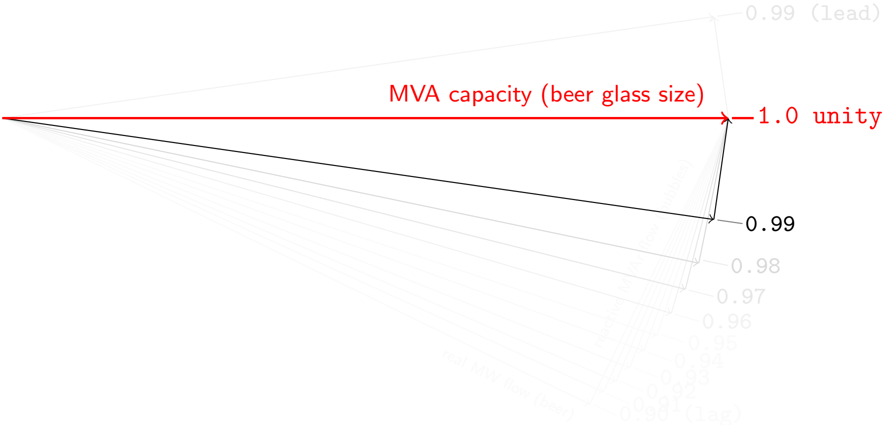

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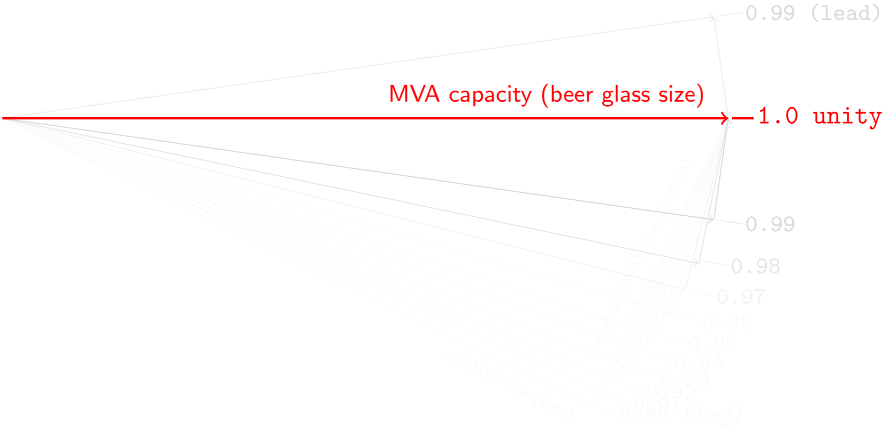
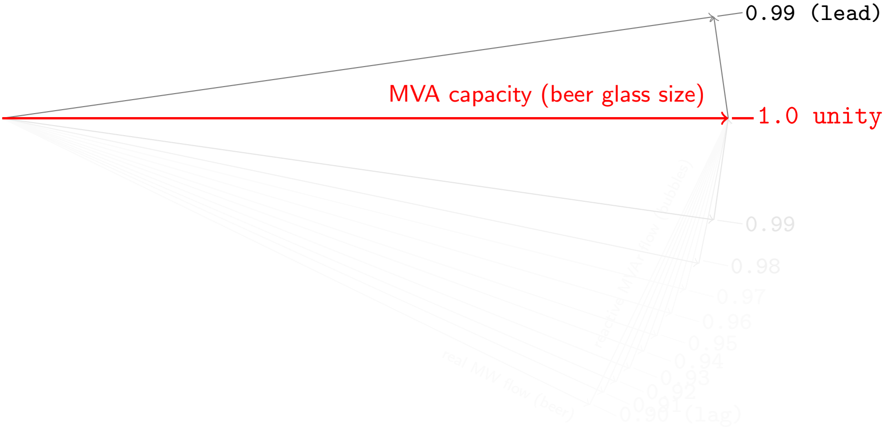
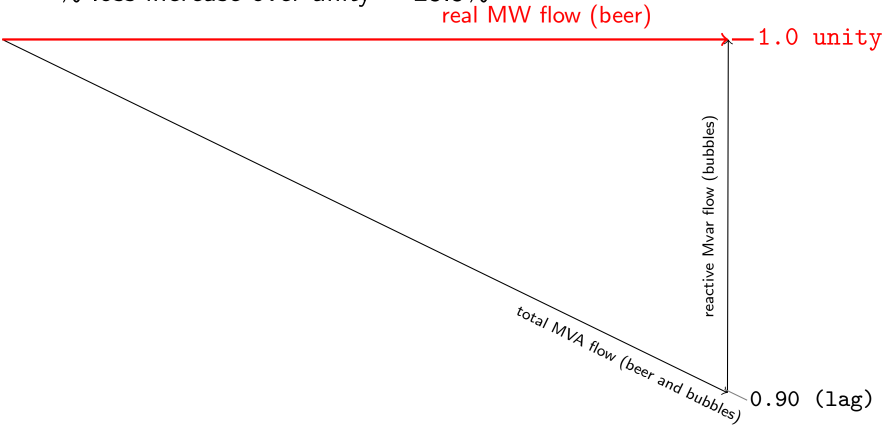


Effect of power factor on real power transfer



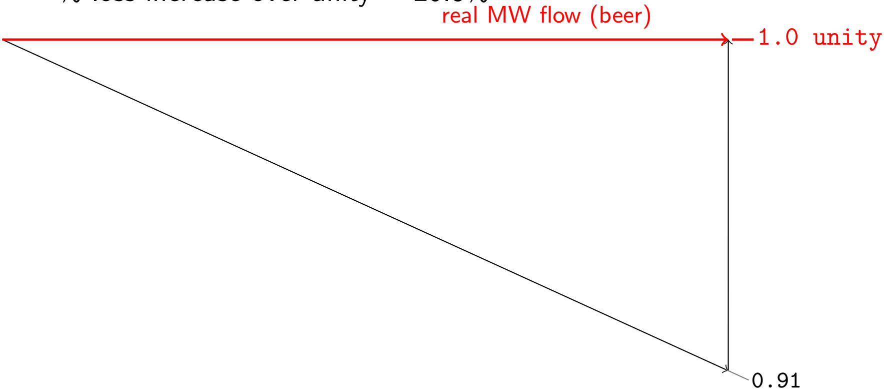
Effect of power factor on total current and losses

% loss increase over unity = 23.5%



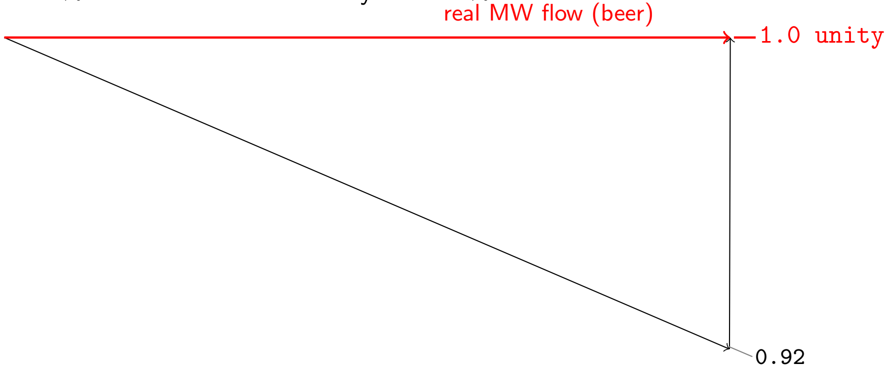
Effect of power factor on total current and losses

% loss increase over unity = 20.8%



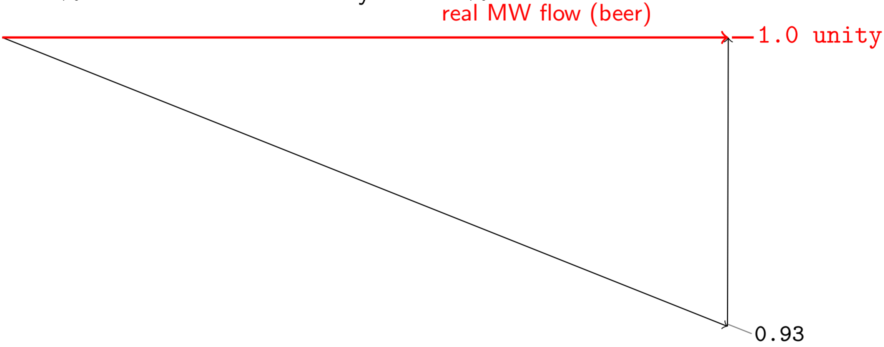
Effect of power factor on total current and losses

% loss increase over unity = 18.1%



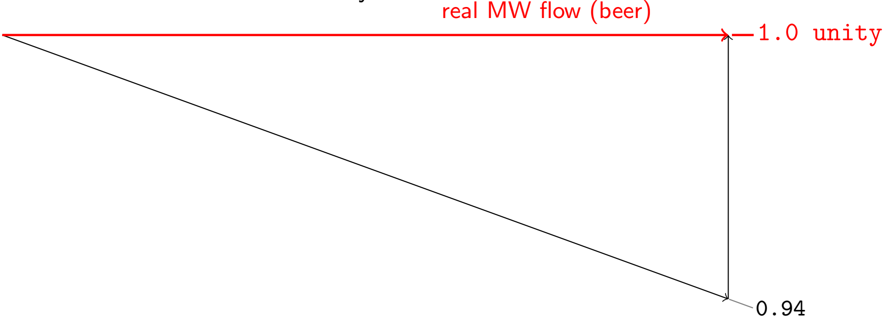
Effect of power factor on total current and losses

% loss increase over unity = 15.6%



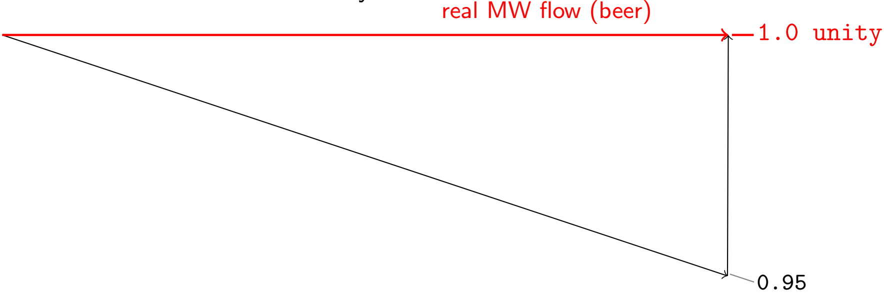
Effect of power factor on total current and losses

% loss increase over unity = 13.2%



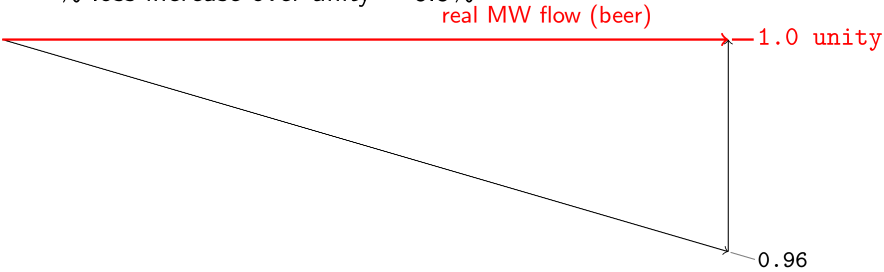
Effect of power factor on total current and losses

% loss increase over unity = 10.8%



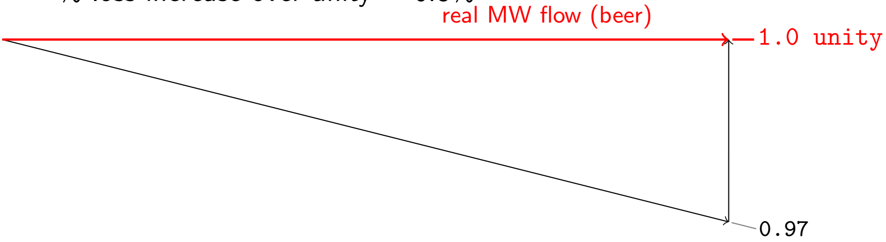
Effect of power factor on total current and losses

% loss increase over unity = 8.5%

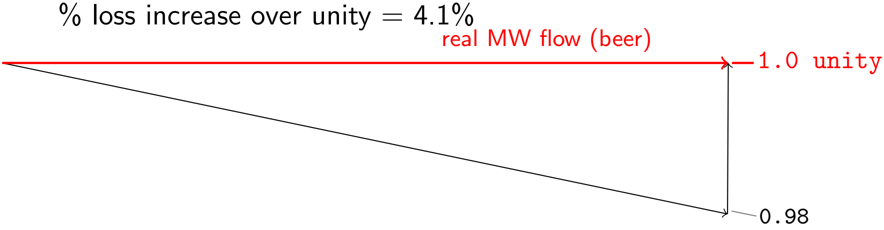


Effect of power factor on total current and losses

% loss increase over unity = 6.3%



Effect of power factor on total current and losses

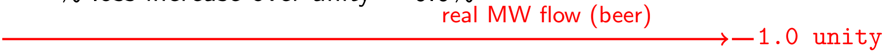


Effect of power factor on total current and losses

% loss increase over unity = 2.0%

Effect of power factor on total current and losses

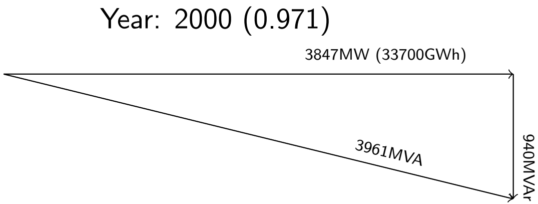
% loss increase over unity = 0.0%



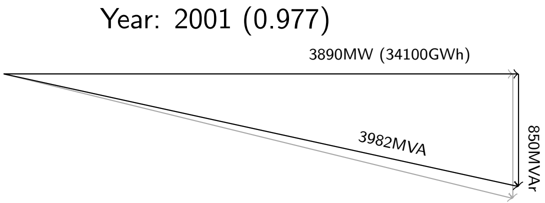
Summary

- not quite ‘bubbles’ and ‘beer’
- what about NZ power factor?

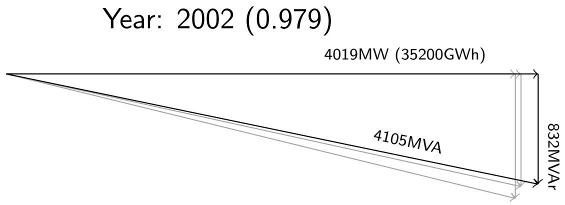
NZ average power factor



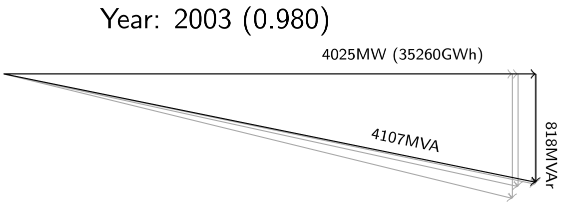
NZ average power factor



NZ average power factor

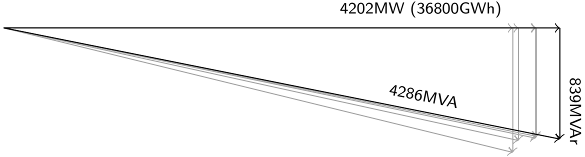


NZ average power factor



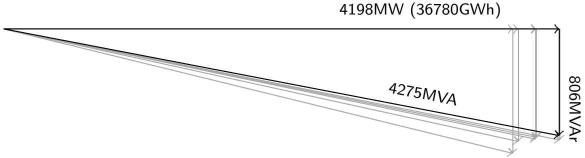
NZ average power factor

Year: 2004 (0.981)

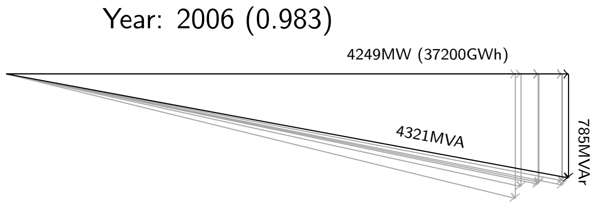


NZ average power factor

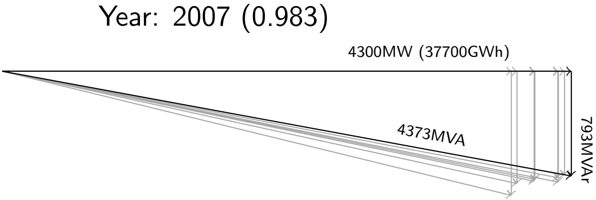
Year: 2005 (0.982)



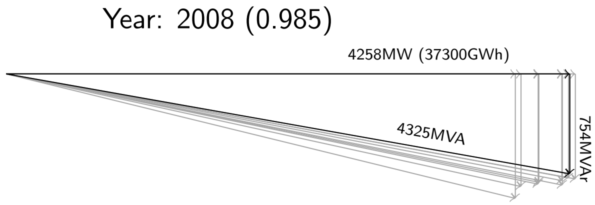
NZ average power factor



NZ average power factor

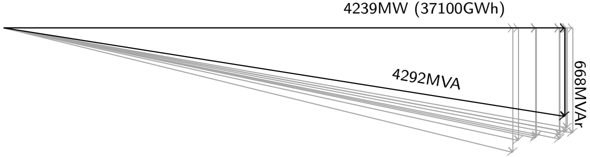


NZ average power factor

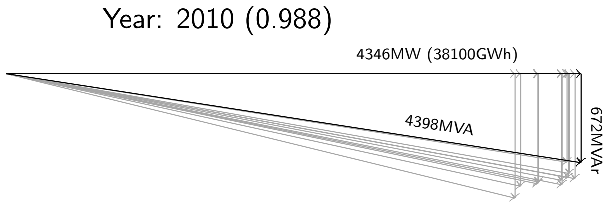


NZ average power factor

Year: 2009 (0.988)

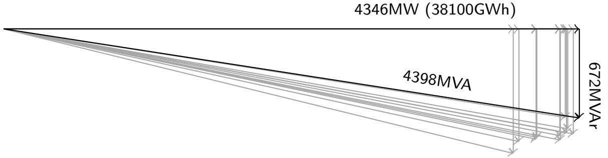


NZ average power factor



NZ average power factor

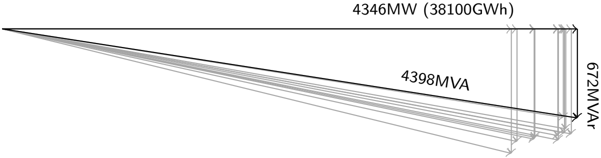
Year: 2010 (0.988)



MW growth: ≈20-45MW/year (200-400GWh/year, or 0.5-1%)

NZ average power factor

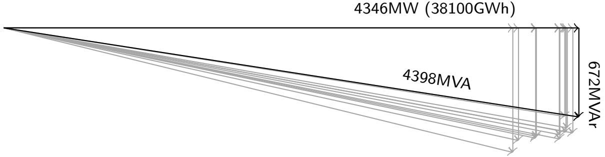
Year: 2010 (0.988)



MW growth: ≈20-45MW/year (200-400GWh/year, or 0.5-1%)
MVAr decline: ≈-22-30MVAr/year (200GVArh(?)/year)

NZ average power factor

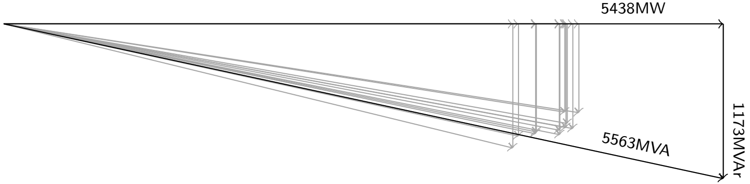
Year: 2010 (0.988)



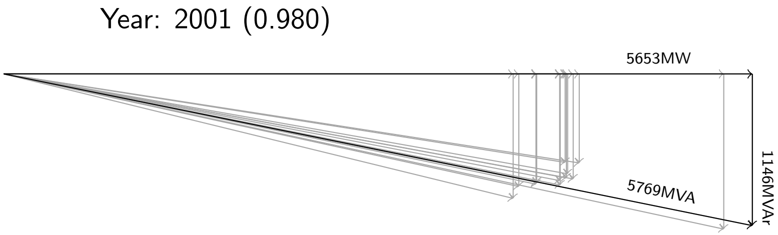
MW growth: ≈20-45MW/year (200-400GWh/year, or 0.5-1%)
MVAr decline: ≈-22-30MVAr/year (200GVArh(?)/year)
Power factor increase: ↑0.002/year

NZ power factor during top 12 peaks

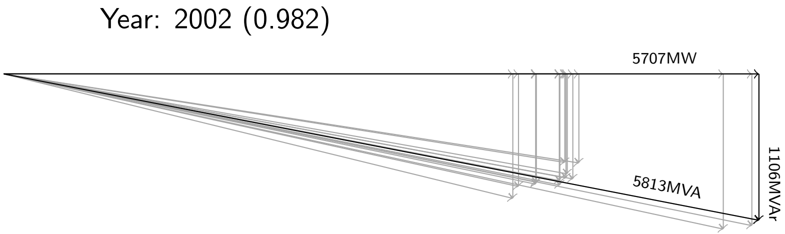
Year: 2000 (0.978)



NZ power factor during top 12 peaks

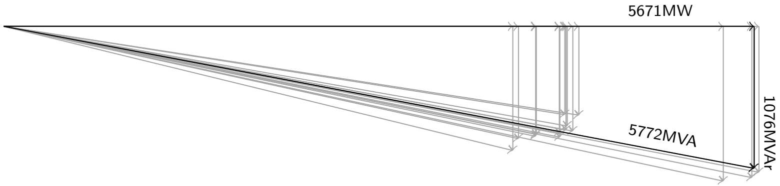


NZ power factor during top 12 peaks

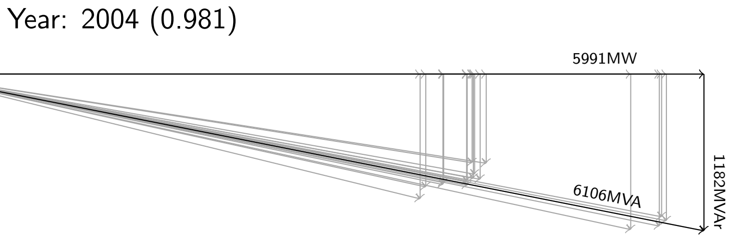


NZ power factor during top 12 peaks

Year: 2003 (0.982)



NZ power factor during top 12 peaks



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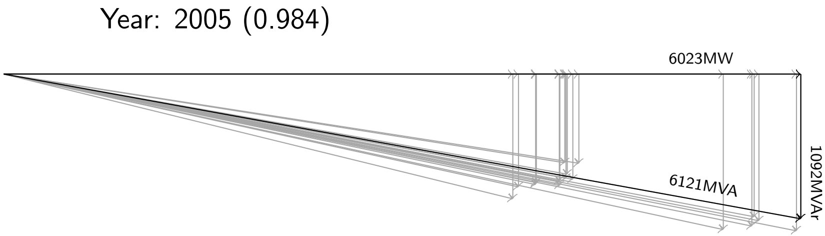
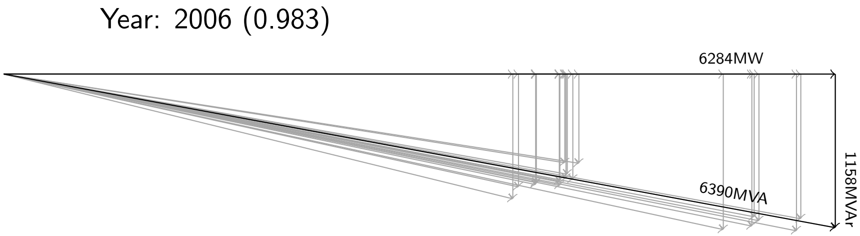
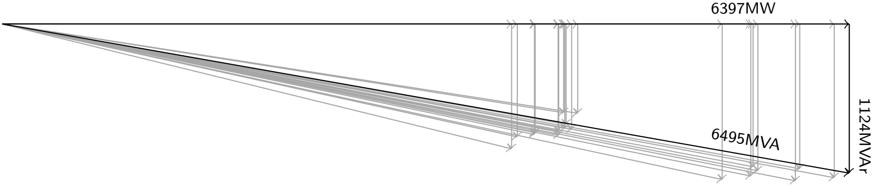


NZ power factor during top 12 peaks



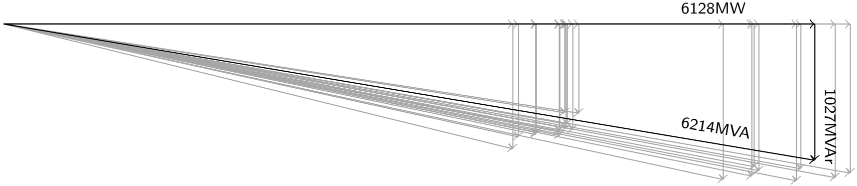
NZ power factor during top 12 peaks

Year: 2007 (0.985)



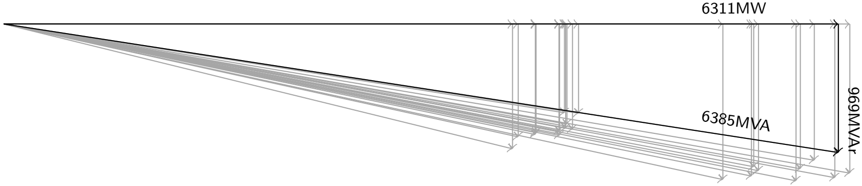
NZ power factor during top 12 peaks

Year: 2008 (0.986)



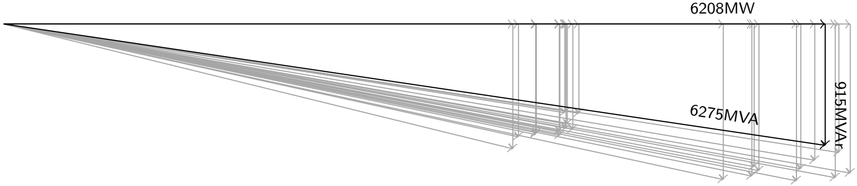
NZ power factor during top 12 peaks

Year: 2009 (0.988)



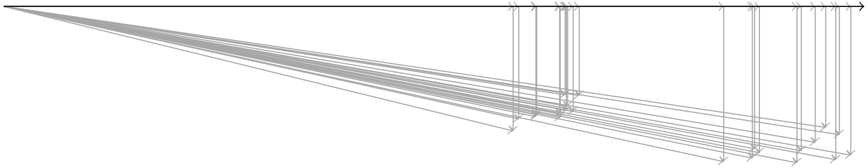
NZ power factor during top 12 peaks

Year: 2010 (0.989)



NZ power factor during top 12 peaks

In the snow the other day... (pf = ?)



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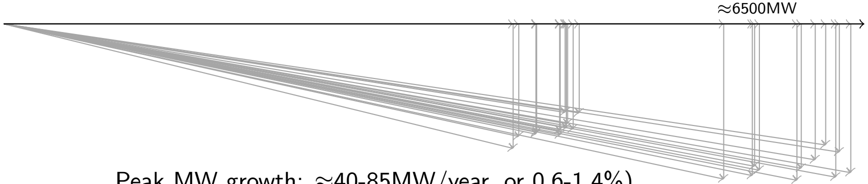
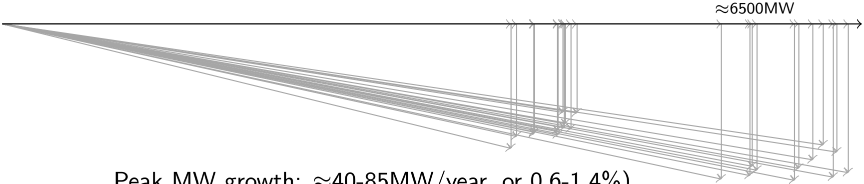


Peak MW growth: ≈40-85MW/year, or 0.6-1.4%)

NZ power factor during top 12 peaks

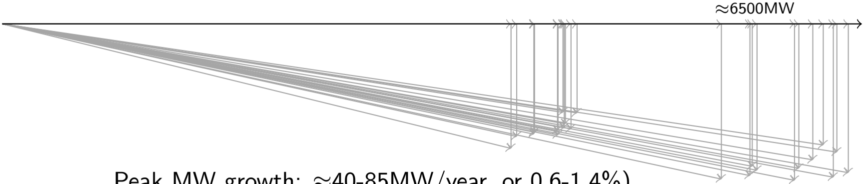
In the snow the other day... (pf = ?)



Peak MW growth: ≈40-85MW/year, or 0.6-1.4%)
Peak MVAr decline: ≈-20-40MVAr/year

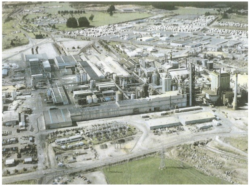
NZ power factor during top 12 peaks

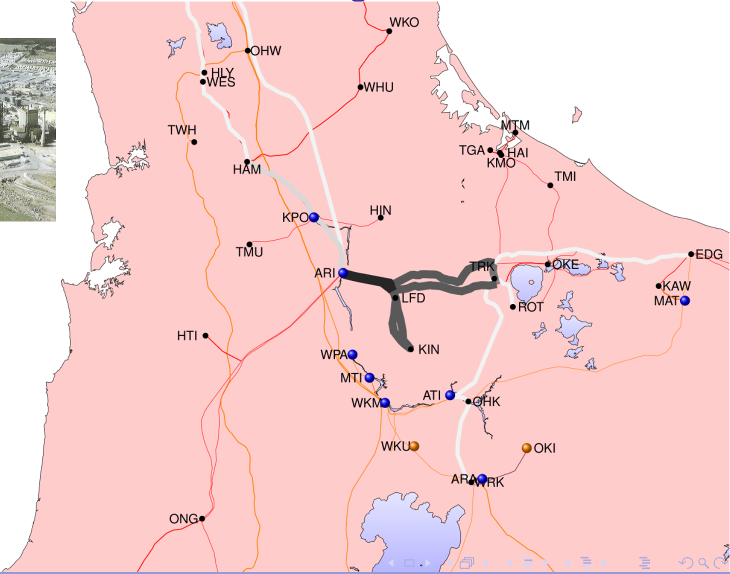
In the snow the other day... (pf = ?)



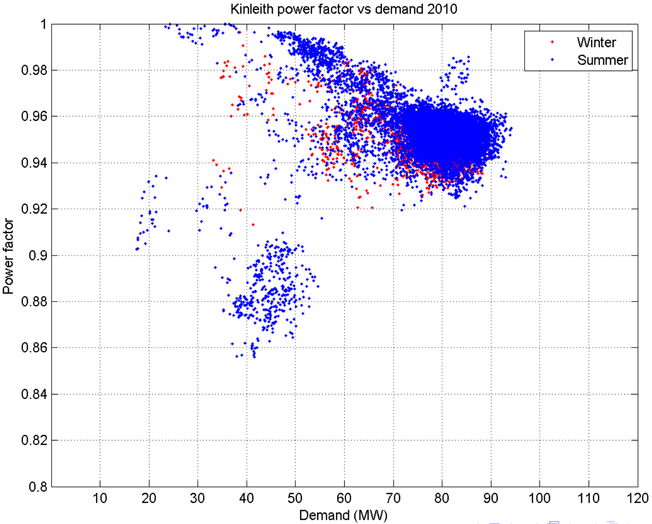
Peak MW growth: ≈40-85MW/year, or 0.6-1.4%)
Peak MVAr decline: ≈-20-40MVAr/year
Power factor increase: ↑0.001/year

Example – Kinleith transmission usage

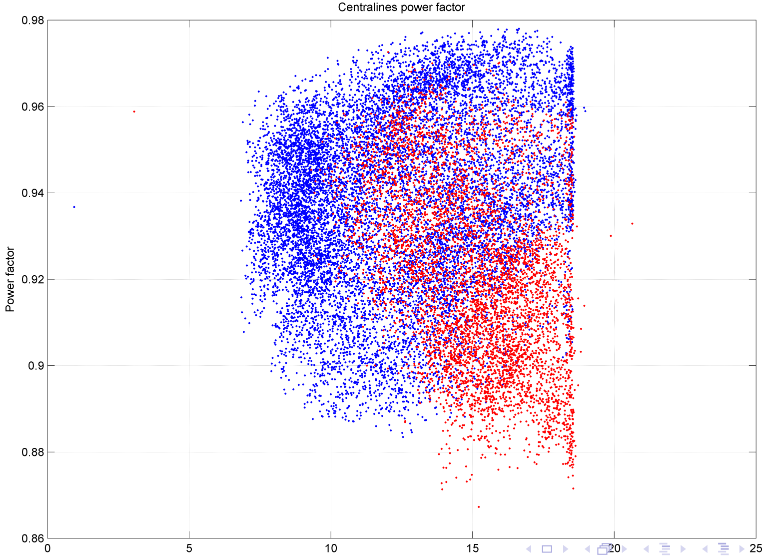




Kinleith power factor ≈ 0.95 (up to 5% increase in TRK-KIN circuits?)



Centralines power factor (Waipawa - Central Hawkes Bay - GXP - 2009)

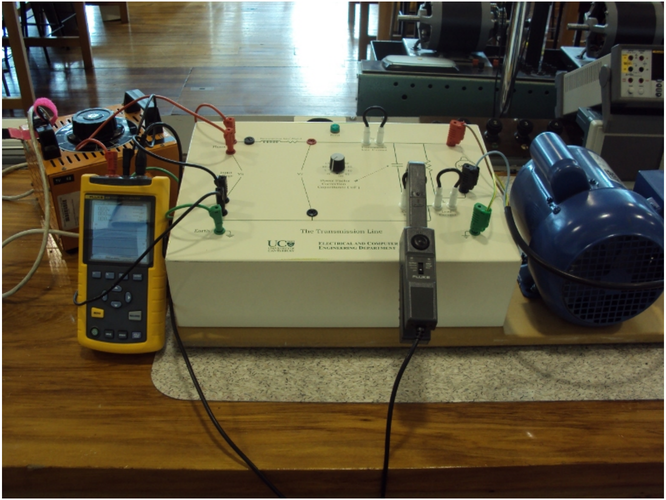


Effect of power factor on voltage stability limits

- what about voltage stability limits?
- first, consider the effect of power factor on voltage. . .

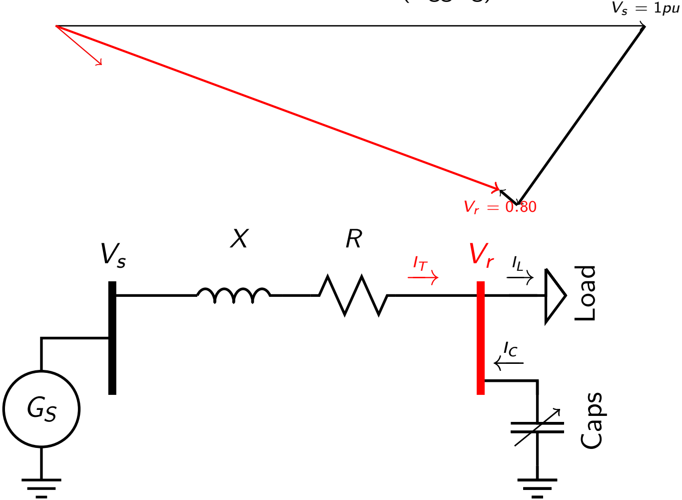
Canterbury University Machines Lab.

ENEL204(ENEL280) Transmission line lab. (Upper Islands in a box. . .)



Two bus power system example:

Power factor = 0.94 (lagging)



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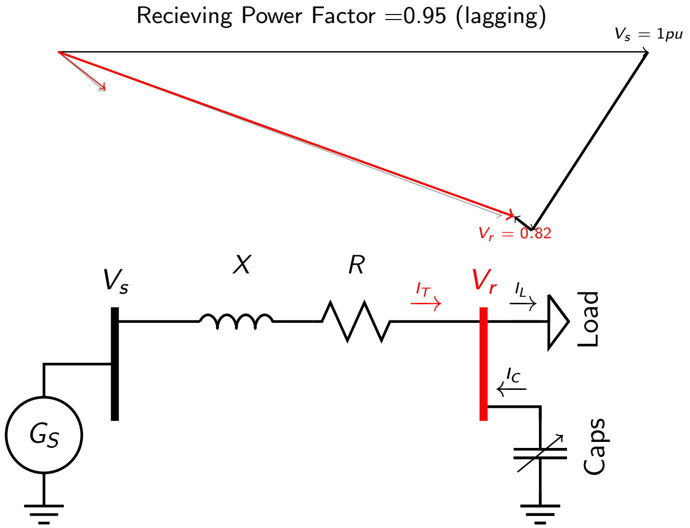

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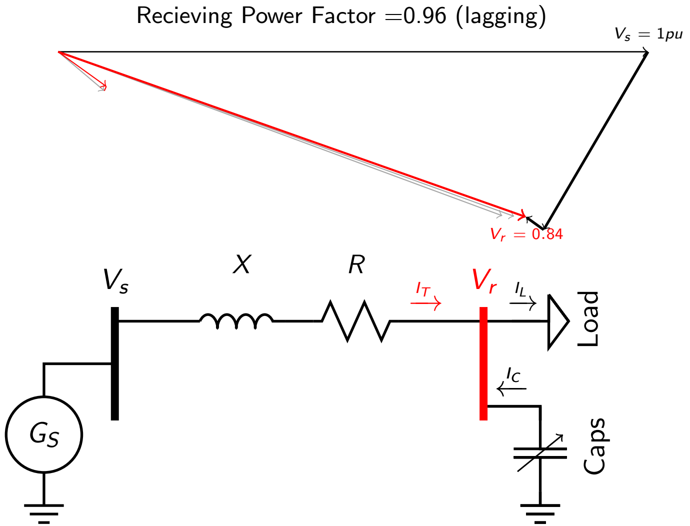
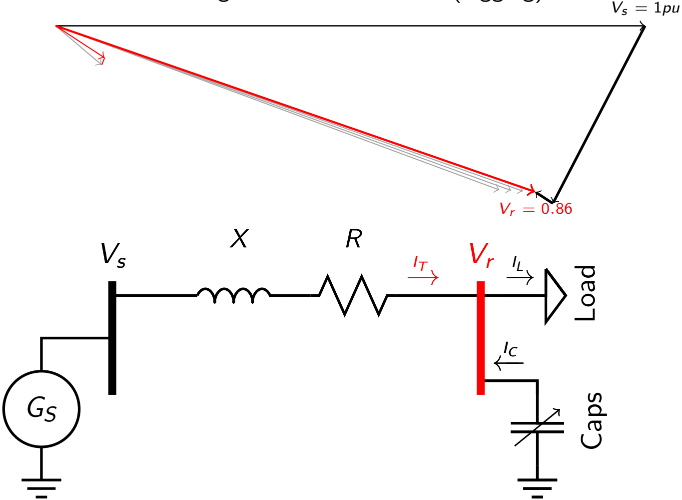
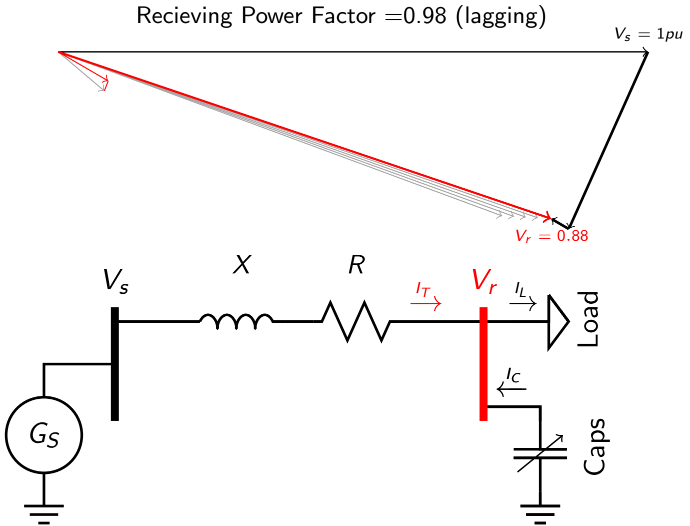


Two bus power system example:

Recieving Power Factor =0.97 (lagging)

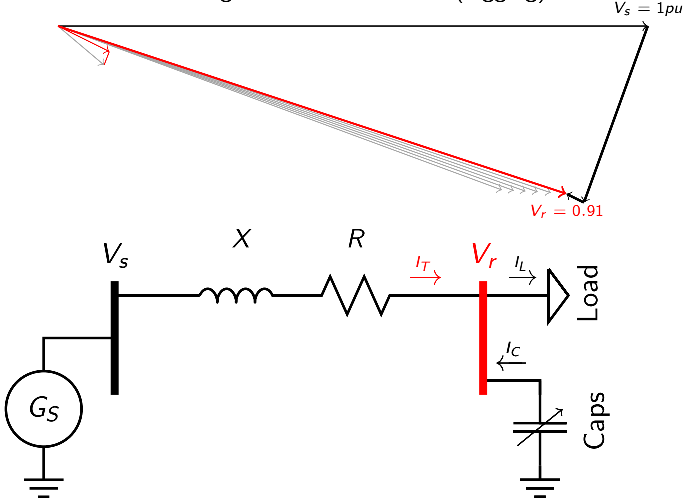


Two bus power system example:

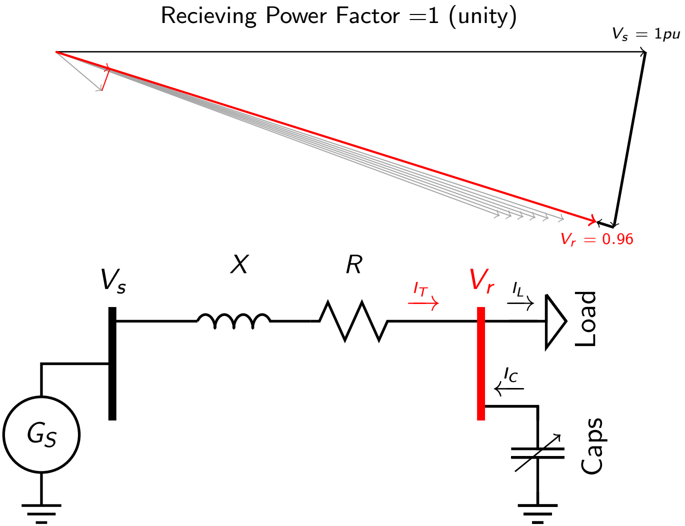


Two bus power system example:

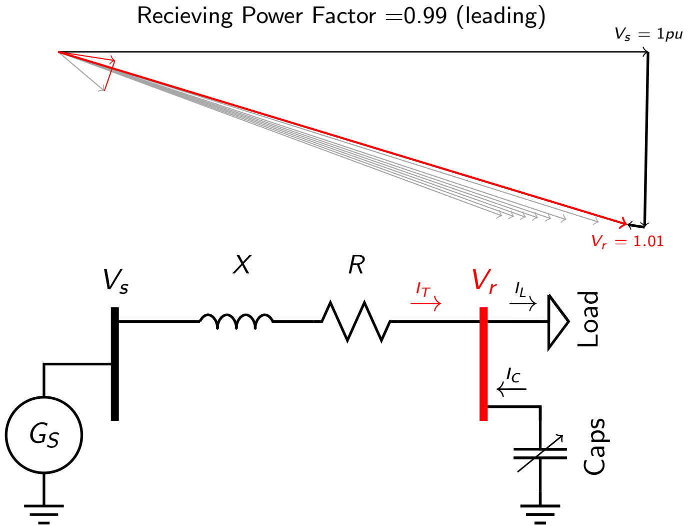
Recieving Power Factor =0.99 (lagging)



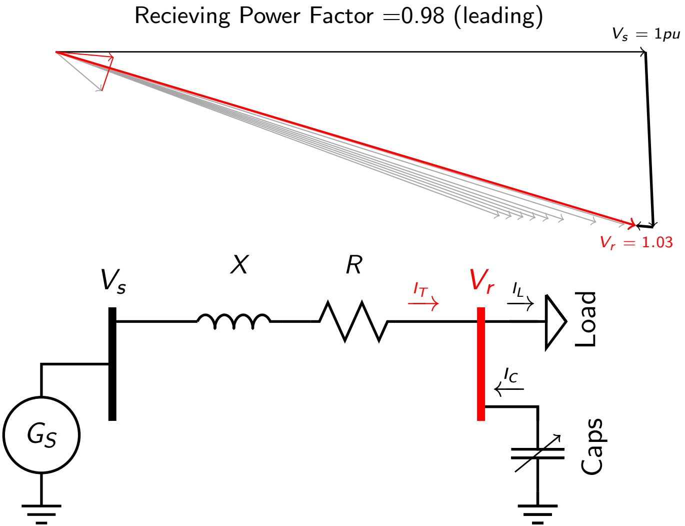
Two bus power system example:



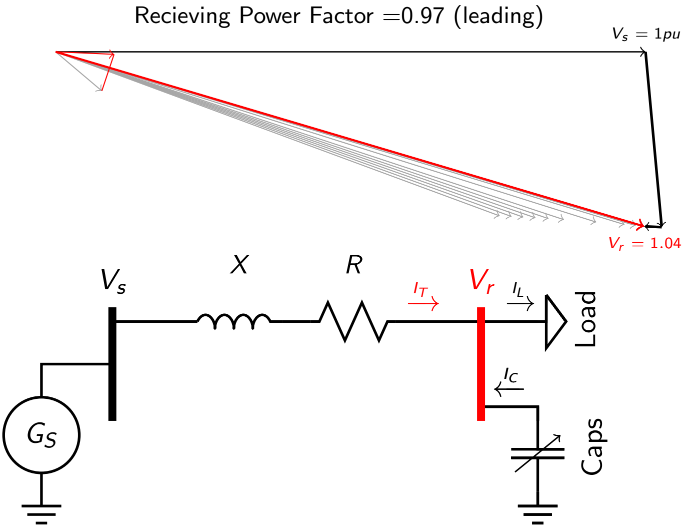
Two bus power system example:



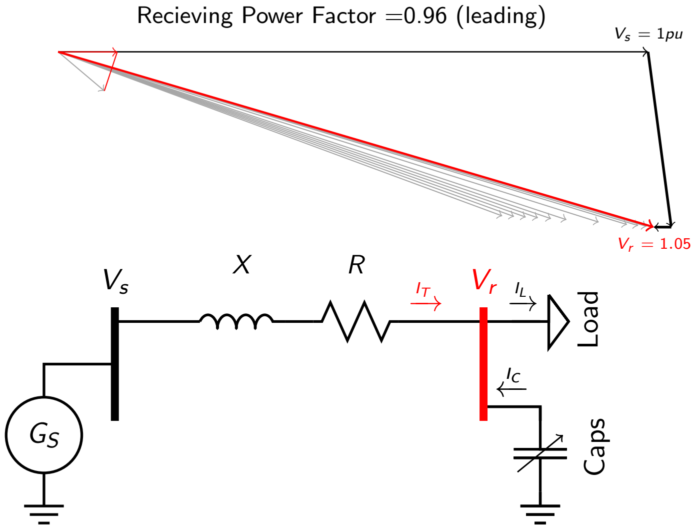
Two bus power system example:



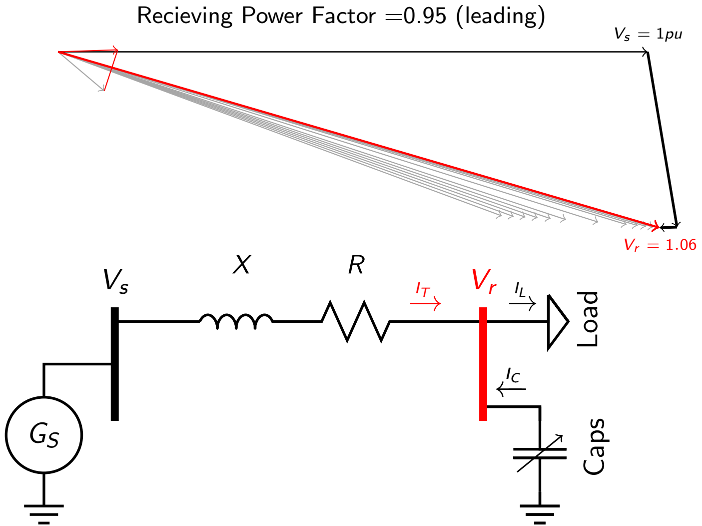
Two bus power system example:



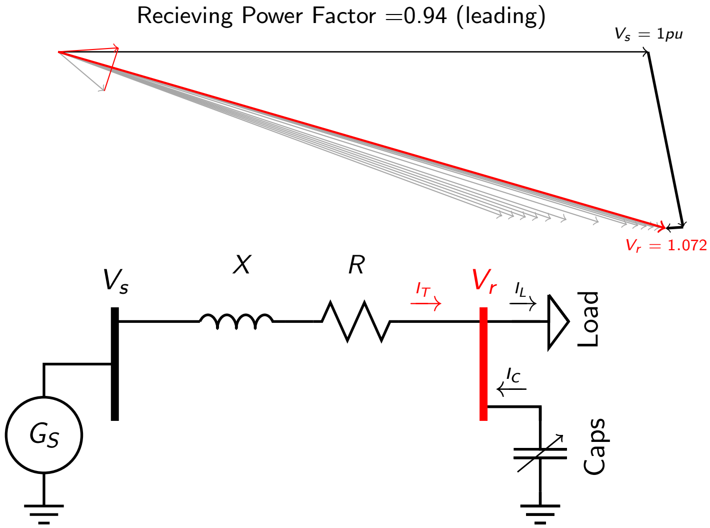
Two bus power system example:



Two bus power system example:



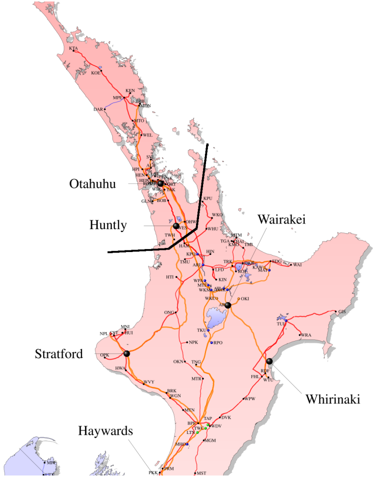
Two bus power system example:



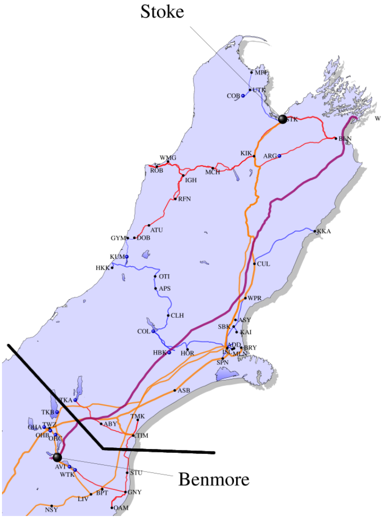
Summary:

- Revieving end voltage (V_r) highly dependent on power factor (esp. around unity)
- Dependence increases with;
  - increased loading I_L; and,
  - higher line impedance, $R + jX$
- Voltage regulation most stable when $|V_S| = |V_L|$
- Most efficient operation occurs with both ends compensated equally
- To some degree, the upper island regions of New Zealand share these characteristics!

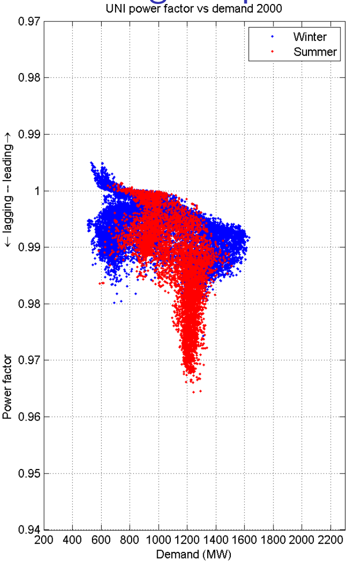
Upper North Island

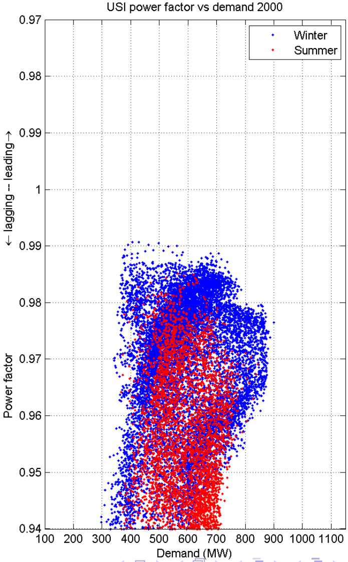


Upper South Island

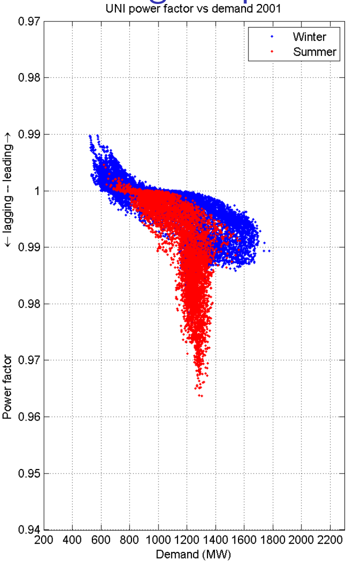


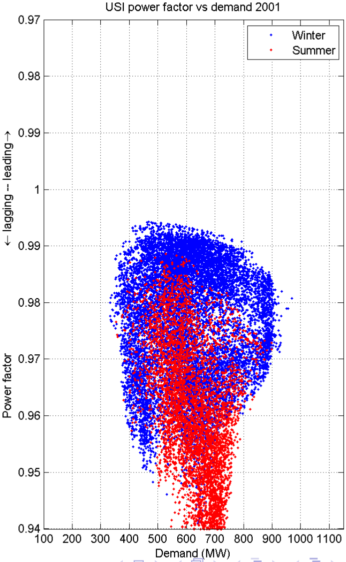
Upper Island regions power factor – 2000



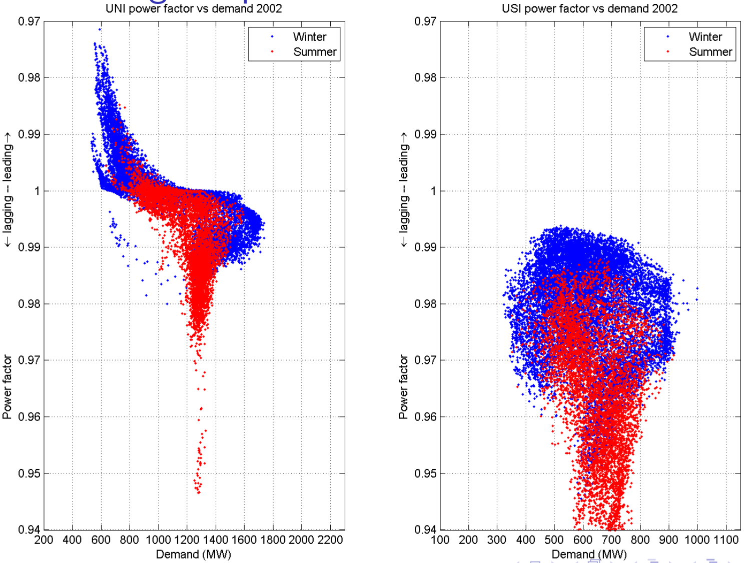


Upper Island regions power factor – 2001

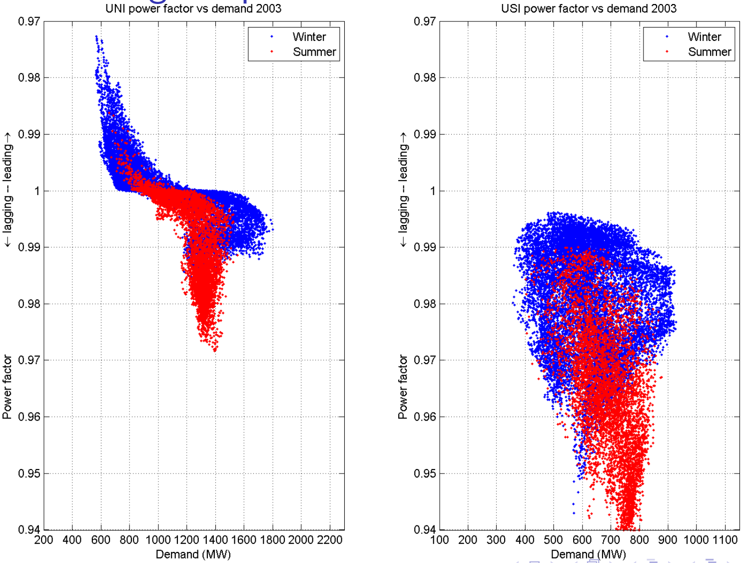




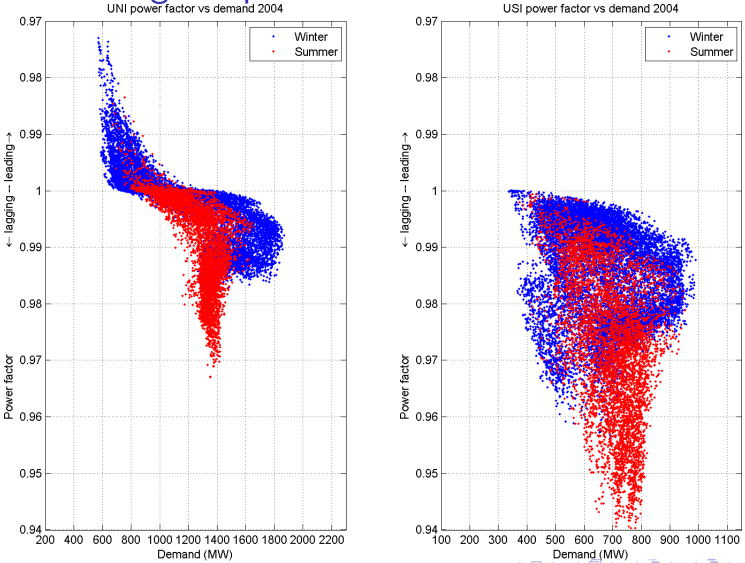
Upper Island regions power factor – 2002



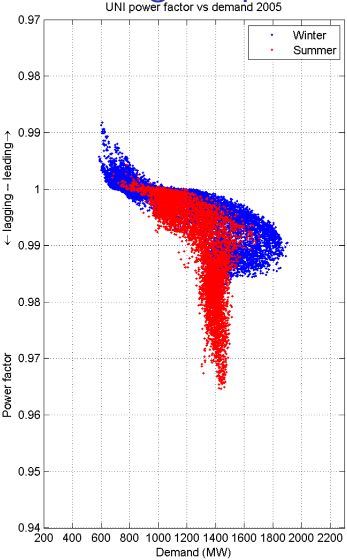
Upper Island regions power factor – 2003

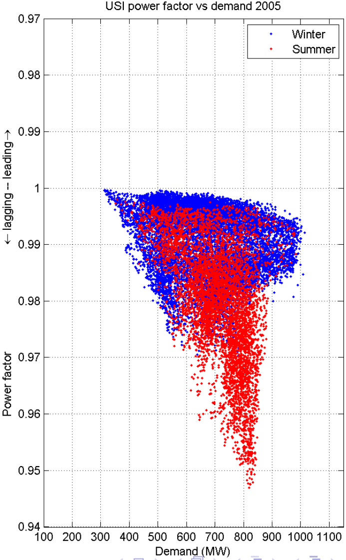


Upper Island regions power factor – 2004

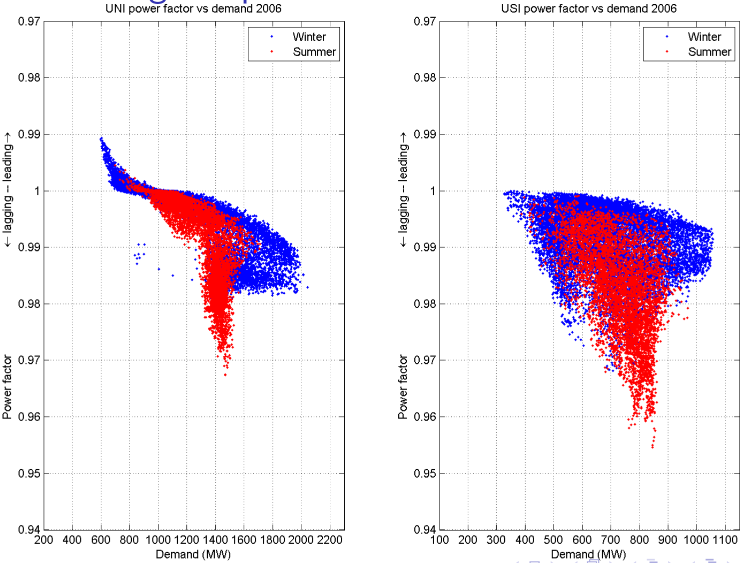


Upper Island regions power factor – 2005

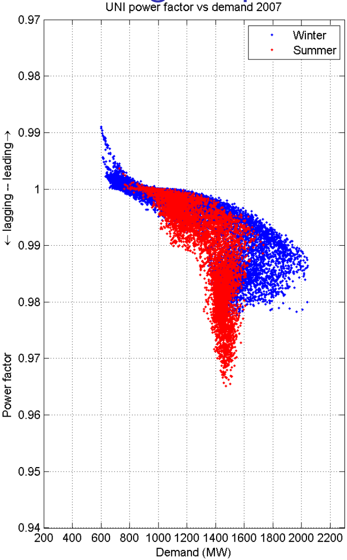


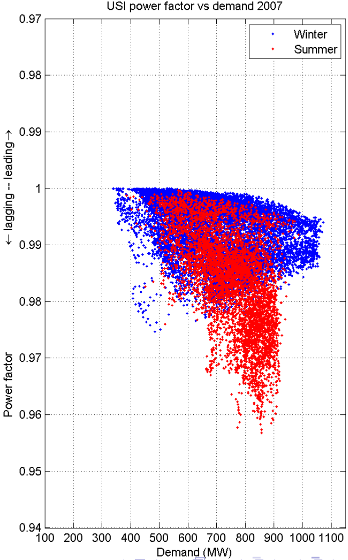


Upper Island regions power factor – 2006

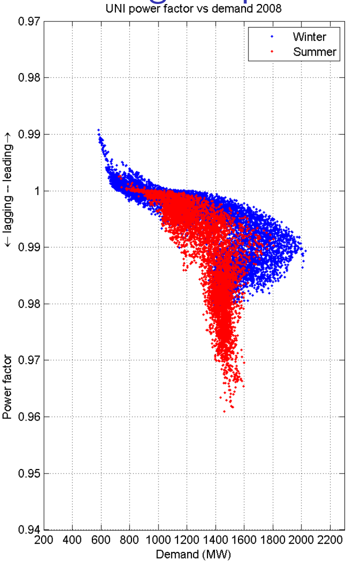


Upper Island regions power factor – 2007

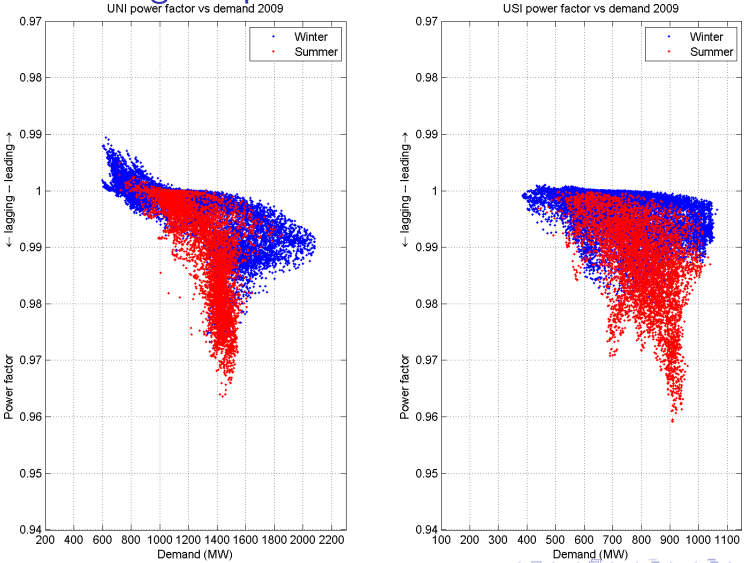




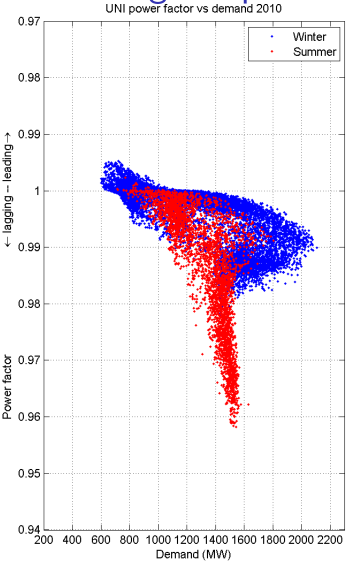
Upper Island regions power factor – 2008

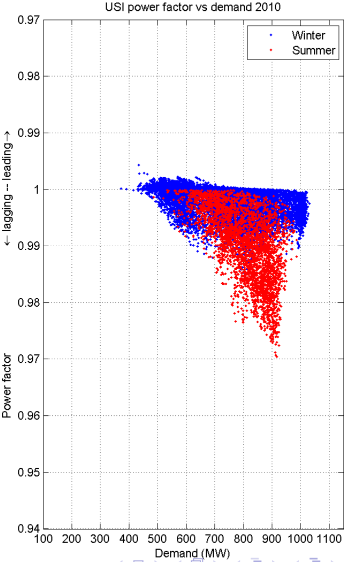


Upper Island regions power factor – 2009



Upper Island regions power factor – 2010

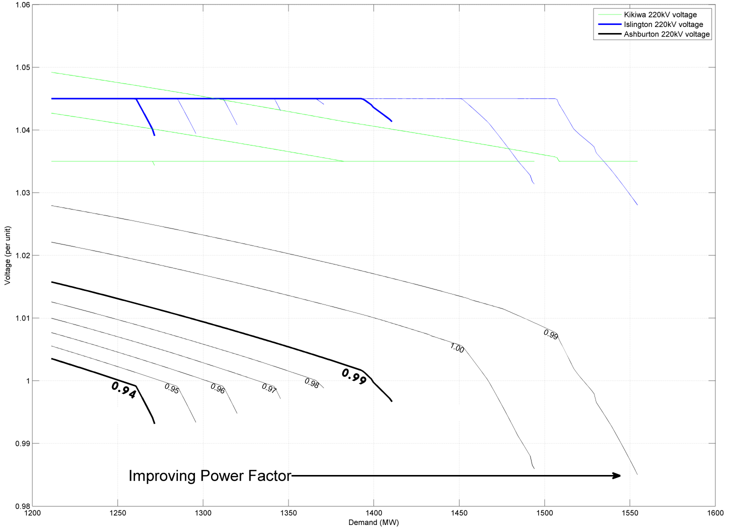




Summary: upper island power factors

- significant improvement in recent years. Why?
- still room for improvement?
- what about **voltage stability limits?**
    - stability limits determined with Power Systems Analysis (PV/QV curve analysis)
    - analysis dependent on assumed power factor.

Example: Upper South Island voltage stability



Summary:

- traditional power factor usage not suitable for regions subject to voltage stability
- voltage stability limits highly dependent on Power Systems Analysis (PSA) assumptions (esp. power factor!)
- USI example:
  - 0.94 to unity increases voltage stability limit 16%
  - significantly more than 6% as per traditional pf usage
  - 0.99 to unity increases voltage stability limit 5%
  - 5× traditional power factor usage
  - benefits beyond unity but subject to dynamic over voltage

Economics of power factor correction

- costs
  - installation of capacitor banks
- benefits

  increased transmission limits

  some loss benefits (small)

  power quality benefits?

Simple USI example:

- 0.99 to unity requires 170MVArs of capacitor banks
- costs $17m
- increases voltage stabiltiy limit 70MW
- an $1m/MW LRMC of transmission gives a net benefit of $53m

Who pays?

- Since 1 April 2010, the Connection Code was changed from 0.95 (lagging) to 1.0 (unity) for upper island regions
- widely critcised. . .
- Ad-hoc advisory group, the Transmission Pricing Advisory Group (TPAG) set up to review changes to the current TPM
- Under TPAG, a static reactive compensation sub-committee has provided advice on static reactive charging.
- three options considered.

Reactive power charging options

Option 1 (amended status quo)
amend requirement for unity $\rightarrow$ unity or leading power factor;

Option 2 (connection asset definition)
widen 'connection asset' definition to include static reactive power investment;

Option 3 (kvar charge)
determine an appropriate kvar charge **(preferred option)**

- currently being consulted on by TPAG

Conclusions

- high dependence of power factor on voltage stability limits
- requires careful treatment of:
  - PSA power factor assumptions;
  - economic calculations, which typically assume a traditional thermally constrained systems
- current proposed kvar charge should help enable improved power factor, and therefore increased voltage stability limits into the future.

Questions?