Addressing Grid-interconnection Issues in Order to Maximize the Utilization of New and Renewable Energy Sources

Report for the APEC Energy Working Group

Oct 2010

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IT Power

- Established in the UK 1981
- Specialist renewable energy, energy efficiency and carbon markets consultancy:
- > 1000 sustainable energy projects in over 100 countries
- IT Power – UK (3 offices)
  - Argentina, China, Fiji, India, Kenya, Uganda
- IT Power Australia
  - established 2003
  - Head Office Canberra
  - Offices in Sydney, Townsville and Suva

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IT Power Staff

ITP (Aust) staff have backgrounds in managing government incentive programs, high level policy analysis and research (incl. carbon markets), engineering (system) design and project management.

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Russel Cahill (Powercorp)

Original report structure

- Review research on issues with RE integration
- Identify best practices and collaborative efforts
- Review R&D activities to overcome technical issues
- Assess the potential for applying best practice

New report structure

- Review of issues with RE integration, review ways to overcome them, review R&D activities
- Identification of best practices and collaborative efforts, includes discussion of best practices to overcome non-technical issues
- Future R&D activities required to overcome technical issues
- Discussion of how to apply best practice

Presentation outline

- Methodology
- Addressing grid-connection issues
- Best practice solutions
- Applying best practice
- Conclusions

Methodology

- Desktop review of available literature from
  - Research institutions and journal papers
  - Includes collaborative work with utilities
  - Not just APEC economies, EU also
  - Also in-house expertise of IT Power and Powercorp
- Rapidly changing area
  - Focussed on more recent developments
  - Referred to other sources of information for a more ‘historical’ review
- Highly technical area
  - Needed to produce a focussed overview with significant detail, but not so technical that is useful only for experts

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Grid-connection issues

- Are site-specific, must take into account:
  - Existing structure of the network
  - Size and location of existing generators
  - Size and location of loads
  - Impedance of various sections of the network
  - The time availability and variability of DG
  - Type and location of existing protection systems
  - The effect of DG at the proposed locations

Grid-connection issues (cont.)

- Voltage fluctuation and regulation
- Power factor correction
- Frequency variation
- Harmonics
- Unintentional islanding
- Fault currents
- Interconnection grounding
- Subtransmission issues
- Other issues

Voltage fluctuation - 1

- Fluctuations outside set values can negatively impact on end-use equipment, brownouts etc.
- Inverters generally configured to disconnect if V outside set limits
  - Voltage sag leading to DG disconnection can make problem worse => greater voltage sag
  - Solutions: have broader voltage tolerances and incorporate low voltage ride-through (LVRT) techniques (which are now standard in Germany)
- If inverters in grid-regulating mode (by providing reactive power support):
  - Helps to avoid voltage sag (and over voltage)
  - Not currently allowed under IEEE inverter standards

Voltage fluctuation - 2

- Voltage imbalance
  - Occurs in a three phase system when the amplitudes of each phase are not the same, or if the phase difference is not 180 degrees
  - Can negatively impact on DG as well as end use devices
  - Can be caused by single phase DG systems being installed disproportionately on each phase
  - Therefore ensure that the same amount of DG (in terms of power output) is installed on each phase
  - Larger systems (greater than 5-10kW) should have a balanced three phase output

Voltage fluctuation - 3

- Voltage rise and reverse power flow
  - Networks designed for power flow in one direction, from generator to load
  - DG can result in localised overvoltage, as well as such high voltage that power flows back up the line
  - Is worse when DG high and load low, but also affected by the reactance and resistance of the network, and the phase angle and magnitude of the DG current
  - Thus, 'safe' levels of DG penetration can vary from 5% to 50% depending on local conditions
- Can result in:
  - activation of network protection devices unnecessarily, destabilisation of tap changers, equity impacts where systems towards the end of the line are more likely to be disconnected

Voltage fluctuation - 4

- Voltage rise and reverse power flow (cont.)
- Current solutions include:
  - Keep DG systems smaller than lowest expected load
  - Use minimum import relay (MIR) to disconnect DG if power flow from utility drops below a present value
  - Use a reverse power relay (RPR) to disconnect DG if power flow from utility drops to zero or reverses
  - Use a dynamically controlled inverter (DCI) to gradually ramp down DG output as load drops, rather than just disconnecting it
- Proposed solutions include:
  - Design networks with low impedances (voltage drops) to give more 'headroom' at the DG end
  - Customers have load-shedding capability, lower power factors and dump loads, all to give more 'headroom' at the DG end
  - Storage

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Voltage fluctuation - 5

- Power output fluctuation
  - An inherent problem with renewables dependent on intermittent resources
  - Short term can result in poor power quality, wear of tap changers and capacitor switches, and long term, loss of power
  - Solutions are geographical dispersal, forecasting and storage
  - Geographical dispersal: Only useful over large areas, and then not always
  - Solar forecasting: Currently being developed, lack small-scale resolution, and may not be appropriate for particular technologies

Voltage fluctuation - 6

- Power output fluctuation
  - **Storage**
  - Can reduce voltage rise, provide peak shaving, load shifting, demand side management and outage protection, help with 'black starts' and provide several ancillary services, including contingency reserves (spinning reserve, supplemental reserve, replacement reserve), and voltage and frequency regulation
  - But, currently expensive
  - Significant ongoing interesting R&D not only on battery types and flywheels etc, but also in related areas such as intelligent control options required for effective integration with DG (eg. NEDO)

Grid-connection issues (cont.)

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- Power factor correction
- Frequency variation
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- Subtransmission issues
- Other issues

Power factor correction

- Poor PF increases line losses, makes voltage control more difficult
- Most inverters are configured to be voltage following and so have unity PF
- But can be configured to provide PF correction in voltage-regulating mode (currently not allowed under IEEE Standards)
- In this mode they can inject reactive power during sags to boost V
- Inverters need to be oversized to provide both reactive and active power at the same time (increased cost)
- They also consume power when providing reactive power support, is owner paid for this?

Power factor correction - 2

- Reactive power control can generally be more cost-effectively and energy-effectively provided by capacitors
- But, inverters are infinitely variable and have faster response times, and if they are installed anyway, then can be justified
- Note that on long feeders, which are highly resistive, real power injection is more effective at V control than reactive power injection, so inverters need to be configured differently
- For optimal voltage regulation it appears that in addition to this sort of automatic voltage regulation, some form of centralised voltage control was required (CRIEPI)

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Frequency regulation

- Frequency a very important type of power quality
- Variations caused by generation/load imbalance but normally well controlled by conventional means
- Increasing penetration of intermittent loads makes frequency control more difficult
- Inverters should be able to help with frequency control and would have very fast response times, but are unproven at this stage
- Currently inverters are designed to trip off when frequency goes outside set limits (as an anti-islanding measure) and so would need to be specially configured to provide frequency support (eg. frequency ride through)

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Harmonics

- Are currents or voltages with frequencies that are integer multiples of the fundamental power frequency
- Can be produced by both loads and generators
- Load harmonics are now managed by IEC EMI standards
- Inverters in Aust and US require less than 5% harmonic distortion, so not a problem at this stage (more stringent than loads of equivalent size)
- Possible that inverters could assist with harmonic control, but
  - Most are now configured to only be an in-phase current source and so cannot help with harmonic correction
  - Use of an inverter to correct harmonics uses energy and the system owner may therefore be paying to correct harmonics caused by other people's loads
  - PV inverters only provide harmonic support when sun is shining
  - Variety of harmonic compensators that are cheaper

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Unintentional islanding

- Is where DG keeps 'live' a section of the network that has been disconnected from the main grid
- Safety issues, maintain fault conditions, equipment damage, transient overvoltages and out of phase after reconnect
- At low levels of penetration, current anti-islanding techniques work well
  - Passive methods: detect over or under voltage or frequency
  - Active methods: attempt to actively move voltage or frequency outside set limits, only possible if grid not live
  - Communications-based methods: where data is communicated between the inverter and the utility and so allow centralised control
- All have problems ….

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Unintentional islanding - 2

- Passive method problems at high penetrations
  - Problems at non detection zone (load = reactive power), especially where inverters have variable PF
- Active method problems at high penetrations
  - May have a minor but negative impact on power quality
  - Not compatible with microgrids at point of connection with main grid and work against a seamless transition between grid-connected and stand-alone modes
  - A mixture of different types of island detection methods can result in an interaction that results in a stable frequency (this is possibly what recently happened in Spain on a 20kV feeder)

Unintentional islanding - 3

- Communications-based method problems:
  - Centralised control systems are unlikely to be perfect
  - Could be problems with the central controller as well as the communications links
  - Likely to be expensive
  - Increase the complexity of the network and are untested
- It is likely that a combination of communications-based and autonomous distributed active methods will be required, especially as penetrations increase

Grid-connection issues (cont.)

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Fault currents

- Possible that DG at high penetrations may introduce new sources of fault currents that can change the direction of fl introduce new fault-current paths, increase fault-current magnitudes, redirect ground fault currents, and increase th time taken to correct faults
- Rotating synchronous generators most likely to be a probl while modern inverter-based DG, should not be a problem

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Interconnection grounding

- Is a highly technical issue
- Essentially highlights the problem of increased chance of ground faults as penetration levels increase
- Currently not a problem, but could be at particular locations where there are high penetrations of DG
- Requires R&D

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Subtransmission issues

- At high penetrations, current could be fed back into the subtransmission network
- Potential problems
  - Ground fault overvoltage
  - Unintentional islanding
  - Switching scheme interference
  - Overcurrent protection coordination
- Again is a highly technical issue and currently not a problem

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Other issues

- DC injection from inverters into grid
  - Is possible but inverters currently minimise it and disconnect if it exceeds very low levels.
- High frequency waves
  - Is where electromagnetic noise associated with the high frequency used by inverters to convert DC to AC may have a negative impact on other electronic devices
  - Currently not a problem

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Best practice solutions

- Is a very dynamic area and so new solutions are constantly being proposed
- What is best practice now could be worst practice tomorrow
- What is best practice is often location-specific as it can be affected by:
  - Grid design
  - Location and nature of loads
  - Location and nature of DG
- Often more than one best practice solution can be implemented at the same time because:
  - they may address slightly different issues
  - approach a problem in different ways
- The following summarises current practice, and suggests best practice

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Best practice solutions - 2

- Voltage imbalance
  - Ensure that the cumulative size of all systems connected to each phase is as equal as possible
- Voltage sag
  - Broaden voltage sag tolerances
  - Use low voltage ride through
  - Configure inverters to provide voltage support (currently not allowed under IEEE standards)
- Voltage rise
  - Keep systems sized less than load
  - Disconnect system from grid using minimum import relay (MIR) or a reverse power relay (RPR)
  - Use a dynamically controlled inverter to ramp down output
  - Configure inverters to provide voltage support

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Best practice solutions - 3

- Voltage rise - 2
  - Reduce the network's series impedance to create more 'headroom' for allowable voltage rise
  - Require customers to improve their power factors, decrease or increase their loads as appropriate, have diversionary or dump loads
  - Storage
- Likely that voltage regulating inverters (currently not allowed), low impedance networks (less useful for existing networks and expensive) and storage (expensive and under R&D) are the best options
- Voltage regulation by inverters may also require some form of centralised control to optimise their effectiveness - which adds to costs and complexity

Best practice solutions - 4

- Power output fluctuation
  - Geographic dispersal, forecasting of RE resource and storage should be used where possible to maximise effectiveness
- Power factor
  - Can configure inverters to provide power factor correction (currently not allowed as above)
  - Need to configure for either reactive power (urban) or real power (fringe) injection
  - Capacitors and inductors generally cheaper, although not as responsive
  - Could make power factor standards for loads stricter

Best practice solutions - 5

- Frequency variation - 2
  - Currently not a problem
  - Inverters could provide frequency support but would need to be specially configured and may interfere with anti-islanding protection
  - Needs R&D, careful consideration should be given to fault ride through, coordination of frequency trip limits with load shedding limits, and centralised control, particularly associated with larger DG systems and microgrids
- Harmonics
  - Currently not a problem
  - Most inverters cannot supply the harmonic currents sometimes required by loads
  - Could make harmonic current standards for loads stricter

Best practice solutions - 6

- Unintentional islanding
  - A combination of autonomous active detection systems combined with a communications-based centralised control is likely to be the most reliable.
- Fault Currents
  - Current inverters should be sufficient
- Grounding
  - No real best practice as yet, requires R&D
- Smart Grids
  - Is considered to BE best practice but as yet is an area of intense R&D

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Applying best practice

- Different APEC economies will have different:
  - need for best practice, best practices likely to be appropriate, capacity to implement best practice
- Differ in terms of:
  - electricity networks
  - renewable energy sources
  - mix of conventional and renewable energy generators
  - matches between generation and load
  - government priorities
  - capacity in government and private sector

Applying best practice - 2

- Roles of government, regulators and utilities
  - Up to governments to ensure that best practices are applied
  - Find out what needs to be done
  - Appropriate regulation, standards and agreements, and the related mechanisms for enforcement
  - Need an independent energy regulator, not the role of utilities, otherwise conflicts of interest
  - Information dissemination (regarding new rules and regulations)
  - Promotion of the use of best practices and
  - Facilitation of training for the appropriate public entities and private companies

Applying best practice - 3

- Institutional and regulatory barriers
  - Standards developed when DG at low penetrations need to be revised
  - They need to be constantly updated as new research into best practice arises
  - Possibly use some form of national committee to follow developments and update standards
  - Utilities should be kept aware of the latest standards that make DG ‘safer’ for their networks, engenders trust
  - Virtuous cycle where application of best practice further builds trust and so engages utilities in the latest DG developments

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Applying best practice - 4

- Existing electricity infrastructure
  - If new build, then no limits
  - Existing, no limits: ancillary service capabilities in inverters, storage and geographical distribution, avoiding voltage imbalance by connecting same amount to each phase of a network
  - Existing, inverter replacement: active detection methods for islanding and communications-based control systems.
  - Existing, difficult: reducing series impedance of networks
  - Existing, impossible: fully integrated smart grids
- Therefore, measures to reduce growth in electricity demand limit how easily best practice can be applied

Applying best practice - 5

- Relative availability of conventional and RE resources
  - Has most impact on the *need for* best practice, rather than the *likelihood* of it being applied
  - The greater the uptake of RE, the greater the need for best practice
  - The type of RE resource also affects the need for best practice
  - Less need: bioenergy, hydro and geothermal
  - Greater need: wind and especially PV
  - Where the DG output is well matched to load there will again be less need for best practice, and vice versa

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Applying best practice - 6

- Stages of economic and technical development
  - Both between and within countries
  - Different issues may need to be addressed and so different types of best practice likely to be required
  - For example, areas with less robust grids will be less able to withstand fluctuating DG, and so most in need of best practice, but may also have lower economic and technical capacity to apply it

Applying best practice - 7

- Local expertise
  - Is required for best practice in design, installation and especially maintenance of DG
  - Can be driven by requirements for best practice laid down by governments, as well as facilities for training
  - Industry associations can also help with information dissemination, training and promotion of best practices
  - Where external expertise is used, knowledge transfer should be used to drive local capacity building
  - Energy professionals in the public and private sector need to be trained on an on-going basis, so that as technologies, products, installation methods, standards, regulations and best practices evolve, knowledge in the national industry also evolves

Conclusions

- Original network design did not allow for high levels of DG
- Up to 10% DG is generally OK but the impact is dependent on the network configuration, length of the lines, size of loads and DG output, and how well matched they are
- Up to 20% DG issues are more significant but can be addressed by minimising VAr flows, power factor correction, increased voltage regulation and careful consideration of fault current levels and ground fault overvoltage issues
- Higher levels of DG can require significant changes, such as overall design and communications infrastructure to coordinate protection and power flow control - still in R&D phase

Thank You

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Questions!