Transmission Investment for Renewable Generation

Psymetrix Ltd.[1] Contribution to Consultation Document OFGEM 98/04

Summary

OFGEM has invited comments on an appropriate 'output' that will show that infrastructure investment to accommodate increased renewable generation has been efficient. One obvious measure of investment efficiency is the proportion of such additional capacity that is available to network users to serve their customers.

The situation as we see it, is as follows:-

- For any given transmission investment to be efficient, the planned thermal capacity must be available.
- If constraints require to be placed on the level of power transfers to ensure system security, the planned capacity will not be available and a fully efficient investment will not have been achieved.
- The need for system security constraints can arise because of the need to ensure adequate system electrical characteristics (e.g. good system damping, transient stability in the event of 'worst case' network faults, etc.).
- Design tools and techniques are readily available to predict transient stability margin at the design stage with reasonable probability. With good design we do not anticipate that this will be a problem.
- The prediction of system damping margin can be much more difficult to achieve at the design stage and we see the outcome as being much more uncertain.
- Inadequate system damping could prevent the planned capacity from being available. The UK experience of the 1990s underlines the serious implications for transmission investment efficiency if the situation is not adequately managed
- The realisation of a buoyant wholesale electricity market with increased levels of commercial power transactions and system flows is likely to have a side-effect in that system damping may well be adversely affected.
- In the situation where there is a short-fall in actually available capacity, whichever of the proposed investment repayment options is adopted by OFGEM, the outcome will be unsatisfactory, for one or more of the following:-
    - The Government - whose 'renewables' targets will not be achieved
    - TOs - who may not receive their anticipated return on investment
    - Network users - who may be unable to connect
    - Electricity consumers - who will ultimately have to bear the cost of any increased security related constraints (running to perhaps £100M/year) and for the provision of transmission capacity that is not actually delivered.
- Consequently it is imperative that TOs take all reasonable measures - utilising available technology that is less capital intensive (c.f. ¶5.10), - to ensure that system electrical characteristics do not limit transmission capacity for any given level of investment, thereby inhibiting a buoyant wholesale electricity market and bringing about an inefficient transmission reinforcement investment.

In view of the future separation of TO/SO roles envisaged under BETTA, we would recommend that OFGEM consider placing a requirement on the SO to ensure that increased infrastructure capacity is fully available for utilisation, and is not needlessly limited by factors such as steady-state stability or inadequate system damping.

As an important step in achieving this objective, we would recommend that OFGEM require the SO to operate the system to an agreed and published minimum acceptable level of system damping – as was the case in the early 1990s. In order for the SO to demonstrate that system damping has been managed sufficiently and economically, system damping should be measured both before the build-up of renewable generation and on an ongoing basis as a means of demonstrating that there is a sufficient steady-state stability margin to ensure system security.

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[1] Psymetrix Ltd has been active for 10 years in providing systems to assist electrical utilities to manage power system dynamic behaviour. Psymetrix has designed, installed and maintained equipment for utilities world-wide that is capable of on-line measurement of power system dynamic parameters, including system damping. In that time the company has acquired a considerable body of expertise and experience in the measurement, analysis and interpretation of power system dynamic characteristics.

Introduction

Psymetrix is pleased to take this opportunity to make a contribution to OFGEM's consultation paper (98/04) on this very important and apposite subject.

For too long, in our view, there has been a presumption that investment in the infrastructure of the transmission network (as opposed to purely connection assets) is beneficial and cost-effective. However, we do not consider that the experience of previous infrastructure investment fully bears out this presumption. In particular, and of especial relevance to this case is the upgrading of the Anglo-Scottish interconnector capacity. This was first planned in 1980, constructed by the mid-90s, but not fully available until 2003. It illustrates the very large gap, in terms of capacity and time, that can elapse between investment in the physical network assets and their full utilisation by network users.

Consequently, we wholly endorse and support OFGEM's stated aim to ensure that any necessary investment in network infrastructure will actually deliver the increase in useable transmission capacity needed to accommodate the expected growth of renewables generation. Our contribution is aimed to assist OFGEM in achieving this objective. We make no comment as to the preferred technical means by which OFGEM might adjust the transmission licensees' price control to take account of the necessary infrastructure investment – we do not consider ourselves qualified to do so, but the Revenue Driver approach would appear to be reasonable. Our comments are addressed specifically to the issue raised in ¶7.7 of OFGEM's consultation, document, namely to the need to identify a measurable output that can assist in establishing whether licensees have delivered an investment that is "fit for purpose", i.e. one that delivers the required real and useable increase in network capacity.

Psymetrix Case

Psymetrix acknowledges the many and varied difficulties faced by a transmission licensee in trying to bring about an appropriate and timely investment in network infrastructure. OFGEM's consultation paper gives several examples of the hurdles that have to be overcome in realising a 'used and useful' investment, and we do not seek in any way to diminish the reality and complexity of these.

However, it remains a fact that previous attempts to increase the transmission capacity of the network have not delivered the capacity planned for, and that electricity customers and network users have not received the promised benefits from the investment. A good example of this, that is very pertinent to the topic of the current consultation, is the upgrade in the Anglo-Scottish interconnector capacity. This was originally planned in the early 1980s to be 2200MW, and the infrastructure works were completed in 1994, yet as recently as 2003 the useable capacity averages only 1600MW[2].

There are many reasons for this, but whatever the technical, political and legal problems that have been encountered, it is undeniable that what network users have received falls far short of the promised benefits from the upgrade. Restrictions placed on interconnector capacity and limited access (in both directions) for low-cost generation have not provided the promised benefit to customers in either market.

This, in our view, underlines the importance of what OFGEM is trying to achieve. It is imperative that OFGEM encourages transmission licensees to take all reasonable and cost-effective measures to ensure that their investment in network infrastructure actually delivers the planned-for increase in transmission capacity, including the application of appropriate and available less capital intensive technologies.

In planning an expansion of the system, network designers take account of a number of factors that effectively determine how much additional power can be transferred through the expanded infrastructure. These include:

a) ensuring there is an adequate margin of network capacity to allow for the reliable and secure transmission of power in the event of planned-for contingencies such as the loss of a major circuit or item of generating plant – the so-called N-1 secure transfer limit;

b) not loading the system beyond the level at which it can recover in a controlled and safe manner from unforeseen, worst-case (albeit rare) network faults – the transient stability limit;

c) ensuring the system is able to survive the effects of small random perturbations in the power flow (e.g., due to load changes or circuit switching) and that such perturbations are well-damped and do not build up into uncontrolled large oscillations in system power flows – the steady-state stability limit.

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[2] ScottishPower Transmission Seven Year Statement, April 2003

Ideally, each of these limits would be coincident so that no one factor unduly restricts the power transfer capability. In their long-term planning of the system, designers can readily achieve a target level of secure transfer: they have a range of well-proven analytical and design tools to help them achieve this at minimum cost. They can also predict the transient stability margin of their planned expansion, albeit with a lesser degree of certainty, given that they have to make reasonable assumptions about the dynamic response of the generators involved. What is much more difficult to predict is the steady-state stability associated with the increased power flows on the expanded system: the analytical tools, generator models and system data needed for this are all much less well defined at this stage of the planning process.

What is known, from experience in the UK and other power systems in the world, is the debilitating effect on the allowable power transfers across the network if the system has insufficient margin of steady-state stability (see Appendix). The UK licensees have expended considerable effort to manage system steady-state stability, with a good measure of success. But it must be emphasised that the UK problem of steady-state instability of the 1980's has not vanished (the basic physical causes are still present): it has merely been contained for the present level of interconnector power flow.

Inadequate steady-state system stability can – if not recognised and dealt with – present a significant risk to system security[3] and in some cases lead to wide-spread blackouts. For example, in the Western USA the WSCC blackout of 10th August 1996 (see Appendix), there is evidence that poor system damping led to separation of the system into four islands. It has subsequently been authoritatively estimated that the societal cost of this incident ranged from a low of $1bn[4] to a high of $7bn[4].

It has recently been reported[5] that all three of the major blackouts in the USA in recent years (July 1996, August 1996 and August 2003) share at least one common element – poor steady-state stability (manifest as system oscillations).

An important and relevant observation in regard to this consultation is, as experienced in both the UK and elsewhere, that steady-state damping in general degrades as system power flows increase. This problem could be compounded by the retiral or reduced availability of the existing generators that presently provide system damping. In the anticipated near-term future, system steady-state stability margin therefore has the potential to diminish and limit the utilisation of the expanded infrastructure.

The financial consequences of this reduction in useable transmission capacity could be very significant. For example, consider the first stage (2GW) of the network reinforcement scheme proposed[6] to accommodate the Government's target for renewable generation. If half of this increased capacity were unavailable (perhaps not unreasonable in the light of the Anglo-Scottish interconnector upgrade experience), additional constrained-off generation could cost in the order of £100m per annum[7].

There are other consequences that could follow from the infrastructure investment not delivering the intended increase in useable capacity – depending on which of the proposed price control adjustment mechanisms OFGEM adopts. If OFGEM chooses the revenue driver option, the TOs' risk not receiving the additional revenue they might have anticipated, and the quantity of renewables generation that can be connected will fall short of the Governments target. If OFGEM chooses the lump sum or cost pass-through option, TOs will get their additional revenue, but network users will not get the additional useable capacity they are paying for and constraint payments will rise. Neither outcome is satisfactory.

Under such circumstances, particularly in view of concerns over potential blackout risks, it is clearly essential that the system operator is able to maintain an adequate steady-state stability margin, and can procure additional damping as needed at the frequencies of concern (which may change as the connection of wind turbine generators changes the generation mix). The procurement of sufficient damping can in general be achieved through means that are less capital intensive than transmission reinforcement options and this is in line with OFGEM's aims (c.f. ¶5.10). We would go further, and recommend that OFGEM considers asking the SO to operate the system to an agreed and published minimum acceptable level of system damping – as was the case in the early 1990s[8].

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[3] "Probability of Oscillatory Instability and its Implications", D.H. Wilson, et. al., Bulk Power System Dynamics and Control - VI, August 22-27, 2004, Cortina d'Ampezzo, Italy.

[4] Bonneville Power Administration, and EPRI estimates, respectively.

[5] "Cascade to Black", L Pereira, IEEE Power & Energy Magazine, May/June 2004

[6] Dept. of Trade & Industry Transmission Issues Working Group final report, June 2003.

[7] Calculated as £25/MWhr x 4000hours x 1000MW

[8] NGC Transmission System Security and Quality of Supply Standard

One such mechanism is for the system operator to define a new ancillary service: the provision of damping torque from selected and technically-qualified generators. Clearly the cost of procuring this ancillary service must be balanced against the avoided costs of constraint payments, and the system operator should be incentivised to 'optimise' the cost of providing the ancillary service. A prerequisite for the system operator in discharging such a duty is its ability to measure steady-state damping of the system at the frequencies of concern: both before the infrastructure expansion and renewable generation build-up (in order to establish a baseline of existing damping and steady-state stability margin) and after reinforcement, in order to verify that adequate damping has been provided (but not too much, to avoid unnecessary cost).

The technology to make damping measurements is readily available. Psymetrix has some 10 years of experience in designing, commissioning and operating equipment to measure system damping and dynamic behaviour. Psymetrix has installed and commissioned a number of such measurement systems, which have been proven in-service by utilities around the world. In the course of this work, Psymetrix has gained much valuable expertise and experience - both off-line and operationally - in cost-effectively acquiring, analysing, understanding and interpreting measurements of system dynamic behaviour. The current generation of this measurement technology is able to provide the SO with an effective and easy-to-use real-time tool to assist in the safe and secure management of the power system[9].

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[9] "Managing Oscillatory Stability using On-Line Dynamics Measurements", D.H. Wilson, et. al., Power Systems Conference & Exposition (PSCE), New York, Oct 2004.

Appendix

In terms of power system steady-state stability, this Appendix provides a brief explanation of:

- the condition and how it arises
- a brief review of UK experience with the debilitating effects that can arise from the condition
- a brief description of a black-out incident in USA involving poor steady-state stability.

Power System Steady-state Stability

There is no absolute reason why an a.c. power system should run at constant system frequency; it does so only because the system electrical load is balanced by the mechanical power driving the generators. Normally, this balance is maintained minute-by-minute by the system operator re-dispatching generation output to follow changes in system load, and – over a time-scale of tens of seconds – by the automatic response of generator governors to changes in shaft speed.

The governors and other generator controllers will also respond to large changes in electrical load (such as are caused by system faults or other large-scale events) to maintain post-fault stability and keep all of the generators in synchronism - so ensuring transient stability.

But there remains the response of generators to small perturbations in electrical load (due to random load changes, network switching events, etc.) that are ever-present on the system. These are too small and too frequent to be seen by the system operator or to trigger a response from governors, so the only way the generators can respond is by small (almost infinitesimal) changes in their shaft speed – converting its rotational momentum to electrical power. Because of the physical properties of the magnetic coupling across the air-gap, the shaft responds to this speed change much like a classical mass-spring system (albeit one that's rotating at 3000 rpm), and oscillates slightly before settling to its new condition. This phenomenon is known as steady-state oscillatory dynamics: the generator rotor, stator, the network and the load all experience small oscillations in speed, voltage and electrical power[10].

Normally, these small oscillations are well damped, and the generator controllers are (or should be) tuned to give adequate damping at the expected oscillation frequencies (typically in the range 1 to 1.5Hz), so ensuring the steady state stability that is necessary for safe and secure operation. However, in many power systems around the world, including the UK, when the power transmitted across the system increases, groups of generators may respond coherently to load perturbations at a lower oscillation frequency (typically in the range 0.25 to 0.5Hz), at which their controllers' damping action is ineffective or even 'negative', i.e. they give positive feedback and make the oscillations worse. Clearly this cannot be tolerated, and the only remedy is either to restrict the permitted power transfer to a lower level, or to fit additional appropriately-tuned controllers to the generators – power system stabilisers (PSS) – to provide additional damping and so increase the steady state stability margin to a safe level.

Note however that even if this is done, the problem has not been eliminated, only managed. If the generators with PSS are not operating, or if power transfers are increased, the steady-state stability margin will be reduced and damping may become unacceptably low. Either way, the result is the same: the network's power transfer capability may be dictated by the steady state stability limit.

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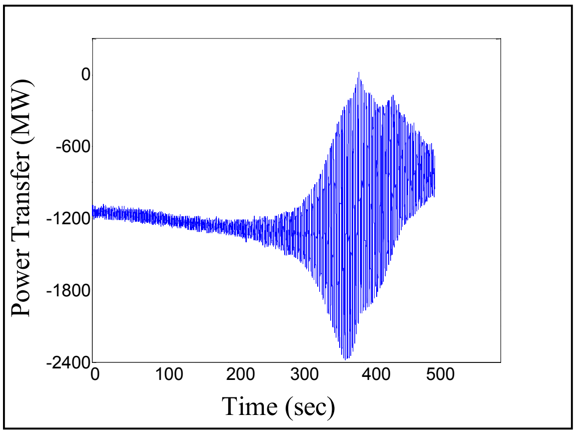
[10] Note: these low frequency (typically 1Hz) oscillations that are manifested in voltage, real power, reactive power, etc. should not be confused with variations in the 50Hz system supply frequency. The system frequency does exhibit <u>very</u> small changes around its nominal 50Hz value due to these oscillations but this does not represent a supply frequency quality problem.

Review of UK Experience

In the 1980's in the UK, problems with steady-state instability were experienced. The effect on the Anglo-Scottish interconnector power flow during one of many such incidents is shown in the Figure below.



It can be seen in this example that swings in power of ~ 2,000MW were experienced. These many incidents were not the result of system faults changing the topology of the system; the system became unstable when unidentified operating conditions were reached. However, although the instability when it occurred could be brought under control in operational time-scales by reducing the interconnector power flow, it was found that the instability later re-appeared at the reduced level of power flow. Ultimately, the interconnector power flow was restricted to ~400MW, about 20% of the maximum transfer capacity of 2,000MW achieved at an earlier period of service (1978/'79).

The GB system did not separate on any of these occasions (due to prompt operator action), but severe wear on generator shafts was noted. In addition to the financial cost, there was also a significant safety risk associated with the possibility of generator shaft breakage.

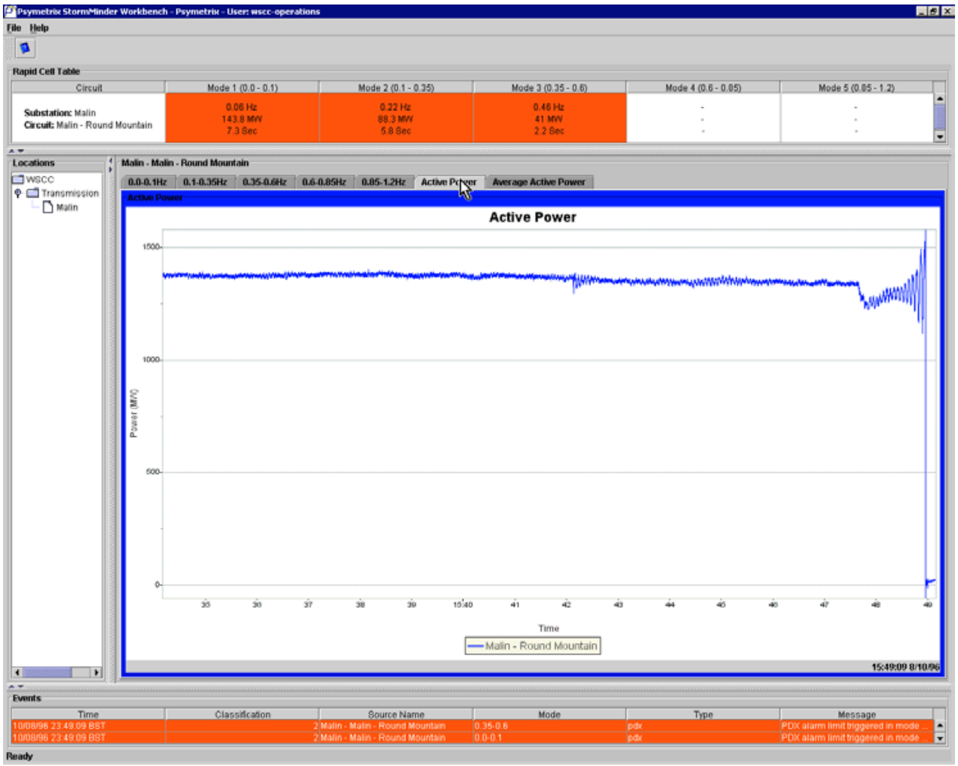
The condition was ultimately resolved using a number of approaches:

- Steady-state stability monitoring was deployed at the interconnector. This included on-line damping monitoring, so that a stability margin could be maintained without an over-conservative constraint.
- Power system stabilisers were deployed and configured to damp the oscillation
- The interconnection was strengthened by uprating the interconnector circuits.

Western USA, WSCC 10th August 1996 Incident

There is evidence that the blackout on August 10th, 1996 that affected the West Coast of North America[11] was a result of poor system damping. In this incident, 30,390MW of load was lost as the western interconnection separated into four islands, affecting 7.49 million customers, most of whom were reconnected after about 6 hours.

In the screen trace reproduced below, the power flow history at one point on the network is shown until immediately after the time of system separation.



Rapid Cell Table

Circuit	Mode 1 (0.0 - 0.1)	Mode 2 (0.1 - 0.35)	Mode 3 (0.35 - 0.6)	Mode 4 (0.6 - 0.85)	Mode 5 (0.85 - 1.2)
Substation: Malin **Circuit:** Malin - Round Mountain	0.06 Hz 143.8 MW 7.3 Sec	0.22 Hz 88.3 MW 5.8 Sec	0.46 Hz 41 MW 2.2 Sec	- - -	- - -

Events

Time	Classification	Source Name	Mode	Type	Message
10/08/96 23:49:09 BST	2	Malin - Malin - Round Mountain	0.35-0.6	pdx	PDX alarm limit triggered in mode ...
10/08/96 23:49:09 BST	2	Malin - Malin - Round Mountain	0.0-0.1	pdx	PDX alarm limit triggered in mode ...

It can be seen at the right hand end of the trace that the oscillations in power suddenly increase from a few MW in amplitude to ~500MW just prior to system separation (shown at the extreme right hand end of the trace). This graphically illustrates the problem of steady-state stability: the system can move from an apparently stable condition (with apparently adequate damping) to an unstable condition with negatively damped oscillations within a very short period of time.

As shown in the figure below, Psymetrix have a power flow record of only about 30 minutes available for analysis prior to the system separation and yet the analysis of this limited time history - utilising the Psymetrix measurement system (post-event) - shows that there was a warning of poor system damping about 30 minutes before the system separation. Had the Psymetrix system been installed on this network the operator would have had ample time for intervention and remedial action and the power system separation and accompanying major blackout could have been avoided.

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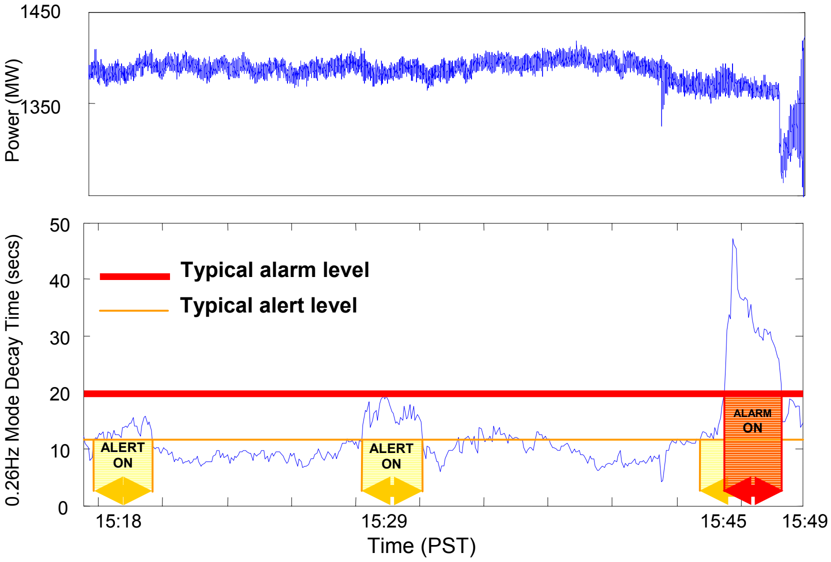
[11] Prior to the disturbance, hot weather contributed to high system loading, and there was a high transfer level from the hydro generation in Canada and the Northwest to California. However, the transfer levels were not violating security constraints. A number of faults occurred on the 500kV network that resulted in a low voltage problem in sections of the grid. In response, the reactive power output at the McNary hydro plant in Oregon was boosted from 260MVAr to 490MVAr. The McNary plant comprised 13 units, which tripped one by one due to a protection error. When the plant power output had dropped to about half its original value, oscillations at 0.224Hz became negatively damped. These continued to grow to about 1,000MW peak-to-peak, tripping the three lines comprising the California-Oregon Intertie, which had been carrying about 4,350MW prior to the disturbance, and caused the first separation. This resulted in voltage and frequency disturbances that separated the system into four electrical islands and caused widespread blackouts.



0.26Hz mode decay time for 10 August, 1996 Western USA, WSCC 10th August 1996 incident