16 October 2020

CT Lab Response to P2025 Market Design Consultation Paper

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Australia is in the vanguard of 'behind the meter' generation. A reality requiring action.

Meeting the challenges of this new age, brings to mind the apocryphal story of the stranger asking for directions to Dublin. The answer: "Well, I wouldn't start from here."

Australia's growth in large-scale wind and solar. The unrestricted access of behind-the-meter solar PV systems to its distribution networks. Together, are making for a very brave and treacherous national experiment. There has to be growth in matching high inertia synchronous capacity with renewable energy generation.

Our submission provides information on grid centric IT systems. These, deployed as a core component of the modern grid.

Systems that provide second-by-second grid-wide data for analytical measurement. An approach that has empowered significant advances in other industries.

The absence of a meshed national grid. Increasing penetration of solar and wind renewables. A combination that makes the physical and equivalent electrical parameter locations of large batteries, high inertia synchronous sources and load centres critically important for the maintenance of reliability, resilience and stability.

An effective way of managing and controlling such dispersed and disparate networks, is by means of a synchronised, second-by-second electrical parameter monitoring system as detailed in the body of our submission.

Whatever markets develop in the future, network analysis and Big Data systems, will be essential. Big data enables the widest range of trading schemes. It can also act as a guardian for network reliability, resilience and stability.

In short, without the system we propose, there will be limits placed on the elaboration of energy and capacity trading schemes in the future. We also demonstrate some immediately available advantages including real-time marginal loss measurement.

As a South African company setting up our own organisation in Australia in 2021, we are at one level excited by the Australian market possibilities for our Otello® GPS-synchronised, multi-nodal system; at another level surprised by the absence of a coordinated, multi-nodal, synchronised measurement system in the vast machine presented by the NEM.

In South Africa, we provide Big Data monitoring systems to ESKOM and distribution metros for thousands of nodes and we submit that such a system is essential for Australian grids

We suggest that the ESB mandate NEM-wide network monitoring and control in the absence of any priority on the part of network asset owners to invest in the synchronised measurements and analytical data essential for reliability, resilience and stability.

It is patently clear that the overall investment responsibility for the proper operation of the NEM is nobody's child—the widely held asset bases have seen to that. Our proposal is based on specific instrumentation and Big Data as used by ESKOM in South Africa; however, the basic concepts behind this system are universal therefore enabling participation by other companies and academia for its successful implementation in Australia.

Sincerely,
Willem van Wyk,
Managing Director
CT LAB

Executive Summary

This submission recommends the adoption of network-wide, synchronous monitoring and control systems in Australian electricity grids so as to provide the enabling factors for flexibility in market designs as called for in the 'Post 2025 Market Design Consultation Paper'. The synchronised network intelligence systems we advocate for, and as detailed here, are not only essential for the physical operation of Australian grids impacted by seemingly unstoppable penetration of non-dispatchable electrical energy sources, but also increase the scope of currently proposed and near-future market schemes. In short, a synchronised, network-wide database, updated second-by-second, allows markets to operate on the same basis, with complete transparency.

Enabled market examples include:

- Five-minute settlement and shorter periods
- Short interval, real-time, marginal loss measurement as opposed to marginal loss factors providing an arbitrary reduction in tradable energy.
- Net solar and wind farm output with line losses accounted for, in kilowatt-seconds
- Short interval markets for frequency and voltage support.
- Reliable operation of VPP and other 'behind the meter' market schemes

The central role of distribution networks

Distribution networks are increasingly susceptible to rapid power variations by virtue of the growth in their distributed energy resources (DER). The networks themselves are only involved in resolving resultant voltage regulation problems. The concept of virtual power plan (VPP) providing meaningful grid support is ab initio, fallacious in that support in not only short-term, but also highly localised.

Even a near-future view of the NEM reveals the essentiality of maintaining substation stability to the largest extent possible. As matters stand, distribution network service providers (DNSP) no operational or financial interest in transmission and sub-transmission networks. DNSP have limited control over inverters and furthermore there is significant control diversity in the national inverter fleet (voltage only, volt-var and volt-watt) adding to fleet management problems. Our proposal for reliability, resilience and stability for the NEM can be boiled down to:

- Maintenance of an agreed minimum external power and reactive power draw per zone substation
- Provision of control within DNSP networks of AS/NZS 4755 (control and switch off of inverters) for the maintenance of grid stability
- Monitoring of all zone substation buses throughout the NEM

Although as submitting party, we have specific technologies available, we hold that the underlying principles of a measurement and synchronisation system are universal in concept so that in the overall implementation of the measurement system, and also for the control aspects, there are many opportunities for Australian industry & academia to participate in their formation.

Our submission, based on extensive experience with networks in the African continent, and in particular those in South Africa, is that no modern electrical power network can operate profitably, efficiently and reliably without a transparent, real-time and near-real time database reflecting virtually all its generating and load buses at identical instants in time, i.e. synchronised, and therefore capable of correlation and control. Such a live database, capable of measuring power flows on time-stamped basis, second-by second, correlated across the grid, including baseload and non-dispatchable market participators, is also suited to short-period participators, including battery supported frequency stability services and spinning reserve.

Overcoming legacy concepts that impede market developments

Reliable integration of non-dispatchable electrical energy sources in Australian grids is restrained through views that there is a soon to be reached ‘natural’ limit to the penetration of renewable, non-dispatchable sources and, on the other hand, a ‘copper plate’ view of networks (power flows choosing their shortest path and encountering no impedance to their flows). The latter is one for which, irrespective of the locations of consumption, generation and stability support, the

only important feature is energy balance.
It is a dangerous view which impacts on the practicalities of various market designs including those for virtual power plants and dispersed battery support for frequency stabilising services.

Although it might be argued that electrical energy market design and electrical engineering do not intersect, the advent of non-synchronous, non-dispatchable power generation has closed the gap between the two. The industrialised world from the late nineteenth century onwards has been powered by alternating current and voltage. The concepts of electrical engineering in terms of control and protection have in essentiality changed little since 1908 when Charles Proteus Steinmetz published his seminal 'Theory and calculation of transient electric phenomena and oscillations' (McGraw Hill Book Company). By then the battle for supremacy of alternating current (AC) power over direct current (DC) power had been decided two decades earlier.

Now, in the twenty-first century, direct current power of renewable electrical energy sources is ascendant and our challenge is to preside over a harmonious marriage between the two competing technologies which threaten to bring back the ghost of Steinmetz and his 'transient electric phenomena and oscillations'.

The transition from legacy technologies

AC power generation, transmission and distribution are legacy technologies. Its improvements lie in the fields protection engineering, DC high voltage transmission and more recently, the use of intelligent electronic devices (IED) in substations. Renewable sources providing DC and asynchronous power are fast-moving technologies, requiring their rapid and effective integration in traditional AC networks and therein lies a big challenge for Australian networks, one that can only be accomplished by real-time transparency of electrical networks.

Historically, electricity generating and transmission/distribution systems have relied on a semblance of what we term today, 'plug and play' operation and control. In traditional electrical power systems synchronisation of generators takes place through the interchange of power and reactive power between generators to maintain frequency and voltage stability. Voltage support under conditions of changing power demand is met by self-regulating, passive devices such as var compensators. These power system components operate without a separate communication channel. However, as non-dispatchable renewable generation sources become larger proportions of power demand, the 'passive plug and play' methodology becomes insufficient to maintain grid stability.

The importance of instantaneous parameters

The NEM alternating current grid stretching from Queensland to South Australia is in electrical terms, not meshed to any extent, and subject to large voltage angle differences. Although Tasmania forms an important part of the grid, it is decoupled because of its DC link with the mainland. Stability of the grid and generator systems has relied on local generation meeting the demand requirements of local loads rather than on a totally integrated basis. Of late, the challenge of maintaining stability is planned to be met via new, capital-intensive, interconnector projects. Notwithstanding the demonstrated need for new interconnectors and upgrading of existing ones to improve stability and resilience, we submit that the high voltage grid and its planned additions, in order to be as effective as possible in this task, be subject to data derived from a synchronised information system. Such a system would provide the following advantages:

- Instantaneous loss factors (appendix 3)
- Instantaneous power capacity margins for stability of high voltage links (appendix 1)
- Instantaneous monitoring of remote energy zone links and control of voltage oscillation (appendix 2)

For the high voltage grid, the following parameters would be monitored on a 1-second, standard time, GPS-synchronised basis in order to permit effective stability control.

- Instantaneous power
- Instantaneous reactive power
- Voltage and voltage angle
- Voltage and current sequence components

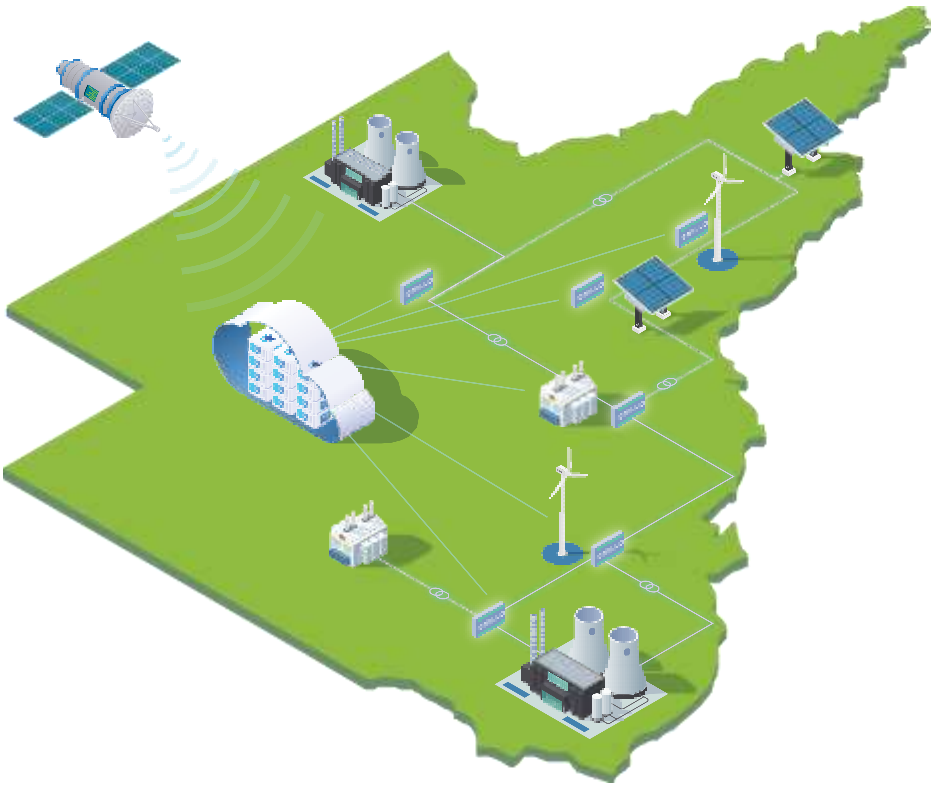
Behind the meter generation

Australia's distribution networks are ill-equipped to deal with 'behind the meter' generation. Some problems are reverse power flow, sustained high voltage and its effect on inverters and as affected by inverters. Others include local congestion limits, phase imbalance, and protection problems because of insufficient short circuit capacities of solar inverters, in addition to voltage oscillation due to synchronisation problems of inverters dealing with voltage phase jumps.

Some problems are being dealt with such as voltage limits. For example, Horizon's Carnarvon network studies using 4-quadrant smart meters to signal inverters to supply lagging reactive power to bring voltage off its high limits and thus preventing inverters switching off. The issues that jump out in 'local' schemes, are a lack of coordination with substations, and more importantly, the invisibility gap for AEMO. The latter is of critical importance as AEMO's Dr Riesz's demonstration of instances of minimum power demand in South Australia (ESIG Down Under webinar of 17 September, 2020). Dr Riesz points out, the risk to stability when local fault condition result in the switch-off of local inverters, causing a rise in externally demanded power and consequent islanding.

Behind-the-meter generation is a major challenge to high voltage grid stability. Regarding a typical distribution network substation as supplying an aggregated load, it is seen by the high voltage grid as one with at times, highly variable power and reactive power demands. Historically distribution grids have not been subject to load variation restrictions. Within the confines of the medium and low voltage grid, reliance has been placed on on-line tap changer transformers to meet voltage regulation caused by load fluctuation. Voltage support within distribution and edge-of-networks has been provided by use of automatic and manual tap-changer transformers and limited use of, for example, series parallel voltage regulators, etc.

We submit that the current volt-var and watt-var regulation requirements on new inverter installations are insufficient for voltage stability in distribution networks and that they would be well served by additional individual circuit branch control, allowing granular, regional selection for best overall voltage control and minimum interruption to feed-in.



At the very minimum all substations connected to transmission and sub-transmission voltage buses must have these buses monitored as well as internal, within substation, medium voltage buses, on the identical 1-second standard time, synchronised basis as recommended for the high voltage networks.

In the first instance following the initial step of our submission, namely the formation of a network-wide, synchronised electrical parameter information system, the entire grid on Australia's South East coast would be transparent on a second-by-second basis and therefore permit its effective control. Without such an information system, reliance on 'plug and play'—essentially, therefor a laissez faire philosophy, will result in increasing instability as increasing, non-synchronous generation intersects with legacy distribution and transmission grids

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Appendix 1

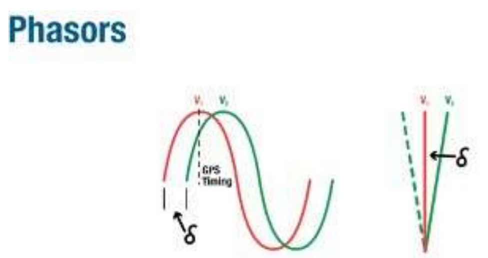
The synchrophasor concept and its central importance

The synchrophasor parameter is central to the requirements of the high voltage, medium voltage and substation (viewed as aggregated load) information system and control. The parameter can be applied to voltage and current. It is a sensitive indicator of frequency variation by means of voltage angle change rate, approaching power flow instability and voltage collapse. The critically important aspect of synchrophasor data is in its collection at identical instants; for example, a voltage angle displacement approaching 90°, indicating impending separation of load from a power line. In a system such as the network on the south east coast of the National Electricity Market with well over 1000 transmission and sub-transmission buses (nodes), gathering electrical parameters synchronously allows correlation, and therefore
real-time and near real-time control.

The phasor for an alternating current parameter is described by the function:

$$a = A\cos(\omega t + \theta)$$

Where a is the instantaneous value of the parameter at instant, t (in seconds), π is the angular frequency (2πf), f is frequency in hertz, A is the maximum value of the parameter and π is the phasor angle. The parameters, a, and A can be current or voltage. The function is shown below. To illustrate the usefulness of synchrophasors, consider the example of power flow through a transmission link between two busbars in a grid. For simplicity's sake, the link is assumed to have no resistance and only self-inductance of X ohms (considered a trivial example but nevertheless illustrative). Power P, transmitted is given by the equation:



$$P = \frac{V_1 V_2 \sin\delta}{X}$$

Where V1 and V2 are sending and receiving end voltages respectively, X represents the inductive impedance of the link in ohms and the angle [X is the difference between the power sending voltage angle (phasor), [X1 and the receiving busbar voltage (phasor), π2.
Similar to the power transmission equation, reactive power, Q is given by:

$$Q = \frac{V_1 V_2 \cos\delta - V_2^2}{X}$$

The synchronous monitoring of power, reactive power and voltage angles throughout a power grid subject to significant penetration of non-dispatchable sources is essential for the control of its stability. Mathematically, the grid comprising formally of an extensive admittance (inverse of impedance) matrix has throughout its nodes (busbars) a range of sensitivities described by partial differentials:

$$\frac{\partial P}{\partial \theta}, \frac{\partial P}{\partial V}, \frac{\partial Q}{\partial \theta}, \frac{\partial Q}{\partial V}.$$

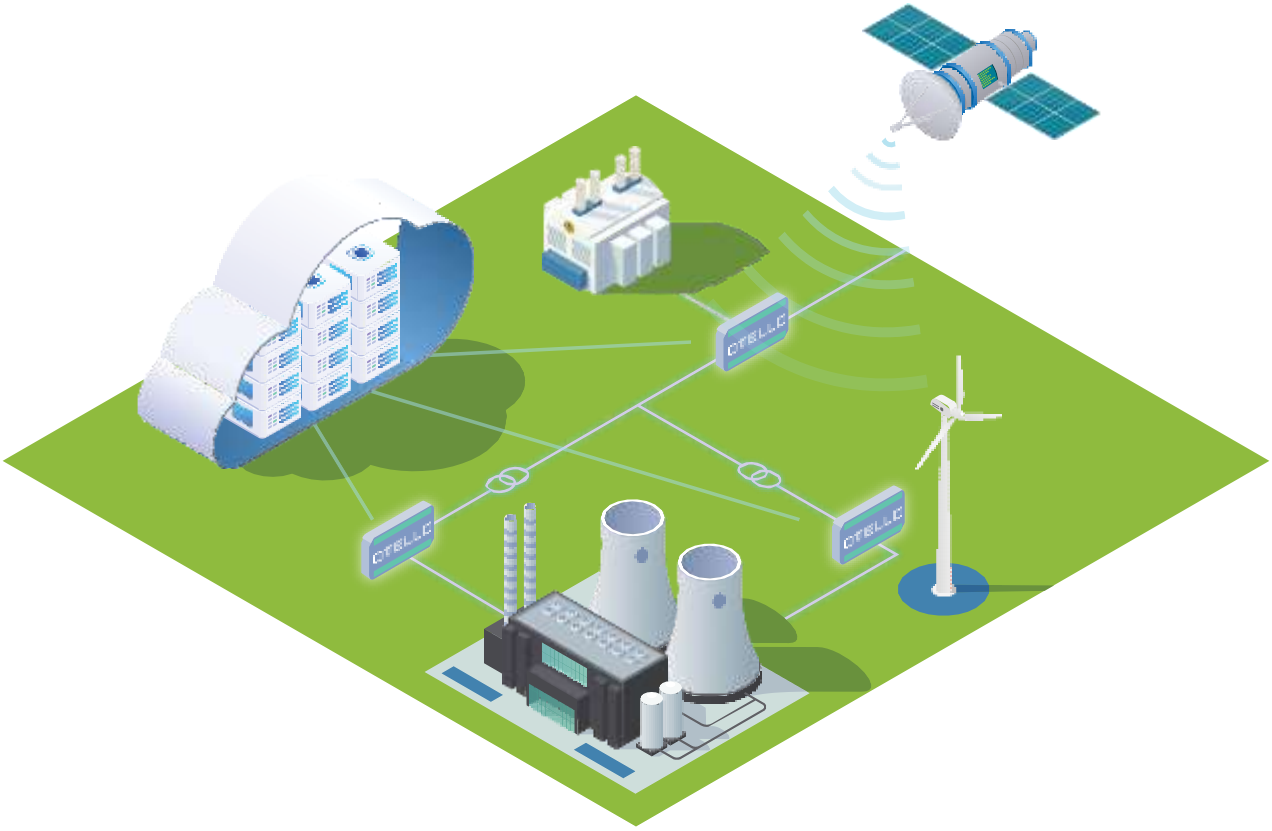
Whereas these differentials indicate sensitivities to power and reactive power changes, solvable by means of iterative calculations when it comes to power system planning, they form no part of systems subject to rapid variations other than by direct observations and using these in control protocols.

Appendix 2

Stability considerations
Rapid changes in power and reactive power bring about voltage angle changes which can be responsible for voltage oscillation in solar and wind farm inverters. Rapid changes in voltage angle at substations can also cause instability downstream for connected inverters.
The general expression for a voltage phasor subject to small signal transients is:

$$v = V\cos\left(\omega t + f\left(\frac{dP}{dt}, \frac{dQ}{dt}\right)\right)$$

Synchronous measurement of voltage phasors can therefore provide stabilisation by constraining and ramping power, for example in the case of distant (from high inertia generation) synchronous sources.



Appendix 3

Loss factors

A useful outcome of multi-nodal, synchronous monitoring is the availability line losses, allowing these to be monitored and stored in a Big Data system on a real-time basis.

Line loss is given by the equation below, where G is conductance if assumed as constant, permits relative line loss measurement to be made only by means of the voltage phasors.

$$(V_1^2 + V_2^2 - V_1 V_2 \cos\delta)G$$

However, where current transformers are also mounted at sending and receiving busbars, loss calculation is trivial as it is the difference between sending and receiving real power, P1 and P2. The synchronous monitoring system extracts on a second-by-second basis, apparent power S, real power P and reactive power Q.

As an example of several solar farms connected to one remote energy zone link, losses in the link can be apportioned correctly. At any time t, the sending power is $\sum_1^n P_{n\ sending}$ for n solar farms. The receiving end power is apportioned in exact accordance with synchronous, instantaneously available individual solar farm output. Energy transferred in kilowatt-seconds for each solar farm is also immediately available for accounting reconciliation.

Remote energy zone monitoring can also provide feedback control for solar and wind farms to flag voltage oscillation and time-variant line congestion monitoring to facilitate optimum power output for market participant