Panel 2

1	Good morning. My name is Trevor Gaunt and I work at the University of Cape Town. I come to this meeting because I expect the Commission's guideline will affect utilities and regulators beyond North America, and because my privileged experience of GICs requires that I contribute.
2	I will address the three topics put by the Commission to this panel. You have them in the agenda. The first is harmonics, distortion, capacitors and reactive power.
3	Although often referred to as quasi-DC, GICs are not constant like DC. They generate varying levels of harmonics and unbalance and in 1989 caused strong voltage and reactive power swings before the Hydro-Quebec system collapsed. The non-active power changes with GIC magnitude and direction and when capacitor banks trip. IEEE 1459 is the conventional definition of non-active power, but it does not accommodate unbalance and DC components. An alternative General Power Theory does.
4	We can think of the General Power Theory as building on the usual power triangle of apparent power S, power P, and reactive power Q big A that can be compensated by energy storage devices. A second orthogonal component, Q little a, of non-active power can be compensated by energy transfer between wires. The little right angle symbols in the diagram show orthogonality. The whole approach is rigorously mathematical in derivation, using second year linear algebra, and very simple in its entirely arithmetic measurement algorithm.
5	Cap banks can correct power factor by controlling the phase shift between voltage V and current I, but the harmonics and unbalance of GIC distortion cause extra heating in the capacitors. Relays normally initiate protective tripping, though some utilities use harmonic-insensitive relays. During the Quebec GMD, coincident with a sharp increase in the E-W geoelectric E-field, SVC protection relays initiated tripping.
6	On a relatively lightly loaded system, 7 SVCs tripped during less than 1 minute, voltage levels dropped, stability was lost and the system separated. Equipment was damaged at several stations. The Quebec power system collapse gave its name to the GMD.
7	As shown in Quebec, tripping of cap banks and SVCs requires extra non-active power to be delivered from generators, lowering delivery efficiency and causing voltage drop. The distortion reduces delivery efficiency too. The non-active power and power factor (an index of delivery efficiency) are inadequately defined in IEEE 1459, with the result that when voltages are distorted by GICs, system collapse is more likely than expected from conventional load flow studies.
8	The second topic for this panel is the suitability of the 75 A/ph threshold proposed in TPL-7.
9	When the magnetic flux in a transformer is distorted by GIC, leakage flux outside the core causes heating in tie plates, winding conductors and the tank. Many construction details affect the heating intensity and location.

	TPL-7 requires simulations of heating in any transformers expected to carry peak GIC exceeding 75 A/ph in a benchmark disturbance.
10	Let's characterize four levels of GICs: The first is an intense, short duration disturbance that can lead to a cascade failure as in Quebec. Second, sustained high GMDs cause severe transformer overheating, leading to failure in days, as at Salem. Third, localized heating by moderate GICs can initiate degradation that continues even after the GIC ends, causing a transformer to fail in weeks to months, as we saw in South Africa in 2003. Finally, high speed streams from coronal holes cause multiple GMDs that can contribute to cumulative low energy degradation.
11	Thus we can define two regions. In one, an intense short GIC initiates system collapse. A blackout early in a storm will protect transformers from further damage. In the second region, overlapping the first, transformers are exposed to possible overheating by high and moderate GICs.
12	We saw multiple transformer failures in South Africa after the Halloween storm. I have been told the failures must have been due to other causes since the GICs did not exceed 15 A/ph in any of them. The challenge led us to develop the Low Energy Degradation Triangle, which has shown a strong correlation between GMD events and degradation in the transformers. The issue is 'what GICs and temperatures lead to failure?'
13	Factory tests by Siemens showed DC of 5 A/ph caused temperature rise of about 15°C in tie plates. Increasing the DC to 16.7 A/ph for just 1 minute caused rapid heating that would take temperatures above acceptable levels within 30 minutes. However, a GIC is not DC.
14	Experience of the damage by real GICs to the Salem and South African transformers, and the tests by Siemens, show NERC's proposed 75 A/ph could leave many vulnerable transformers undetected. I recommend a threshold of 15 A/ph, appreciating that not all of them will be vulnerable.
15	My recommendation is based on the concept of 'public benefit'. Independently of GICs we can define a cost of failure for equipment and systems. GICs simply add to that cost. We can identify a probability-based 'value at risk' against which to assess mitigation options. V@R is not defined by the risk of system collapse but by all processes affecting reliability. V@R can replace contingency analysis in both planning and operations.
16	With or without GICs, planning and operating decisions (in blue) are based on measurements (in yellow), historical failure probability, forecasts and system shape (in white) and derived values (in green). This process illustrates the public benefit approach to reliability.
17	The third issue for this panel is the non-uniformity of E-fields. I'll be brief.
18	The spherical equivalent currents system allows GICs in non-uniform fields to be calculated. Instead, NERC's uniform field benchmark oversimplifies reality. Real GICs have greater statistical dispersion than with a uniform field model, changing the influence of non-active power on system collapse. Non-uniformity of E-fields requires appropriate power system study techniques.
19	Thank you.