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Metamorphosis: Grid 2.0 Emerging at the Edge of the World

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Abstract: Were we to rebuild the power grid today, we wouldn't build the one we have. We would build a resilient, non-hierarchical network, smart and adaptive at every node, with diffuse and multi-scaled power producers and consumers. If this is the Grid 2.0, can we find an evolutionary path to it? This profound complex systems problem no feasible adjacent possibilities for Grid 1.0 is typically solved by evolution through metamorphosis. Caterpillars become butterflies by breaking down the caterpillar system into its base components and reorganising (most of) them into a new butterfly system. But this can only be done in the quiet edges of the enveloping super-system Stewart Brand's outlaw regions. We're taking the first steps to metamorphose Rarotonga's grid in the remote Cook Islands of the South Pacific. Here the conditions are just right. We invite collaboration to help realise our vision and its transpose lessons for the super-system's centre.

Key words: Smart grid; Sustainability; Critical infrastructure; National security

I. Introduction

If the world had its druthers, it would not build today the electricity grid it inherited from yesterday. That grid — let's call it Grid 1.0 — was built for a 19th century world and was adapted progressively to the needs of the 20th century. The build was constrained by the laws of physics, but it was also constrained to fit an evolving socio-economic system. And as a result it, too, became a complex adaptive system, a creature of its history, adapted to its environment, and subject to iron laws of evolution.

Grid 1.0 emerged — and we use the word in its complex systems sense — at the end of the 20th century in a form fundamentally ill-fitted for its current function. Evolution fits systems to the recent past not the future. But the 21st century earth system has step-shifted through the ongoing process of globalisation[1]. We struggle from within this system to describe the changes showering down on us. But there is no denying that the earth system has changed in fundamental ways in both its biophysical and socio-economic dimensions. The word 'revolution' is much used – the internet revolution, the 'just in time' revolution, the nanotechnology revolution, the biotechnology revolution — not to mention the Anthropocene, climate change and the Arab Spring.

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And more change is on the way. The 21st century socio-economic system is not settling into any sort of equilibrium, much to the consternation of the economists who need the assumption of equilibrium in order to model the economy. Rapid, disruptive, perhaps accelerating, change is the new normal. Grid 1.0, if it is adapted to anything, is not adapted to these sorts of changes[2].

So a fundamental question for our century is whether Grid 1.0 can now evolve to fit the newly-emerged globalised world, and its social, economic and physical characteristics. It's fundamental because Grid 1.0 sits at the heart of the critical infrastructure of any advanced society. The proper functioning of our critical infrastructure is a key determinant of our welfare and prosperity — our national security.

One might put up the counter argument that the continuing existence of Grid 1.0 proves that it has evolved to fit the 21st century, but that is not the case. Many systems become dinosaurs, reaching the limit of their adaptive capacity, surviving for a while through sheer inertia before becoming extinct. We argue that the evidence shows that Grid 1.0 is just such an object. The earth system, Grid 1.0's ultimate super-system, has achieved its present globalised state — flat, hyper-connected, interacting, high-frequency and fast-changing — by all sorts of work-arounds despite, not because of, Grid 1.0. The link between the Grid 1.0 and the global socio-economic system — its immediate super-system — is jury-rigged to accommodate Grid1.0's incapacity to change. It must reach a tipping point soon[3].

Overlaying Grid 1.0 with 'smart grid' technology has been heralded as a solution to the inherent physical challenges of the existing infrastructure. Mechanisms for distributed control and even end-user participation[4-6] may provide technical stop-gap measures, but the problem with Grid 1.0 is more than a technical problem, as seen by large scale resistance to the introduction of smart meters by many utility companies.[7]

A. If Grid 1.0 is the problem, metamorphosis is the solution

Our argument here is twofold. We say that Grid 1.0 has reached the end of its evolutionary tether — it has nowhere it can really go. We need a new grid: Grid 2.0. Furthermore, we argue that the only feasible way for a new grid to emerge is through a process we call metamorphosis. Instead of adding more bells and whistles to Grid 1.0, we need to break it down into its low-level building blocks — its atoms, if you will — and reassemble (most of) them in new ways.

We choose the metamorphosis analogy deliberately. Metamorphosis is how evolution solves the problem of fitting an organism to a dramatically different environment, whether it is a caterpillar metamorphosing into a butterfly, a planktonic phyllosoma larva into a lobster, or, most amazingly, a bilaterally-symmetrical planktonic brachiolaria larva into a pentaradially-symmetrical starfish. We think metamorphosis offers a path for all complex adaptive systems, not just living ones, out of evolutionary quandaries.

Interestingly, it is only now that we think that it is possible to metamorphose the electrical grid.

At the end of its life, Grid 1.0 has thrown up some possibilities that are only just becoming apparent. In a curious way, its current failures are helping create the environment for the emergence of Grid 2.0.They are doing this not by providing a smooth path for an incremental transformation, but by providing new building blocks, new atoms, which can be used in the metamorphosis. So the vast effort on political, financial and intellectual fronts that has been made thus far on many futile 'smart grid' projects has not been entirely wasted.

This work has created a host of new components from which a grid — any grid — may be built. We now have in the world a range of energy sources at many scales, new sorts of storages again at many scales, extensions of the reach of the grid into transportation, and the beginnings of more subtle uses of the power of the grid, once more at all scales, through the injection of information everywhere into the grid[8].

Of course Grid 1.0 has countered these new components at almost every turn by system feedbacks that attempt to nullify the attempted change. This is to be expected. The present grid is tightly adapted to a stable world, and is quite brittle in the face of perturbations. We have seen enough cascading failures — a classic symptom of a complex adaptive system outside its comfort zone — to know this. But perturbations are a canonical feature of today's world and, likely, of future worlds[9-10].

So even if these new components are not used, or only grudgingly, by Grid 1.0, their mere existence is enough. A richer set of building blocks makes the metamorphosis task easier. Indeed, we argue that at the end of the 20th century, the task was almost impossible. It looked as if the earth system might be burdened with a dysfunctional grid through to the middle of the new century. Now, with the possibility of metamorphosis and a richer set of atoms, the task is merely daunting.

B. The nature of the metamorphosis task

To better understand the nature of the task, we need to consider, at a very high level of abstraction, both the nature of today's grid and the nature of the enveloping system in which it is embedded.

Profoundly, Grid 1.0's connectivity is wrong for today's world. Both the biophysical and socio-economic systems that together comprise the earth system are non-hierarchical at more or less all scales, and are likely becoming more so. Most critical infrastructures are evolving in the same way, often creating robust scale-free networks, like the internet, financial services or transportation networks. They are responding to the increasing variability of their environment. Indeed, we argue that one of the most fundamental properties of any critical infrastructure in the Anthropocene has to be resilience and that that is most likely achieved through scale-free networks[11-12].

But today's power grids remain resolutely rooted graphs and so remain hugely sensitive to perturbations. While there have been proposals to integrate microgrids incorporating distributed generation to allow Grid 1.0 to evolve into a smart grid (e.g. Erol-Kantarci, Kantarci & Mouftah[13]), there is almost no way to smoothly change a rooted graph to a scale-free graph, so that this property of Grid 1.0 alone confirms the need for metamorphosis.

Grid 1.0's entropic structure also sits awkwardly with the entropic structure of the Anthropocene. Today's power grids are simple rivers of energy, cascading and dissipating as they spread from relatively few large sources to numerous sinks. Households or communities that use wind or sunshine to produce small amounts of energy are often viewed as troublesome sinks that frequently clog, pushing dirty water back into the local community. Our power grids are a tribute to the triumphs of 19th century thermodynamics, but sadly of declining utility in the 21st century Anthropocene. They are simple machines when today's requirement is for more lifelike systems. We've known since Schrödinger[14] that lifelike systems exist primarily in the eddies of energy cascades where negentropy or information can get some leverage. Scale-free and other non-hierarchical networks create such eddies — feedback cycles really — and so allow information and ultimately intelligence to gain purchase on the system.

It is no coincidence that non-hierarchical critical infrastructures are evolving to become intelligent while today's power grid resists this trend despite attempts to bolt-on 'smarts'. The connectivity structure of non-hierarchical systems gives negentropy somewhere to live, creating the conditions for intelligence to emerge. There is nowhere for negentropy to live in an hierarchical power grid optimised to increase the efficiency of its energy cascade.

We argue that a grid fitted to the Anthropocene, Grid 2.0, should have information everywhere. It needs this so that it has the capacity to become aware autonomously and at all scales.

Another feature of the Anthropocene that is not mirrored — cannot be mirrored — in Grid 1.0 is what we might call evanescence. It arises from the today's faster cycle times of both the biophysical and socio-economic systems together with the spikes and perturbations that the clash of these cycles brings. It means that old connections between components of these systems break and new ones reform continuously and at all scales. Unlike Grid 1.0, which gives primacy to the integrity of the network, Anthropocene networks are evanescent. Such stability as they have is a dynamic, emergent, often evanescent property functionally distinct from the static neutral stability sought by Grid 1.0.

So the grid for the Anthropocene needs to be more or less scale-free and self-similar, with production, consumption and storage of energy at all scales, with feedback loops at all scales to allow power to flow in all directions and to allow for the emergence of intelligence, and with the capacity to break and reform links autonomously.

This is an engineering task for the physical grid and the enveloping biophysical and socio-economic systems that only metamorphosis can achieve.

C. Why Rarotonga is beautifully edgy

But we have a problem in executing this task, in creating an exemplar of Grid 2.0 from which memes can spread. The problem is so urgent that it needs more than toy solutions found in laboratory simulations or small greenfield settings. It needs a metamorphosis of a real existing grid. And this in turn creates two problems, one theoretical and one intensely practical.

The theoretical problem is well-known. It is the tendency of larger complex adaptive systems to consume neighbouring smaller ones. Ramón Margalef[15], the great theoretical ecologist first formalised this, but it has been observed, if not understood, in social systems by historians from the time of Thucydides. Stewart Brand[16] acknowledged this phenomenon in his ideas about the locus of innovation. New ideas, Brand thought, come from the edges of systems, from outlaw country, from the frontier, where they can get a chance to grow.

And this problem is reinforced, or perhaps it is merely expressed, by the practical problem of asking an owner of a major grid to take their system, break it down and metamorphose it. The immediate response is a nervous no, a disbelieving no, an astonished no, but in all cases, no.

So we need to turn to somewhere at the edge of things, where there is a frontier approach to life, where there is a high motivation to try new things because of the crippling cost of power, and where the world is lightly regulated: somewhere which is the right size — a society not just a community but yet nicely scaled, and, most importantly, where metamorphosis of the current grid would make a major positive difference to the society.

Rarotonga, in the Cook Islands, fits the bill admirably.

D. Metamorphosis, Grid 2.0 and Te Aponga — the story so far

The Cook Islands are a small independent Polynesian state in the South Pacific in free association with New Zealand. Rarotonga is the most populous island with its main town, Avarua, the nation's capital. Rarotonga's electricity grid is owned by a public utility, Te Aponga Uira O Tumu Te Varovaro, known to the locals as TAU or just Te Aponga. Te Aponga generates, distributes and retails electricity from a single power station in the Avatiu Valley using a bank of eight diesel generators. It is a classic rooted network with six main high-tension feeder lines from the central generation site and subsidiary lines branching off from those main feeders. There are about 4000 consumers connected to the grid, with the most of the electrical consumption used in support of the tourism industry.

Rarotongans pay hugely over the odds for their power. The diesel to run the generators must be imported, expensively, from New Zealand 3000 km away. Currently Rarotongans pay about \$0.90 per kWh (compared to an expensive ca. \$0.20 per kWh in Australia). This *very* expensive power is a major drag on the economy of this developing country, preventing private enterprise from flourishing. It contributes in a significant way to the ongoing depopulation of the Cook Islands, as young Cook Islanders leave their country for New Zealand or Australia where they can get a job and enjoy a reasonable cost of living[17].

But Rarotongans, like other Polynesians, are a resourceful people and can draw on their strong community traditions — often called 'the Polynesian way' — to solve hard complex problems collectively.

The Murienua district in Rarotonga is where these cost pressures have met these problem solving traditions leading to a community project to metamorphose their grid. The Murienua Power Cooperative, led by its energetic chair, James Beer, a local businessman, has begun work with a Canadian technology start-up, Sweet Lightning, Inc. Sweet Lightning, in Cook Islands Maori, is roughly 'electricity from the sun'.

This work involves creating, in the first instance, a smart street in Murienua, with a mix of neighbourhood sinks, sources (mainly solar) and storages (pumped water storage with microhydro) for power[17]. All the neighbourhood devices will be aware of each other and able to respond adaptively to local changes in supply and demand of power. They'll be connected in a resilient mesh. The street will be linked to the main grid by a single line, held at the appropriate tension but with no net flow in either direction.

Our economic modelling shows clearly that the consumers in the street will pay the Murienua Power Cooperative much less for their power than they currently pay to Te Aponga. The Cooperative will price its power above its break-even price but significantly below Te Aponga's price, and the profit will go into an evergreen fund to be used to deploy the model to other streets in the neighbourhood, and so on until the Cooperative is servicing all the consumers on one feeder line. The intention is then to reproduce the scheme in a similar way on another feeder line with the ultimate aim of creating Grid 2.0 on Rarotonga.

The first solar panels have been installed in the street. The site for the pumped storage has been secured, using an existing large cistern at 200 m elevation and fed by a mountain stream with an already existing large diameter supply pipe. Economic modelling is underway. Sweet Lightning is developing the software necessary to create a 'community' of intelligent agents to control such a grid.

Watch this space!

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