Overview of The Agile, Fractal Grid

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The Agile, Fractal Grid (AFG) is both an approach to grid architecture and a way of thinking about the future of the grid as automation, distributed generation, and advanced control technology matures. AFG is one possible answer to the question: What might the grid look like in its most evolved form?

Agile and Fractal

"Agile" is what AFG aspires to be. The grid should be agile in the sense that it is capable of "dynamic alignment with changing local conditions."[1] These local conditions include, but are not limited to, quotidian outages (for instance, those caused by vegetation); normal variations in the output level of distributed resources (for instance, a drop in PV output caused by clouds); cyber attacks; physical attacks on grid infrastructure; sudden changes in load; the addition of new grid resources; and natural disasters. The AFG should take these events in stride and, to the extent possible, keep delivering service to as many loads as possible at all times.

"Fractal" is how AFG achieves this goal. The geometric figures known as fractals are distinguished by the fact that they exhibit the same characteristics at every scale—any piece of a fractal, no matter how small, looks similar to the whole. Thus, in a fractal grid, any part of the grid can perform all the functions of the entirety, including generating power and servicing loads.

A large fractal grid is really just a set of smaller fractal grids, called "control areas," all of whom have decided to collaborate at that point in time. Each control area decides whether to collaborate (act as part of the whole) or not collaborate (act independently of other control areas) based on whether collaboration will help or hinder its objectives. The ability to devolve and reassemble quickly and seamlessly enables agility.

A control area is defined by the assets that it controls (generation, automation devices, load, etc.)[2] as well as the lines, transformers, and other equipment that form the infrastructure needed to support controlled assets but are not actively controlled themselves. When a control area decides not to collaborate with its neighboring control area, it takes its assets with it. Control areas can themselves be fractal—in other words, they may be composed of a number of smaller control areas. The devolution can be recursive, but is bounded by the requirement that each control area must have generation and/or storage; load; and a control system capable of making and acting on the decision to either collaborate or not.

Algorithmic and Communication Considerations

The decision by control areas to collaborate or not is at the heart of the fractal, agile grid. To make this decision, each control area must know its own load and its own generative capacity. If there is a bulk energy storage system (BESS) within the control area, this also factors into the decision.

A control area must be able to communicate with its neighboring control areas, in order to find out whether its neighbors can help it meet its objectives. For instance, control area A may find that, due to a drop in PV output, it is temporarily unable to serve its own load. If it is currently in a state of non-collaboration, it may poll its neighbors to see if they have excess capacity. If control area B has power to spare, the two control areas may decide to enter a state of mutual collaboration. If B is also suffering from a drop in PV output, A & B may remain separate in order to explore other options for meeting their needs.

It's possible that collaboration decisions may not be binary. Under certain conditions, control areas may want to enter into a state of partial collaboration. The algorithms making the decisions may want to factor in reliability and economic parameters. Also, just how local decisions are made when control areas collaborate is an open question. Do all the collaborating control systems operate in lockstep? Or does a single control system still have the option to make local decisions (beyond the decision on whether or not to collaborate)? Much work is still needed to determine the optimal algorithm (or algorithms) that will govern the behavior of control areas.

Implicit in all these scenarios is a communication system that is fast, robust, and secure. This is an indispensable ingredient of the AFG, where control decisions are made by automated control systems in real time. The internet—at least in its current form--does not provide sufficient reliability and security to serve this function.[3]

Collaborate: Y/N?

Obviously, the algorithms that make the decision to collaborate (or not) can be highly complex. Is the presence of critical loads (for instance, hospitals) within a control area factored into the decision? How much weight is given to the price of electricity? Is carbon reduction a factor? It is assumed that each control area exhibits "greedy" behavior, seeking first and foremost to satisfy its own objectives.[2] However, it is also assumed that under normal operation conditions most control areas with choose to collaborate, since this allows for the sharing of resources and maximizing of efficiencies (including natural economics of scale in generation technology).

Ideally, in an AFG "all segments of the grid operate with the same information and control model—regardless of scale."[3] This is because even small variations in behavior between control areas could complicate the decision making process for all. However, this ideal may be hard to achieve in the real world. It may be necessary instead to set appropriate boundary conditions and standards that define the nature of interactions between control areas yet still allow for variation in local algorithms.

Finally, assuming that some sort of centralized command and control structure for the grid remains in place, how do individual control areas factor in messages from central control. Are they treated as suggestions? Directives? Is this determined by situation? (For instance, during a state of emergency central command might exert more authority.)

These questions are currently being explored in a pilot project organized by NRECA and implemented on a grid in Pennsylvania. The algorithms for control areas have already been written for this pilot project. Data on their performance on an operational grid should be available later this year.

[1] "The Agile Fractal Grid," *Smart America*. [Online]. Available: http://smartamerica.org/teams/the-agile-fractal-grid/. [Accessed: 13-Mar-2017].

[2] C. Miller, "Agile Fractal Grid," 03-Mar-2017.

[3] C. Miller, M. Martin, D. Pinney, and G. Walker, "Achieving a Resilient and Agile Grid," National Rural Electric Cooperative Association, Apr. 2014.