Grid Fault Recovery and Resilience: Applying Structured Energy and Microgrids

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About William Cox

• Principal, Cox Software Architects LLC

• Consulting Software Architect
  – Complex systems, Service-Oriented Architectures, eBusiness/eGovernment, due diligence, ...
  – Leader in NIST Smart Grid Framework & Roadmap
  – Member SGIP Smart Grid Architecture Committee

• Specializing in Transactive Energy, Collaborative Energy, Smart Grid architecture, interoperation, and information definition
About Toby Considine

- President, TC9 Inc
- Strategic Technology consulting
  - Information and interaction standards for building design, operation, energy use (oBIX)
  - Strategic Technology Consulting in emerging markets and Venture Formation
Structured Energy Introduction

- Structured Energy (ISGT 2013) described how to structure microgrids with structured composition and decomposition
- In this paper we apply those concepts for Grid Resilience
Self-management Is Key

• Consider a Microgrid as an abstract object with information and operations, some private
  – Provide an interface to the outside
  – Private operations to the inside

• Struggle over knowledge and control
Structured Energy: Relationships

• Microgrid relationships: recursive definition

• A **microgrid** is an aggregation of one or more **microgrids** which provides energy switching, transportation, and management across its **constituent microgrids**

• This creates a hierarchical structure where the edges are from a **microgrid** to its **constituent microgrids**
What Do We Gain?

• A combination of microgrids is itself a microgrid
• Joining my office park’s microgrid $\textbf{M1}$ with that of a nearby industrial park $\textbf{M2}$ creates a new microgrid $\textbf{M3}$
• Self-management of $\textbf{M3}$ needs to take place
  – Coordination of behavior, inputs, and outputs supports self-management
• 2 or 3 microgrids?
• How do we coordinate?
Well-behaved Grids...

• Provide better behavior to the Microgrids in which they participate
• Energy flows can be net, not separate
  – Regulation often distorts the electrical reality typically in the name of incentives
• MicroMarkets scoped to each microgrid
• Combine microgrids by spanning markets and response
Structured Energy Conclusions

- Microgrids form a topology over components
- A model and tools for
  - Assembling microgrids
  - Disassembling microgrids
  - This paper—grid resilience using these techniques

- Structured Energy takes advantage of smoother and better managed loads
  - Reduction in complexity
  - Simplified collaboration and management
Grids as Aggregations of Microgrids

• Structured Energy view of a grid
• Directed Graph
  – Edges from top toward the bottom
  – Parent is higher
  – Child is lower
Terminology

• *Up* is toward the root
• Feasible aggregation path
  – showing one only
Feasible Aggregations

• Many possible aggregations of microgrids to assemble Grid G
• We’ve shown just one in the previous slide
• Constraints include (see Energy Ecologies for an easy-to-compute set of feasible aggregations)
  – Connectivity for delivery
  – Energy flows available (perhaps indirectly)
  – Sufficient suppliers and consumers to balance
Fault Containment

• Assume single fault at M
• Affected microgrids in G are
  – L, the Parent of M
  – M’s siblings
  – M’s children
Fault Containment (2)

• Affect nodes as little as possible
• If L can operate without M, the fault is contained
  – More generally, “without one of its components”
• Iterate until we find a containing microgrid that can operate normally
  – Following the red path
Fault Resilience

- Consider the transitive closure of the children of L
- With care in architecture and redundancy, multiple arrangements can be feasible under L
- Feasible arrangements can be pre-computed
- Apply graph exploration algorithms, redundant links, prune based on feasibility
Resilience of the Faulted Grid

• Three steps
  – Consider alternate aggregations applying business criteria such as
    • Number of connected grids, customers, components...
  – Select alternate aggregation(s) that improve the situation given the fault
  – Reintegrate the component microgrids (below the fault) with the respective un-faulted microgrids
Architecting for Fault Resilience

• Distributed resources must be distributed and diverse, both geographically and in control/management
  • E.g. Storm Sandy issues with PV that couldn’t be used because of failures remote from the DER

• Multiple connections for both communication and energy flows increases the resilience by increasing feasible aggregations

• Structured fault containment reduces risk of new technology and interactions
Summary

• Applies techniques used in network fault detection, communication path management

• Independent of the underlying technologies—uses interconnection and service capabilities
  – Fault drives containment and reintegration
  – Allows independent evolution and reinvention (SOA)

• Simple algorithms—no variation based on component implementation
  – Easier automated implementations
Conclusions

• Structured Energy gives insights and new approaches to fault containment and resilience

• Our approach has significant benefits for
  – Storm outages
  – Growth and dynamic integration of independent microgrids
  – Innovation
Future Work

• Applying broader definitions of recovery
  – Beyond containment and resilience

• Graceful insertion as well as resilience
  – Evolution as well as recovery
  – Timescales can be short or long

• Incorporate new components without losing resiliency and containment
Questions
References (1)

• Tools for assembly and re-assembly
  – Structured Energy ISGT 2013 (slides)

• Price and Product Definition
  – OASIS Energy Market Information Exchange (EMIX)

• Services and interaction
  – OASIS Energy Interoperation
  – OpenADR2 Profiles of Energy Interoperation

• Schedule
  – WS-Calendar extensions to iCalendar
    PIM (abstract model) for WS-Calendar in progress
References (2)

• Selected papers (most are linked from here)
  – **Structured Energy: Microgrids and Autonomous Transactive Operation** (Cox & Considine) ISGT 2013 (slides)
  – **Automated Transactive Energy** (Cazalet Grid-Interop 2011)
  – **Energy, Micromarkets, and Microgrids** (Cox Grid-Interop 2011)
  – **Applying Energy Interoperation and EMIX to DR and Transactive Energy (slides)** (Holmberg Grid-Interop 2012)
References (3)

– **Energy Ecologies** (Cox, Considine, Grid-Interop 2012)

– **Understanding Microgrids as the Essential Architecture of Smart Energy** (Considine, Cox, Cazalet, Grid-Interop 2012 Best Paper)

– Cox & Considine, **MicroMarkets and Transactive Energy - A Phased Approach**, Grid-Interop 2012