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 **M1** with that of a nearby industrial park **M2** creates a new microgrid **M3**
- Self-management of **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…

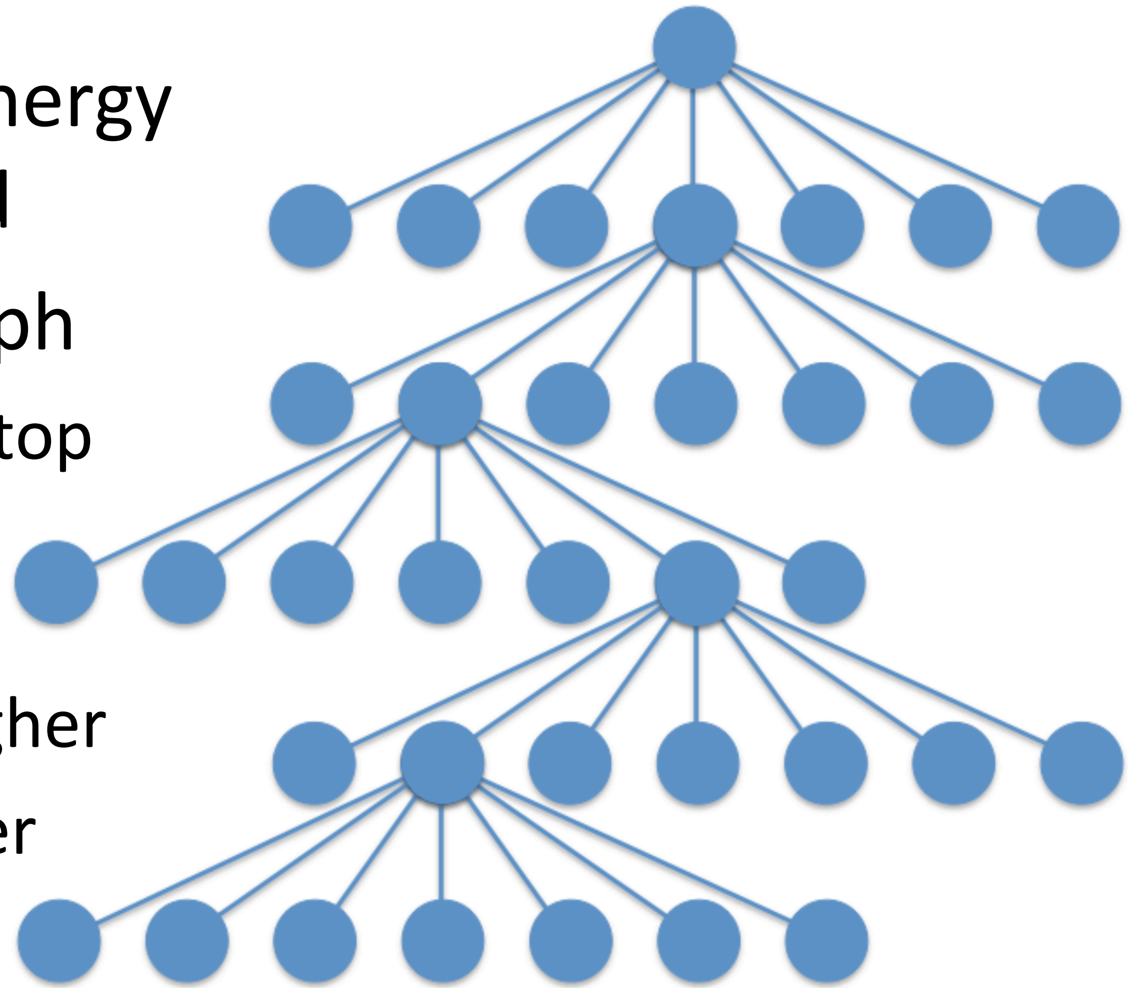
- Provide better behavior to the Microgrids in which they participate
- Energy flows can be net, not separate
  - Regulation often distorts the electrical reality typically in the name of incentives
- MicroMarkets scoped to each microgrid
- Combine microgrids by spanning markets and response

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

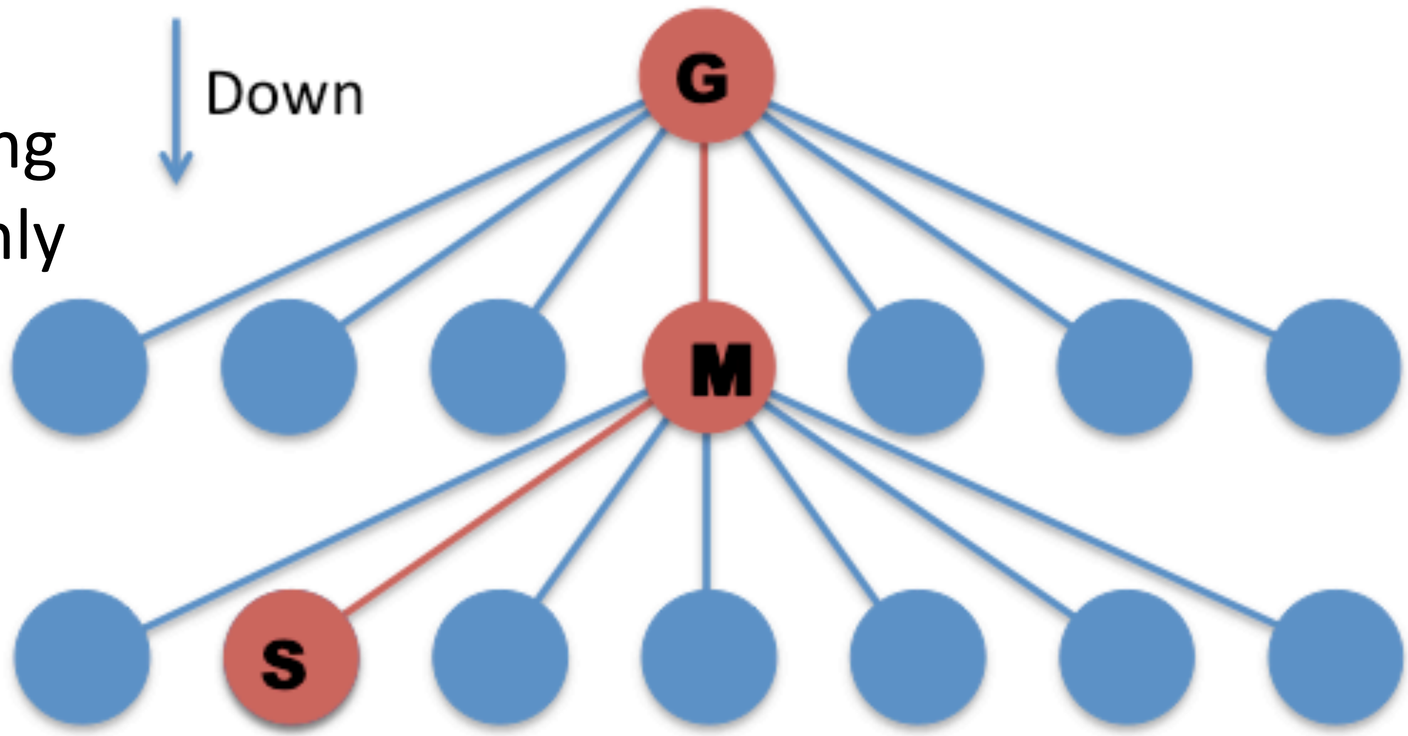
Grids as Aggregations of Microgrids

- 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

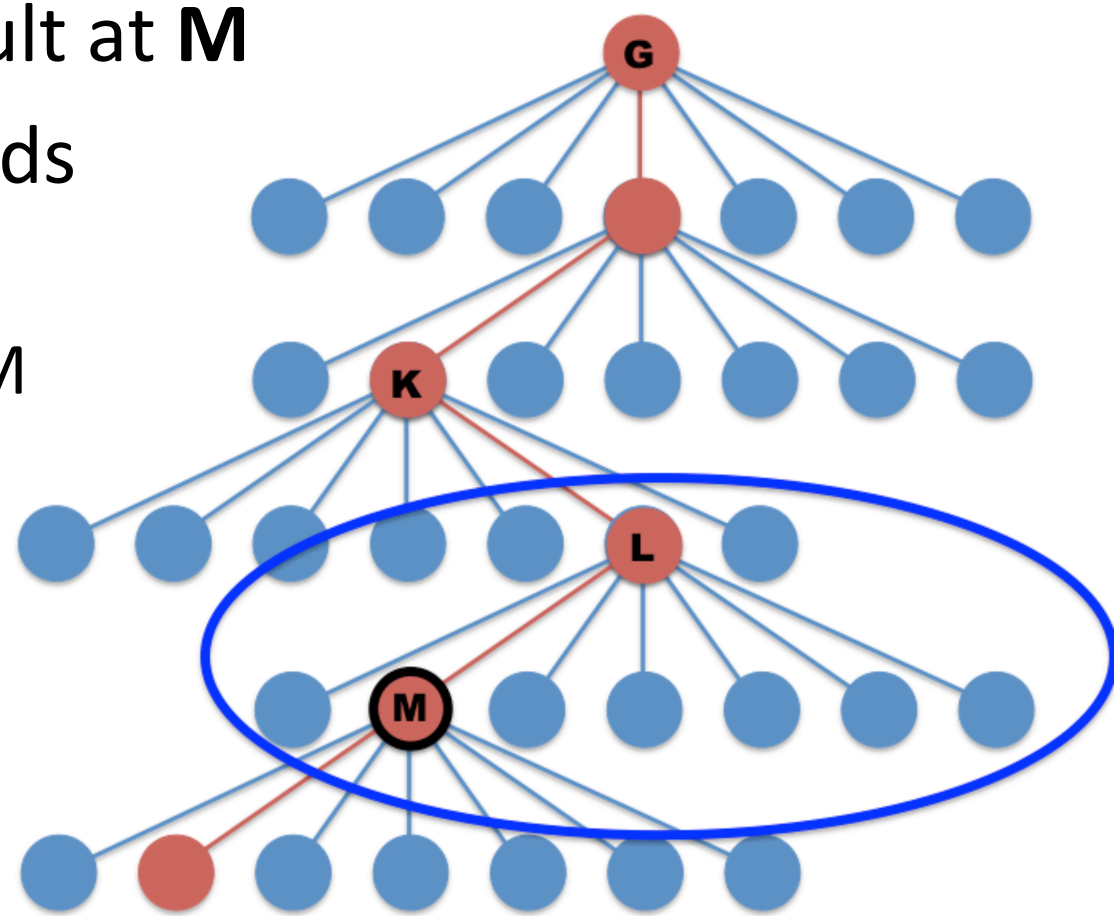


Feasible Aggregations

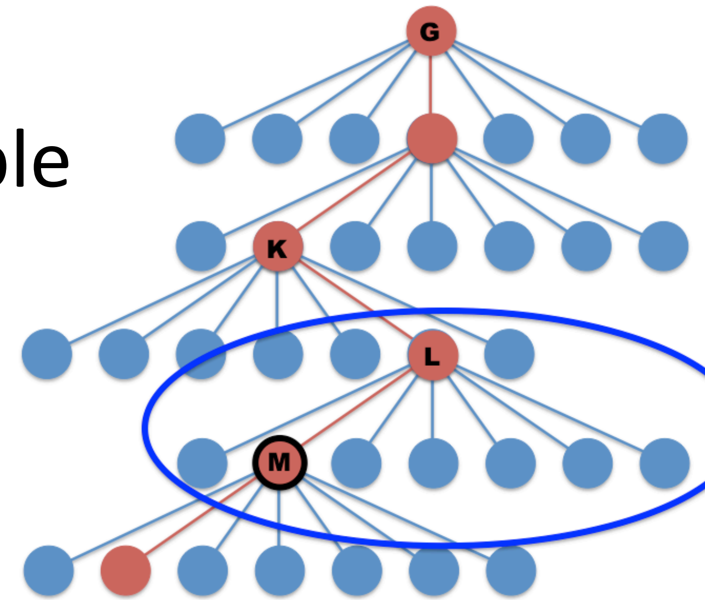
- Many possible aggregations of microgrids to assemble Grid **G**
- We've shown just one in the previous slide
- Constraints include (see Energy Ecologies for a easy-to-compute set of feasible aggregations)
  - Connectivity for delivery
  - Energy flows available (perhaps indirectly)
  - Sufficient suppliers 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

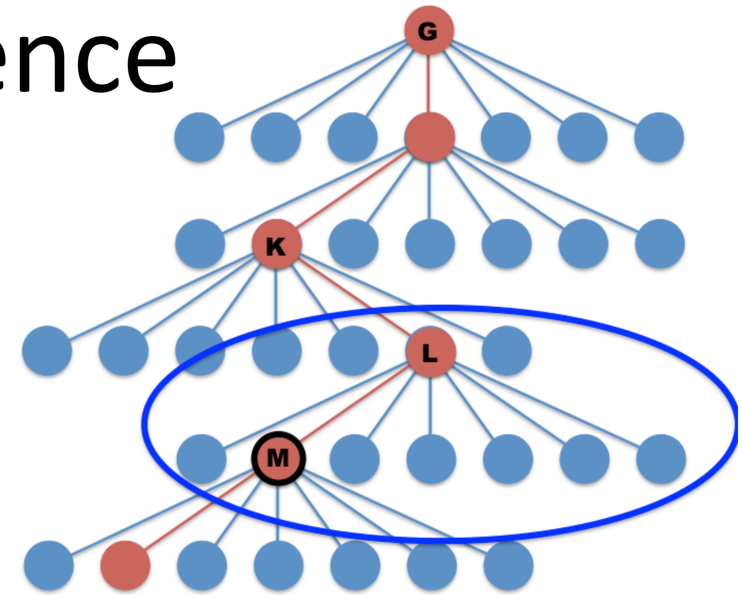


Fault Containment (2)



- 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