SANDIA REPORT
SAND2011-5048
Unlimited Release
Printed May 2011

Advanced Concepts for Controlling Energy Surety Microgrids

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Abstract

Today, researchers, engineers, and policy makers are seeking ways to meet the world's growing demand for energy while addressing critical issues such as energy security, reliability, and sustainability. Many believe that distributed generators operating within a microgrid have the potential to address most of these issues. Sandia National Laboratories has developed a concept called *energy surety* in which five of these "surety elements" are simultaneously considered: energy security, reliability, sustainability, safety, and cost-effectiveness. The surety methodology leads to a new microgrid design that we call an *energy surety microgrid* (ESM). This paper discusses the unique control requirement needed to produce a microgrid system that has high levels of surety, describes the control system from the most fundamental level through a real-world example, and discusses our ideas and concepts for a complete system.

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I. Introduction

In their book *The Bottomless Well*, Huber and Mills showed that the world's demand for energy will continue to grow at ever increasing rates [1]. Today, researchers, engineers, and policy makers are vigorously seeking ways to meet this demand while simultaneously addressing critical issues such as energy security, reliability, and sustainability.

Many experts now believe that distributed generators[1] operating within a microgrid[2] have the potential to address most of these issues. At Sandia National Laboratories (SNL), we have developed a concept called *energy surety* in which five of these issues (referred to as "surety elements") are simultaneously considered. These five issues are energy security, reliability, sustainability, safety, and cost-effectiveness. The surety methodology leads to a new microgrid design that we call an *energy surety microgrid* (ESM) [2].

Menicucci and Boyes discuss the ESM concept and its potential applications [3, 4]. Figure 1 describes the concept graphically. In summary, the ESM has five key operational features.

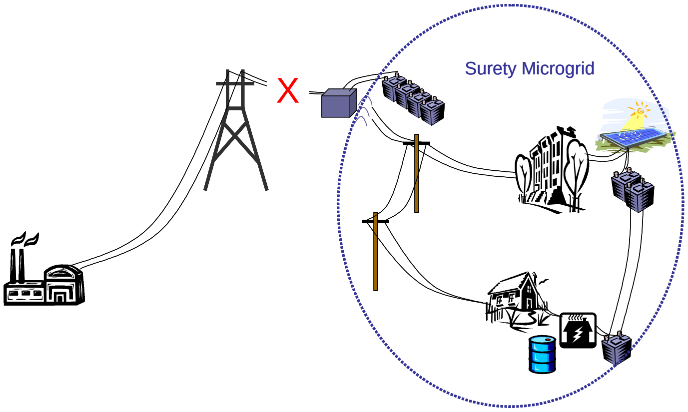

Figure 1. Conceptualized energy surety microgrid.

First, it contains distributed generation sources and loads that can be inserted and removed with minimal physical or logical changes. This concept is often referred to as plug-and-play and is similar to the way a modern computer uses its USB port to accept different kinds of devices.

Second, the ESM's control system eliminates single points of failure. If an event disables the system's main defenses, the control system can maintain critical operations. However, secondary capabilities may be impaired.

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[1] We consider distributed generators to include diesels, microturbines, photovoltaic arrays, wind turbines, fuel cells, flywheels, batteries, and internal combustion engines, among others.

[2] We define a microgrid as a subset of the grid in which small generators (roughly 200 kW or less) and loads are interconnected by a local distribution system. The microgrid may operate in an islanded mode or be connected to the electric grid.

Third, the ESM's control system can optimize the use of power system components to ensure the most efficient and cost-effective operation. Most of this capability is accomplished with minimal or no human intervention.

Fourth, the ESM has the ability to operate either as an islanded system or grid-tied and has the capability to alter between these two states automatically, as dictated by system conditions. This is represented by the red "X" in Figure 1.

Finally, the ESM is an adaptive system. It is aware of changes to the number and state of available resources.

To the best of our knowledge, no control system in existence integrates all of these capabilities and does so to the extent they are present in the ESM. We set forth in this paper to describe how the ESM achieves these goals conceptually. Particularly, we concentrate our discussion on the logical model for the ESM, i.e., how to manage and control an ESM.

Another key aspect of an ESM is its data model. For simplicity, its design will be described in another paper. We will, however, discuss some data model concepts where they are relevant to the description of the logical model.

We begin the discussion with a description of the challenges posed by the high surety requirement. We then describe the basic ESM logical model and show how this new approach improves the overall level of surety in a microgrid application. We especially highlight the advantages of distributing intelligence throughout the ESM system. To illustrate this, we also present a real-world example. Finally, we outline the additional research and tools needed to fully realize our concepts.

II. The Challenge

Working microgrids currently exist. Nevertheless, for the most part they are designed to optimize one or two of the five surety elements. For example, Ft. Bragg (a US Army post) operates a microgrid in which a control system manages various on-site generators on a real-time basis [5]. The main purpose of these systems is to increase efficiency and cost-effectiveness of energy use.

The Consortium for Energy Reliability Technology Solutions (CERTS) is exploring new approaches for controlling distributed sources on a microgrid. Its theory is based on one presented by Lasseter and Piagi, which allows a microgrid to operate in a stable mode with essentially no higher-level controls [6]. A laboratory-scale implementation of this concept has been operated successfully at the University of Wisconsin–Madison. This approach minimizes the physical changes required to add or remove sources. Moreover, it also minimizes the creation of single points of failure.

However, we believe a microgrid system has to address all five surety elements (listed in Section 1) for it to become a solution accepted by industry, government, consumers, and vendors alike.

The priorities of those stakeholders are very diverse. These different priorities lead to microgrid implementations with relatively low surety levels and create incompatibilities that do not solve current problems, but merely redefine them. Even when dealing with a single surety element incompatibilities are not rare. For example, a microgrid implementation that achieves 99.9% reliability is significantly different from one that achieves 99.9999% reliability. Likewise, a microgrid implementation that minimizes installation costs is significantly different from one that minimizes maintenance costs.

The problem is that in contemporary solutions the surety characteristics of the microgrid are intrinsic system features. As such they are mostly static and modifications generally involve high costs. The challenge is to create a microgrid implementation where, for the most part, the surety characteristics of the system are operational characteristics instead of intrinsic characteristics.

Today, there are accepted practices for designing a microgrid to meet some surety elements in particular. Yet, practices for addressing key operational features are missing, such as the following:

1. Standard logical interfaces: A common context in which every system component has a clearly defined role.
2. Ability to adapt to system changes: The ability to maintain complete awareness of the composition and state of the system at all times.
3. A uniform, integrated framework: A common architecture that enables the implementation of flexible and interoperable systems.

The ESM concept provides one way to implement a microgrid that not only addresses the missing operational features, but all five surety elements simultaneously. Section III.A discusses the ESM logical model. Section III.B presents how the ESM achieves adaptability. Section III.C describes the framework that enables the ESM to be flexible enough to meet the diverse set of stakeholder priorities.

III. A Logical Model for Microgrids

In order to achieve the design goals we mentioned in the previous section, we must redefine the way we think about the components of a microgrid and their roles. Specifically, we have to think of a microgrid as a collection of complex entities. For example, a generator is more than just a genset. It consists of fuel storage, switchgear, instrumentation, and wiring. It also consists of firmware, software, and communications lines. We must consider all of these items when installing, operating, or maintaining the generator. Thus, we will refer to it as a “source” instead of a generator and say that it is a logical representation of a generator and everything associated with it. We will define logical representations for all microgrid components in a similar way. In summary, we will define a logical model for microgrids.

High surety levels require systems that can process data and aggregate them in a standard way. Current advances in grid automation are incorporating this concept for data communications [7,8]. Nevertheless, the same is yet to happen for data processing. Today, most microgrid implementations (and energy management systems in general) fall into two extremes: centralized processing and distributed processing. Systems with centralized processing have major vulnerability, scalability, and maintenance issues. Systems with totally distributed processing are highly dependent on the communications link, have relatively slow response times, and generally are less efficient (computationally speaking). Thus, there is a need to look at data processing and aggregation in a different way.

Our logical model has centralized command and distributed data processing. Furthermore, the command structure is not based on centralized processing, but rather on hierarchical processing. We believe a hierarchical approach is necessary to minimize complexity and maximize robustness.

However, the key concept is that the hierarchy is dynamic rather than static. It is analogous to the way an army works. There is a well-defined hierarchy starting with generals and ending at privates. Each rank has a specific mission with well-defined scope. When an event disables one rank (the general, for instance), the rest of the army adapts to the new configuration and continues operation.[3] This is true even if communication lines are lost. It is the hierarchy that keeps the army functioning. It is the dynamic nature that makes it adaptable. These are the keys to achieving the “missing” operational features mentioned previously.

A. Basic Components of the ESM

The most basic configuration for a power system is shown in Figure 2. It consists of a source connected to a load and contains the following generic electrical components: sources, loads, lines, and connections. We also call all these components power system resources since they are the basic units that will allow us to build system configurations of any complexity level. For consistency, we chose to use the same names for the components in the logical model as those in the physical (electrical) model. Thus, from this point forward when we refer to a “source” we are referring to a logical node, not a physical one (unless explicitly noted).

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[3] Even though the system as a whole continues operating, some temporary degradation of performance is possible as a result of the disabling event.

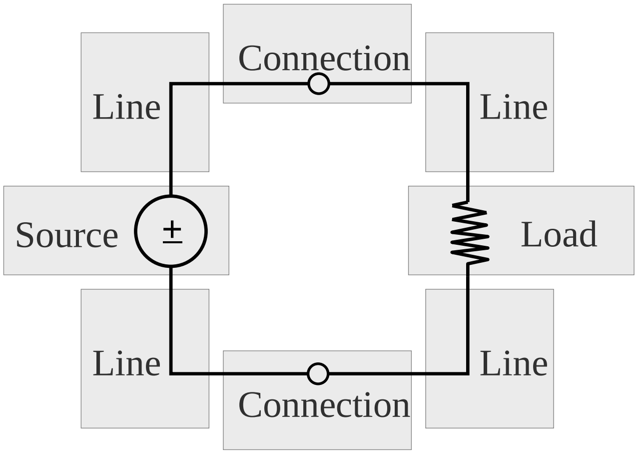

Figure 2. Logical and electrical components of a power system.

The purpose of the logical node is to hide all of the implementation details from the processes above it in the hierarchy. Operational details are communicated by the logical node to higher-level nodes. This encapsulation is a necessity to minimize vulnerabilities and limit complexity.

In practical terms, a logical node is a smart controller located in the vicinity of the physical device it is controlling. This node collects data from the device and its environment and aggregates them in a way specific to its role.[4] It also has the ability to command the physical device, if applicable. How "smart" a node is depends on its role, and each microgrid component has a unique role.

1) *Sources:* A source is any logical node whose primary function is to generate energy. This includes physical devices such as diesel generators, photovoltaic (PV) systems, storage systems, wind turbines, and fuel cells, among others.
2) *Loads:* A load is any logical node whose primary function requires energy consumption. This includes resistive, capacitive, inductive, and complex loads, among others.
3) *Lines:* A line is any logical node whose primary function is to transport energy. This includes transmission lines and cables, among others.
4) *Connections:* A connection is any logical node whose primary function is to redirect energy flow. This generic category includes devices such as transfer switches, relays, points-of-common-coupling (PCCs), and transformers, among others.

Some physical resources may be represented by a combination of logical node types. A storage device, for example, can be represented by either a load or a source at any given moment in time, and thus in practice it would have logical structures for both node types.

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[4] The detailed description of the incoming and outgoing data sets (interfaces) for each logical node is the subject of the forthcoming paper on the data model for an ESM.

B. Functions of the Basic ESM Components

The basic ESM components enable two key operational features: interoperability and adaptability.

Interoperability is a term commonly used interchangeably with “plug-and-play.” These terms are both overused. For clarity, we believe a definition is needed. When we say a power system is plug-and-play we mean any component can be added to or removed from the system without having to modify either the remaining physical devices or the management and control system that operates it. Interoperability at only one of the two levels is not sufficient because each component is an active member of two networks simultaneously: a management network and an electrical network. Furthermore, plug-and-play also means that nodes can communicate and interact with each other.

Adaptability means that the power system can adjust and function well within a changing environment. We also say the system has to achieve this with minimal or no human intervention.

> 1) *Interoperability with Management Processes:* The primary goal of an energy management system is to manage power flow according to given policies. To do so, the system must be aware of the state of all resources at all times and accomplish this while supporting all possible types of equipment. It is a daunting task.

For example, a power system operator may need to know the level of generation reserve of a diesel generator. In order to enable the operator to accurately answer that question, current energy management systems need timely information on several parameters like current output, generator ratings, system temperatures (ambient, block, etc.), rpm, and fuel levels, among others. It also must know how each of those parameters contributes to determining generation reserve.

Next, the type of source[5] needs to be considered (e.g., a microturbine versus a diesel genset). In any case, the answer we seek is the same, but the data requirements and the relationships among those data parameters are different. For example, we may seek to know the reserve capacity for the generator. In the case of a diesel, we must know the reserve fuel level. But in the case of a PV generator we must know potential hours of sunshine remaining.

Current microgrid control systems solve this problem by requiring the controller (or “energy manager”) to know beforehand how many types of sources there are, what data set is needed from each, and how to produce power information from each data set collected. Moreover, they also require the energy manager to be modified every time a new technology needs to be supported.

The ESM addresses this challenge by simplification: the management system only needs to understand power data. Any other data are dispensable.

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[5] We discuss only sources for the sake of simplicity, but it should be emphasized that the same concept applies to all four basic ESM component types.

Thus, the data set required at the source level is relatively small. It consists of three main types of information.[6] awareness, usage, and capability. These can be summarized as follows:

1. Awareness – Data describing what is online. At connection to the microgrid, the logical node broadcasts a message saying, "I'm a new node (source, load, etc.) in the microgrid." Similarly, at disconnect time it may broadcast a message saying, "I'm going off." In summary, the system has auto-discovery and self-description capabilities.
2. Usage – Data that describe the power level of the resource.
3. Capability – Data that describe the power requirements or capabilities of a resource. Knowing the resource's power capability or need at any given point in time is the single most important thing needed to manage the resource optimally.

In this approach, the logical node (as explained in Section III.A), instead of the energy manager, encapsulates the technology knowledge and provides the right response for a given type of node. Therefore, the energy manager does not need to collect the data and process them to generate a response. This frees up logic and processing assets in the energy manager. Those assets could be used for implementing more sophisticated behavior or to simplify the management system. Furthermore, the approach has the potential to reduce vulnerabilities in the system by processing data locally instead of transmitting them to a remote node for processing. Figure 3 depicts these concepts.

At the lowest level, called the physical level, the device's controller communicates with its source node through a standard mechanism such as IEC61850[7], CIM[8], or LonWorks.[9] The standard mechanism produces a data stream specific to the technology, but vendor-neutral. This enables plug-and-play functionality at the physical level. We could replace a diesel generator from vendor X with a diesel generator from vendor Y and it would be able to interact with the management and control system seamlessly. Note, however, that in early implementations standard mechanisms may not be widely available and a protocol translation stage may be needed to understand several common automation protocols.

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[6] This is a high-level list. As mentioned before, the data model is described in detail in a separate paper.

[7] International Electrotechnical Commission, *Communication Networks and Systems in Substations*; an introduction to the standard can be found at http://en.wikipedia.org/wiki/IEC61850.

[8] Distributed Management Task Force, *Common Information Model*; an introduction to the standard can be found at http://en.wikipedia.org/wiki/Common_Information_Model_(computing).

[9] An introduction to LonWorks can be found at http://en.wikipedia.org/wiki/LonWorks.

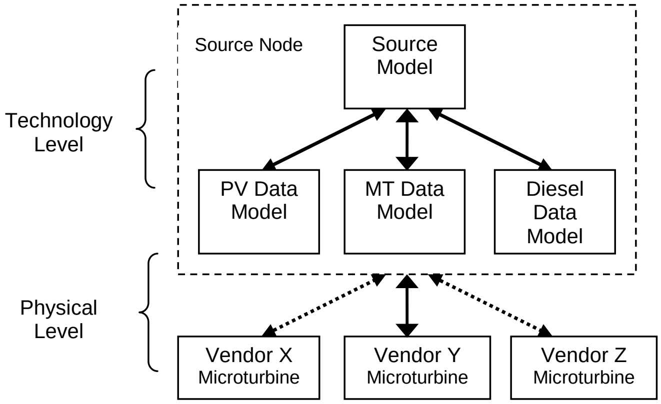

Figure 3. Layers of abstraction in the source node.

At the source node, the data are processed to translate it into the data set required by the source model. The resulting data stream is both vendor-neutral and technology-neutral. This enables plug-and-play functionality at the technology level: We could replace a diesel generator from vendor Y with a microturbine from vendor Z and it would be able to interact with the management and control system seamlessly. Thus, we have enabled plug-and-play functionality with management processes.

Furthermore, when a new technology is developed (for sourcing power, for example), only the logical node associated with the new technology has to be updated. New technologies will not cause a fundamental change in information exchange because logical nodes only exchange information relative to power. Management processes will still be able to ask pertinent questions to the logical node and get accurate answers without any modifications. This interoperability works both ways. When new functionality is added to the management process, logical nodes do not have to be modified. They will still be able to interact with the new management process and communicate power capabilities or needs.

> 2) *Interoperability with Physical Processes:* Plug-and-play functionality at the physical level is primarily a question of stability: Can a resource be added to or removed from anywhere in the system without destabilizing it? Current solutions to this challenge usually involve re-engineering the system to accommodate the change. These solutions are relatively costly in both time and money. Additionally, they are only temporary as the exercise usually needs to be repeated for each change to the system.

The ESM addresses this challenge in two ways: local and system-wide stability controls.

First, each logical node monitors and controls stability in its local environment.[10] In this context, the logical nodes are autonomous, i.e., they execute this function regardless of the presence of management processes and their network. This autonomy is essential because minimizing the

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[10] The extent to which a local node can control the stability of its environment varies with node type.

role of communications in stability control minimizes the possibility of having single points of failure in the system.

This concept follows the research of Lasseter and Piagi [6]. Their approach has proven to achieve automatic load sharing between generators of a specific class and how to handle resynchronization of the microgrid to the grid. It also provides insight into how to handle fast electrical transients in a microgrid.

Second, the ESM implements system-wide stability controls at the management level. This functionality is necessary because the logical nodes only know their local environment. As such, they are not aware of the effect a change has on the system as a whole. For example, what if a big load is added to a system where sources have relatively slow response times? What if multiple sources are removed in a relatively short time? Without knowledge of the system, the logical node is limited in its ability to minimize disruptions.

The stability controls at the management level help the ESM to anticipate/prevent the incidence of stability issues. This happens because when a resource is added to or removed from the power system, its logical node performs two key operations: first, it controls the point at which the resource connects to the power system; second, it automatically announces the appearance (or disappearance) of the resource to the management processes *before* it happens physically.[11]

In other words, when a resource is added to the ESM, its connection point to the electrical network is always left open. Next, the resource is connected to the logical network. When this happens, the auto-discovery and self-description features allow the management processes to become aware of the resource and its power capabilities (or needs). The management process can then evaluate the effect of the new resource on the microgrid. Based on this analysis, the management process will communicate to the logical node whether or not it can close its connection point at this time and if it has to operate under any restrictions (lower power levels). This process ensures that when the new resource becomes an active node in the power system it has a minimum impact on stability.

> 3) *System Adaptability:* Power systems are highly dynamic. As such, management processes must be able to quickly respond to system events or else they will lose control of the system. In order to accomplish this it is not sufficient for components to be plug-and-play at setup time. The system must also be responsive to changes in the state of existing components. Moreover, it must also detect and handle the effects on one node caused by changes in another node.

The ESM addresses these issues with distributed processing and full system awareness.

First, as described previously, every logical node in the ESM understands and controls its local environment. Their limited scope allows the control software in the node to have very detailed knowledge of the role of the node without undue complexity. For instance, a source node has algorithms that describe the behavior of generators. As such, it knows what the operational limits of generators are. Additionally, it knows how to operate them outside those limits and

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[11] Resources could be lost unexpectedly. In this case, local controls are the first line of defense against instability.

when it is safe to do so. In summary, logical nodes know what the power capability of their physical device is under different system conditions. This intelligence allows the logical node to adapt its operation to changing local conditions. Equally important, it allows it to provide critical and timely data to the management processes. Having up-to-date power capability data from each logical resource enables the management processes to make better decisions and make them faster. They can concentrate on optimizing resource interaction and not on figuring out each resource's current state.

Second, management processes define the system dynamically. Specifically, a microgrid is defined simply as a collection of logical nodes. Logical nodes, in turn, represent all power system components (as described in Section III.A), not just sources or loads. Furthermore, all nodes in the system exhibit auto-discovery capability. These features enable ESM management processes to maintain an accurate representation of the microgrid under any circumstance.

With an accurate representation of the microgrid at all times and timely power data for each resource, ESM management processes can adapt to a wide range of conditions.

C. Interactions Among ESM Components

In the previous section we discussed how the basic ESM logical nodes interact with the physical devices in their domain. We also mentioned briefly how they interact with management processes. Now we will discuss the underlying framework: how to implement a microgrid using the ESM logical nodes.

So far in this paper we have used the term "management processes" to describe the part of the power system responsible for making high-level decisions. In other words, they are the processes that impose operational policies onto the rest of the system. A microgrid cannot be operated optimally without such processes. Note that we say "operated optimally." As discussed in Section III.B, the ESM does not depend on management processes for functions such as local stability control. However, none of the basic logical nodes (described in Section III.A) is aware of the "system" or "network" they are a part of. Obviously we cannot build a fully functional microgrid with just these logical nodes. Where in the ESM are the higher-level processes implemented? What makes a collection of logical nodes behave as a system? The answer is the microgrid logical node.

> 1) *The Microgrid Logical Node:* In Figure 3 we showed the relationship between a physical device (a microturbine) and its logical node (a source node). In Section III.B(3), we defined a microgrid as a collection of logical nodes. It is the collection that defines the system. It is at this level that we can talk about power and energy flow between components. This is the microgrid level and is represented in our logical model by the microgrid logical node.

A microgrid node is any logical node whose primary function is to manage collections of basic nodes (sources, loads, lines, and connections; defined in Section III.A). Figure 4 depicts the concept. Again, remember that the basic nodes are capable of independent operation such as maintaining stability on a local level. The management functions provided by the microgrid node are higher-level functions such as resource optimization, economic dispatch, etc.

At the microgrid level, an abstraction process takes place analogous to that in the technology and physical levels and described in Figure 3. Microgrid nodes produce and consume generic information about the nodes in the level underneath it. This information is generic because it only deals with the power characteristics of the system components: awareness, usage, and capability (as discussed in Section III.B(1)).

From the perspective of the microgrid node, all instances of source nodes look alike in terms of operational characteristics: We could replace a source node for a diesel generator from vendor Y with a source node for a microturbine from vendor Z and it would be able to interact with the microgrid node seamlessly. The same is true for the other three node types: all load nodes look alike in terms of operational characteristics; all connection nodes look alike and all line nodes look alike. We have enabled plug-and-play functionality at the microgrid level.

At the utility level, communication is between a microgrid node and its associated energy manager processes. The information stream is specific to each microgrid's particular configuration. However, since all microgrids are made up of sources, loads, lines, and connections, a microgrid logical node is capable of communicating with and managing any kind of resource collection. Thus, at the utility level the communication appears to be with a generic microgrid. Just as we can implement plug-and-play at the device level, here we could swap any microgrid in and out of the power system, and as long as its interface supports the ESM it would be able to interact with the energy manager processes seamlessly. We have enabled plug-and-play functionality at the utility level.

Note that the grid control point (GCP) in Figure 4 represents the *logical* interface between the microgrid and its higher-level processes. As such, the GCP itself is a complex system composed of several subsystems. This report does not describe the design of those subsystems. The GCP is included to illustrate the fact that the ESM is designed to interact with other systems.

2) *Interactions Between Microgrid Nodes and the Basic Nodes:* The ESM logical model is a modular model. Each physical component is represented by its associated logical node and management processes are represented by the microgrid node. In order to build a control system for a microgrid, we need to have at least one microgrid node and any number of instances of the basic nodes.

It is up to the microgrid's designer to decide how big a collection of resources a microgrid node can manage efficiently and reliably. This decision will depend on operational goals and other policies. However, we must emphasize the dynamic nature of an ESM. The designer's choices will determine only the initial state of the microgrid. Once operational, the system will adapt to the current situation and reconfigure itself accordingly.

The general approach is this:[12] The first element of any ESM should be a microgrid node. This is because it is the node with knowledge of the system and all policies. Next, logical nodes for each physical device are added to the system. As soon as a basic node is added to the system, it will go through its "discovery" phase. In this phase the logical node announces the node's presence and describes itself to the microgrid node. This "discovery" causes the microgrid node to register the basic node as a member of its resource collection.

As soon as the basic node has been registered with the microgrid node it will start exchanging power information with the microgrid node. In addition, the microgrid node will send commands to the basic node to adjust its operational parameters according to the policies active in the microgrid node.

A few points from this discussion (also seen in Figure 4):

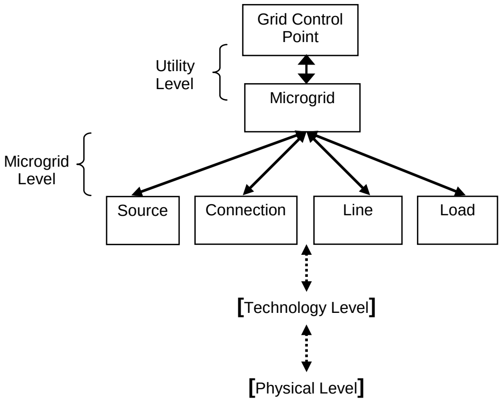

Figure 4. Logical diagram of the energy surety microgrid.

1. Microgrid nodes communicate with all other node types.
2. Basic nodes communicate only with microgrid nodes.
3. In the absence of a microgrid node or a communications network, the system will turn into a collection of multiple independent nodes (from an information perspective).

3) *Interactions Among Microgrid Nodes:* A microgrid node's primary function is to maintain a balanced power flow between the sources and loads in the lines that it controls.[13] This means it is aware of the power system dynamics within its resource collection and knows whether it has a deficit or a surplus of power.

Moreover, a microgrid node exchanges information with other microgrid nodes (if available) in order to supply or request the necessary power transfers. This is true whether the operational directive for the microgrid node is to maintain stability, to optimize energy exports, or any other operational goals.

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[12] As mentioned previously, we are describing the basic concepts of the ESM logical model. Its implementation and data model will be described in a forthcoming paper.

[13] The management and control framework cannot be complete without addressing economic dispatch and business functions overall. However, we have omitted their discussion here for the sake of simplicity.

As such, a microgrid node looks like a source or a load to other microgrid nodes depending on whether it has a power surplus or a power deficit. Since microgrid nodes know how to manage sources and loads, it follows that they also know how to manage other microgrid nodes. This means that the collection of resources managed by a microgrid node can include other microgrid nodes, which enables a hierarchical arrangement of resources. We have enabled a completely modular, intelligent, and distributed control system.

In addition to managing their resource collection, a microgrid node should have the intelligence necessary to negotiate with other microgrid nodes for the best allocation of the resources they manage. These transfers would be executed according to given policies, functional priorities, and current and expected system dynamics.

It is important to emphasize that at any time each logical node is managed by only one microgrid node. That is, microgrid nodes do not share resources. This helps simplify the management processes inside each microgrid node and in turn has the potential to make the system more robust. Remember that microgrid nodes interact with each other and can exchange power between them. Not sharing the physical resource does not prevent power exchanges. Furthermore, reliability is not a concern because of the dynamic nature of the system (see Section III.B(3)). If the Microgrid node managing a given resource fails, another microgrid node in the system will automatically take its place.

The source for the microgrid node’s intelligence is the algorithms embedded into it. There are a multitude of tasks that fall into the domain of a microgrid node: resource allocation, resource optimization, power flow analysis, fault recovery, economic dispatch, etc. Each of these tasks is a research field in itself and beyond the scope of this paper. The key is that we are providing a framework in which the knowledge (algorithms) from these various fields can be applied in a practical way without having to modify the framework itself.

D. Security in the ESM

Because of the multiple layers of control and the distributed nature of the system, the ESM gives a high priority to securing the logical network. Issues such as authentication and intrusion detection are critical. When a node shows up in the system (specially a microgrid node), the system must make sure that the node is authentic before it allows it to initiate communication with other nodes. The ESM uses standard security mechanisms such as those defined by IEC27001 and IEC27002:2005. However, this topic is outside the scope of this introduction. We will describe the security mechanisms of the ESM in a separate report.

IV. Conceptual Application of the ESM Concept

To complete our introduction to the ESM concept, we present an example of applying the ESM concept to a real-world situation. The example describes events that may unfold at a military base, a likely first application of our concept.

A. Reconfiguring Resource Allocations Dynamically

Assume we have a small military base with a diesel generator and a PV array as sources on an ESM that is powering five buildings.

A microgrid node is running in a control room and periodically exchanges information with every source node concerning its power output. Under an appropriate schedule, load nodes also exchange information with the microgrid node describing their respective power usage. Simultaneously, every node (sources, loads, lines, and connections) makes sure that its associated resource is operating according to active policies and operating goals.

Suddenly, the base is attacked (either maliciously or by nature) and loses its PV array, one of the buildings, and some power lines.

The microgrid node automatically identifies the changes to its resource collection and changes operating goals to maintain safe operations. Because of the unexpected failure, the microgrid is operating under a different priority allocation. As part of the reconfiguration process, the microgrid node re-routes power flow (changing the state of connections) to offset the lost lines. It also notices that one of the remaining lines has reported that it cannot handle as much power as it normally would and is getting overloaded. The microgrid node executes additional re-routing commands as necessary to alleviate the situation.

After some time, the base commander decides that the command center’s building is no longer safe and decides to move its operations to a safer building. This involves an increase in the load level at the new location. The base commander queries the system for a location that can support the new load. Because of the attack, no additional sources are available at the time to supply the new preferred location. The microgrid node is aware of this condition. However, it queries the available source to find out if it can meet the new load levels and for how long. It presents the answer to the base commander. If he or she accepts, the microgrid node then commands the source to operate at the new levels. As soon as new resources (lines, sources, and connections) come online, the microgrid node then restores the original source to normal operating levels.

Note that in this example human interaction is minimal. The intelligence at all levels of the system is being exploited to optimize coordination and response time.

V. Future Work

This report presents an introduction to the ESM control concept. Realization of that concept is ongoing and will require significant efforts on several fronts to become a proven reality. Some of the key challenges are:

1. Creation of standardized information models for Distributed Energy Resources (DER), including storage devices.
2. Detailed description of the information set required by each logical node (the ESM Data Model).
3. Harmonization of the ESM concept with international standards.
4. Extension of the existing framework to complete functionality description at all logical levels.
5. Defining the level of intelligence necessary for each node type.
6. Evaluation, adoption, and/or creation of algorithms suitable for implementation into the appropriate node types.
7. Applying the concept at a test setup to offer initial validation.
8. Scaling of the concept in order to make application at large installations possible.

VI. Summary and Conclusions

We have presented an overview of the current state of microgrid automation and its limitations. We have also presented how a multi-dimensional approach is needed to overcome those limitations. Energy surety is such an approach, taking into consideration energy security, safety, reliability, sustainability, and cost-effectiveness.

We identified the main challenge: to create a microgrid implementation where, for the most part, the surety characteristics of the system are operational characteristics instead of intrinsic characteristics. In order to meet that challenge we propose a framework which we call the energy surety microgrid (ESM).

The ESM can achieve high levels of surety by providing a way to address all surety elements simultaneously and in an integrated and modular way. The surety elements were discussed in the introduction, Section I:

1. Safety – Standard logical and data interfaces mean minimal incompatibilities. This improves stability, simplifies maintenance, and reduces the probability of errors and accidents.
2. Security – Limited roles for system nodes reduces complexity and allows for more robust authentication schemes.
3. Reliability – Interoperability (plug-and-play) enables engineers to choose the fastest path to recovery in the event of a failure by using technology-neutral and vendor-neutral nodes. This minimizes down time and effectively makes the system more reliable.
4. Sustainability – An ESM facilitates the implementation of different types of electricity generation technologies, especially ones that use indigenous and potentially more sustainable resources.
5. Cost-Effectiveness – Interchangeability of devices and standard interfaces lowers procurement, integration, maintenance, and upgrade costs.

VII. References

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