ELECTRIC POWER
RESEARCH INSTITUTE

Concepts to Enable Advancement of Distributed Energy Resources

An EPRI White Paper on DER

February 2010

Acknowledgments

This report was prepared by

EPRI Power Delivery and Utilization

Principal Investigator
G. Horst

This report describes research sponsored by the Electric Power Research Institute (EPRI).

Input and ideation springboards for the concepts presented in this whitepaper were leveraged from many converstions, presentations, and products that implement various concepts relative to what has become known as the "smart grid". Inspiration for this whitepaper included a wide variety of organizations both within and outside of the energy industry. Although an attempt to cite these sources of input would be difficult, the author would like to thank the many persons and organizations who have contributed emerging products and ideas through various conferences and discussions that represent pieces of this emerging concept. The citations below are limited to those specifically referenced in this document.

Carlos Romero "*Virtual Power Plants: Making Distributed Energy Resources Actionable in Smart Grid Commercial Operations*" ElectricEnergy T&D Magazine | July-August 2009 Issue 4-Volume 13

OpenADR research has been carried out by the Demand Response Research Center (DRRC) which is managed by Lawrence Berkeley National Laboratory.

This publication is a corporate document that should be cited in the literature in the following manner:

Concepts to Enable Advancement of Distributed Energy Resources : White Paper on DER. EPRI, Palo Alto, CA : 2010. 1020432.

Abstract

A shift in approach from designing control systems to a focus on enabling technology utilizing smart grid communications holds a key to a larger door into the smart grid revolution. The expansion of grid technology allows us to consider a focus on *motivation in lieu of commands* and *information as an alternative to control*. This whitepaper offers an update to our traditional control-based thinking to present an approach that enables independent development of smart grid products. The proposed concept architecture can act to also simplify the prioritized action plans undertaken by various industry groups and initiatives.

Sophisticated solutions have been offered that utilize smart grid technology to take over some key aspects of device control. As an alternative, we need to give consideration to concepts that provide an elegant simplicity enabling us to work smarter at a fraction of the cost to accomplish the desired results. In the emerging smart grid system, there are key elements to provide "smartness" for the power grid that reside at the end nodes. The devices and systems at the end nodes can utilize information exchanges with a resource energy controller to modify energy consumption based on the information exchanged.

This paper will describe the functionality enabled by true smartness at the end nodes. This re-focused approach lets us not only address obsolescence issues, but also enable the continuous improvement and innovation upon which our economy depends. Replacement of the *command & control* approach with an *inform & motivate* approach allows the customer and the power grid to interoperate with full transparent, extensible, and scalable interoperability.

The concept discussed also opens a doorway enabling a device manufacturer to design their product or system to be qualified as a virtual end node that is able to participate in any larger smart grid entity above it without fear of obsolescence. This concept presents a simple but workable approach for management of onsite or remote resources of both a similar and non-similar nature to accelerate development of the overall smart grid as well as smart grid enabled products.

Contents

List of Figures

Executive Overview

When we discuss the concept of a smart grid we typically envision utilizing modern communication technology to control more products, devices, or systems in an effort to synchronize generation and demand. However there are caveats with an approach that could involve moving critical decision making about the operation of a device or a system to an off-premise third party. Along with becoming the surrogate control system, comes responsibility for product durability, safety, customer satisfaction, service and maintenance. The designers of customer products and systems spend significant resources to optimize the operation of their products via proprietary control designs. A few simple changes in the way the product or system is allowed to operate, done by an independent external control system, can negate the goals of the product design. It quickly becomes cumbersome to assume that the external control systems can not only become intelligent enough to accurately manage the third party devices but also keep up with innovative changes in the products at the end nodes of the grid.

This document presents a design concept for a simple but workable approach for management of onsite or remote resources of both a similar and non-similar nature in a device independent manner. This approach is intended for configuring, controlling, monitoring, and automating the response of distributed resources of any size or capacity. The concept presented allows many of the smart grid interfaces to become technology independent. Instead of focusing on specific hardware and systems, we focus on the energy. The paper discusses smart devices that let us focus on the energy of the resource rather than attempting to control the device itself. By focusing on the energy, we communicate our energy and grid needs and directives to all types of devices and systems in a technology independent manner.

This approach should enable device manufacturers to independently develop smart grid products that qualify as virtual end nodes. Products and systems will be able to participate in any larger smart grid entity without concerns of obsolescence and the impact of third party influences. Small devices should be able to participate alone or as part of a larger aggregate of resources. These truly "smart" elements of the grid simplify distributed energy resources and accelerate development of the smart grid enabled products we eagerly await.

Key Background Elements

Where are the points of control?

Developments in the smart grid arena have started to move some intelligence and decision making responsibility toward the load consumption end of the grid. In other cases the control of end use devices has been moved upstream. There are related benefits and concerns related to which systems architecture approach is utilized. These often relate to emerging requirements, such as user-configured preferences for end-use priorities, economics, and green attributes for electric supply. The bottom line is that the energy usage at the end of the line needs to become responsive to a broad range of coordination signals such as price notification, reliability issues, frequency management, voltage, etc. We need to be able to trigger a response in support of grid and market needs yet enable automatic consideration of changes in the environment. We don't want to forget to adequately enfold the considerations of the electricity consumer who is calling on the power for a specific purpose at a desired time. Having a level of interactions with the end nodes only seems natural since this is where the electricity consumer may be willing to adjust demand or inject reserve power.

The grid "end node"

For at least 20 years, there have been devices that could be referred to as smart grid components. Perhaps they are not end nodes by definition, but rather, by implementation. These components are devices that represent the load and consume energy from the power grid. Whether these are commercial devices, industrial devices or residential consumer products, we could refer to these as energy consumers of the grid system. For the purpose of discussion we will refer to these devices or systems as *Virtual End Nodes.*

Where the "smart" in smart grid comes into practice has become an emerging definition and provides a potential for misalignment. We have heard reference to items such as a "smart appliance". Once this definition is probed a bit deeper, we often determine this is simply a reference to the ability to tell the product to turn off or delay in lieu of removing the power source from the product by with a remote controlled switch. If a product simply turns

off when told to, the product is really not one we should refer to as "smart" because it would be simply implementing something similar to a forced hard on/off control. "Smart" needs to imply that the device/product itself is able to apply intelligence in the process of assisting the smart grid.

Several demand response pilots have been conducted where internal components such as heating elements or compressors are controlled outside of the appliance or device. In that approach, we have to assume the controlling entity possesses adequate knowledge of the internal operation of the product to control the load safely, accurately, and without risk of consumer objection. The device designers and manufactures would be handing off what could be critical operational control to a third party. It may be unrealistic to assume that the product manufacturers will relinquish this degree of control to an unknown external system in a mass deployment of their products. In this scenario, the external third party control could impact the satisfaction of the consumer regarding their product performance. In addition there is potential for adverse impact of safety, product durability, and premature product failure. Sooner or later we have to enroll the assistance of the device manufacturers to arrive at any finality and realize the approach.

In parallel to this thought, we may want to expand our definition of the end node of the grid since more systems are emerging that have the capability to inject excess power back into the grid. When defining a virtual end node, questions regarding the definition of the end node (device/product) should include:

- Can the end node be either a producer or consumer of energy or perhaps both as with the Plug-in Electric Vehicle (PEV)?
- Where might an "end node" reside? What defines an end node? Is it a single component, product/device, or a grouping of devices such as a building or community? If it's not the building, perhaps it is something that is part of the building such as a cooling unit. If we want to call the cooling unit a virtual end node, one could also present a similar argument that it's not the cooling unit, but rather, a component such as a compressor, fan, or motor. You could also reverse the argument and call an entire community or corporate campus a virtual end node.
- What must be known about the virtual end node in order to utilize it as an energy resource? Keep in mind that the control systems in the end node have been carefully designed to control each particular device or system components for the optimal benefit for which it was conceived. Will utilization of the end node as an energy resource parallel, duplicate, or infringe on the sensing or controls within the control system.
- How will issues be handled effectively? For example:
  - Impact on customer comfort
  - Customer acceptance (or rejection) of any changes in standard operation
  - Durability or premature failure of the products/devices attributable to the external control functions
  - Safety issues
  - Product warranty, service and maintenance issues and related cost allocation
  - Diagnosis of product or DER system failure

These questions serve as examples of the issues that come into play when external control is enabled. As newer devices continue to grow more sophisticated, considerations for controlling them as a load consuming node become more detailed making traditional external command and control approaches cumbersome, expensive, and risky.

In the pages that follow, we will discuss the advantanges of leaving specific end-node device details out of the definition of a virtual end node. If we properly define the qualifications of a virtual end node we can focus on the capabilities of each end node. We will learn that we only need to qualify a virtual end node by its smart characteristics without being concerned with its materials, or components. This can lead us to a more elegant approach to distributed energy resources.

Components of an Energy Resource

In a smart grid system, the next element below any given point of reference could be considered the customer of the grid relative to that point of reference. A substation is a customer of the transmission lines. A house is the customer of the circuit / transformer, and an appliance is a customer of the house or residential meter. The energy flows to the customer where it is utilized. For our discussion we call the next element below or beyond the current point of reference, a customer or an *end node* with respect to the point

of reference. If an end node has the ability to exchange electronic data with the element above it in the energy system, we have the basis for a smart system. We can start to look at how we would utilize the "smarts" in the end nodes to make the overall system smart and accelerate development of smart grid enabled products.

A grid "resource" defined

For the purpose of a discussion on distributed energy resources (DER), we need to define a "resource". In addition to the definition of a resource being a support or an aid, the definition in my dictionary goes on to define a resource as ***"having the ability to handle a situation in an effective manner"***. If we consider our focus on particular grid situations, then a resource would be the technology or system able to handle the situation effectively. In the definition of a resource, the "how" of the response is left out in lieu of a focus on being *effective*. In other words, the "resource" is not given a specific command to carry out. It is notified of a situation.

In order to handle a situation in an effective manner, some knowledge of the "situation" must be relayed to the "resource". A system that is focused on command and control does not necessarily relay knowledge of the situation since the commands invoke the "how" and fail to meet our definition of a resource. One could argue that a lack of a situational knowledge transfer disqualifies a device as being considered a resource.

Although traditional command and control approaches may be quite effective, we want to focus on the additional advantages of pushing smart grid intelligence out toward the end node resources. In previous generation direct load control programs there were valid reasons to select a particular target device to control. The device was selected because its electric load can be altered easily at the right time, for a duration needed, and at a cost that makes economic sense. Simple devices were selected because simple controls could be utilized.

Now we are ready consider the simplicity of being able to communicate the situation and letting the solutions come from a variety or combinations of resources and methods. As long as the responding resource is able to reliably deliver what is needed, we should not be concerned with exactly how that capability was realized and what devices or components were involved. We can relieve ourselves of the knowledge burden of having to understand the safe and reliable operation of a growing variety of participating end node power consuming devices and focus on the big picture of operating the smart grid.

Remember that our definition of a resource is now simplified to one that is able to receive the message and address the situation about which it has been informed. Utilizing its own "smart" discretion via engineered embedded intelligence, the end nodes will likely be able to produce a more effective response from a broader variety of systems and devices than any external access method of the traditional "command & control" methodology. In addition, we have enabled, rather than restricted, innovation. If a device or entity is able to receive, unpack, and respond to the situation identified via a smart grid message, it can be considered a DER. This simple definition is what qualifies a resource.

Grid Messaging

To trigger a response from a resource in support of a grid situation or optimization, messages describing the situation must be passed along to the resource. The resource will handle the situation based on knowledge of the current state of the device, its components, and the control system and, where appropriate, user preferences and the user interface. Since we are now leaving the "how" up to the discretion of the end node (which we referr to as a Virtual End Node or a "VEN"), some effort will need to go into determining the information that must be communicated.

In managing energy in a commercial building, why did we precool? In a water heater program, why did we disable the device from operating for a few hours? Why did we change the thermostat? Why did we call on the industrial contract to invoke the demand response? These "whys" contain some of the information that should flow through the smart grid and out to the intelligent VENs.

Assume the market wholesale price is headed up due to high demand and we want to shave or defer peak load. We should consider several messages that can relay this information through the grid. If any rate-payers are on a variable time-based rate or a program where they have agreed to incentives to shed load, the VENs can receive the dynamic rate information and handle the situation appropriately. If the DER is a water heater or a controller for a system of water heaters, it may respond to the price message by disabling

the units until a later time. If the DER is an interactive consumer device, it may utilize the user interface to alert the consumer. If, when, and how the consumer is notified or involved, may be left to the discretion of the VEN. In some implementations the consumer device may have already have been programmed to respond automatically without customer notification. Whether or not the customer is notified in any way is a decision best left up to the VEN device or system.

* This has been a key point of clarification serving as a confirmation of understanding and acceptance of the smart DER devices. When an interested party states that a load shift event and a brief grid reliability event don't need separate messages because **"in both cases the load gets turned off anyway"**, we need to back up and clarify the differences.

If the event is a reliability event, then a brief emergency load shed message to the VEN can be utilized. This serves as an example of where the meaning of the situation is required to enable the decision making at the VEN. In traditional direct load control systems, devices may be deactivated in the same way for a number of reasons including reliability, price, peak shifting etc. However in the smart grid paradigm, there is much to gain with a descriptive message. If the event is a grid reliability event of a brief nature, smart devices that are not a candidate for a load reduction of a longer duration may be willing to contribute to the solution. This enables huge potential benefits. The device may be performing a function during which, although a delay of several hours may not be feasible or acceptable, a short delay could be considered reasonable and enable the addition of a large amount of reliability resources. *This is where we start to see the advantage of a message that relays the situation rather than just the requested response.

To enable additional types of devices in a smart grid system, we need to rely on the device to know if it can respond. It may not respond because a short-cycle of the device would have negative consequences on the equipment. The device could be in a critical process where any interruption is not acceptable. Note that this *is a real-time decision* that may not get the same response from the same device 100% of the time. But we have to consider the fact that appropriate communications to a smart device enables the device to participate. Otherwise this device could not participate if the unacceptable consequences may occur only a very small percentage of the time. Leaving this decision at the VEN leaves both safety and process success issues in the hands of the device design relieving the utility or grid of this responsibility and potential for significant liability.

In the case of a device that interacts with a consumer throughout the customer utilization process, a long delay may never be acceptable. However, if the intelligent electronic control knows the duration of a reliability event will be brief, a response may be acceptable. Even a simple consumer-interactive device, such as a stove or hair dryer, could pause the heating element for 30 seconds while the fan continues. It is important to realize that if any undesirable possibilities exist in a very small percentage of the potential events, then traditional direct load control would not have been allowed on this particular device. But intelligent devices may be able to contribute in a large number of events simply because we communicate a more descriptive message and let the devices make appropriate decisions.

Discovery

Modern communication protocols provide an electronic mechanism referred to as "discovery". In the basic sense, the originator of the messages or control signals must know that another device is out there that may react. When I plug in or power up a peripheral device on my computer, the device is "discovered" and the computer usually knows the capability, capacity, type and so forth. Likewise in the smart grid, the existence of a DER system or device may need to become known to the higher level grid entity.

In the simplest form, devices are informed of the situation in a one-way open-loop manner and verification comes from meter data. In the concept discussed in this paper these simple devices can be accommodated in the smart grid. However, we also have to consider that we may want to know specific response capabilities. In a more advanced two-way closed loop system, we are seeking device capability and characteristics that were used to select appropriate devices in demand response programs. Perhaps these may include identifying itself by:

- Producer / Consumer (e.g. load or generation)
- Response times
- #Watts

- Persistent or Variable resource and their ramp rate
- Operational "states" of the device (e.g. off / on / process / static / interactive)
- Duration of resource response
- Ability to report it's status dynamically
- Category such as renewable
- etc . . .

Carlos Romero pointed out in a recent article in *ElectricEnergy T & D* that if we focus on the characteristics required to inform and manage the resource, there is a great opportunity for efficient aggregation of DER. The resources may report data in terms of what we are accustomed to managing and look more like a virtual power plant. Going a small step further, reporting what the resource is capable of, in theoretical maximums, is of less importance than what it can provide right now or in a future time segmented schedule. This allows the aggregated resources to be managed in a way that looks like a single larger resource. For example, the details of what specific AC units can respond and for how long becomes something that is managed by the aggregation process to make many end points appear as a single resource that is presented in terms and parameters to which we are accustomed.

The Dynamic Nature

We will need to assume that certain capabilities will change dynamically. Perhaps we can refer to these as the dynamic operational parameters. A bare (non battery backed) PV system would report that it is a variable resource. This would have to be considered by the system controlling this VEN and be reflected in the ramp rate reported in the discovery process. Another PV system may contain batteries to stabilize PV output and cover the cloud transients. If so, we should NOT need to know the system contains a battery. Since the support offered by the storage device invisibly supports the device characteristics, we can consider battery data as unnecessary information. Batteries may be contributing to a more favorable reported ramp rate that ensures that this variable resource will not drop off quickly and unpredictably. This information is reported in the dynamic and discovery parameters. The battery-backed consumer-owned PV system will reflect the fact that it guarantees it will continue supplying power when the clouds pass over and is able to indicate a given minimum period of time that its electricity output will remain stable.

> "any new product can be easily introduced into the market with smart grid capability if it can appropriately define its capability using a standard set of **discovery parameters** and **dynamic operational parameters**"

The battery may also be the device that enables the PV system to report that it can help shift peak or inject power during system peaks. In this case the PV is providing a renewable way to charge the battery as opposed to the battery supporting and stabilizing the PV output. Either way you look at it, with this item taken care of by reporting capability instead of battery information, we need not care whether that capability is supported by a battery, the type of battery, or if it is supported by a flywheel. In fact we could change the backup source from battery to compressed air storage without changing anything but the dynamic operational parameters that are updated dynamically in real time.

A DER end node, by defining its ability to respond, becomes an available resource controllable by the next higher level entity. Although the concept should have a method of validation or certification, any new product can be easily introduced into the market with smart grid capability if it can appropriately define its capability using a standard set of *discovery parameters* and *dynamic operational parameters*. The smart grid systems do not need to know any details about the inner workings (the "how") of the product. In this way, an open market of new product design, innovation, and continuous product improvement is enabled.

The Systems View

We have discussed how we can logically separate the physical devices/resources from their respective characteristics. This concept now makes the systems view become manageable because the utility entity can identify the criteria needed from a DER device or system in terms aligned with capability rather than tied to physical systems. An important added benefit is that the utility need not necessarily own or install end node systems or devices to benefit from the resources. The main concern is assurance that the DER can deliver the capabilities it claims.

Under this architecture, the logic driving the priorities can still remain at the utility entity. The resources can still be called on for any of a number of reasons. These could include capacity, reliability, financial, emissions or any other future goal of the system. The business drivers remain in the logic of the utility entity that communicates the grid status and needs down to the end nodes.

As the number of DER devices and systems grows, the mix of the capabilities offered by individual resources may vary widely. Managing details of a plurality of dissimilar resources may not be a reasonable task for a utility to manage. There may be little, if any, benefits of retaining that level of control as long as similar benefits can be gained from a properly architected DER system that is owned, installed, and operated by customers and consumers.

Defining Distributed Energy Resources (DER)

Note that our definition of DER has been broad. This is a systems design advantage that becomes apparent as we start to explore the larger picture. The utility entity should not be in a role of operating buildings or becoming the surrogate control system for a product or device since that would demand responsibilities for successful operation, maintenance, safety, consumer satisfaction, and even blame for failures. It would be irrational to think that the utility industry can learn enough about each of the millions of existing products to take on the task of operating customer-owned end loads. The requirement of learning enough about forthcoming new products would consume an unjustifiable amount of resources. What we desire is a reasonable amount of control over an aggregated amount of end-use loads and distributed generation.

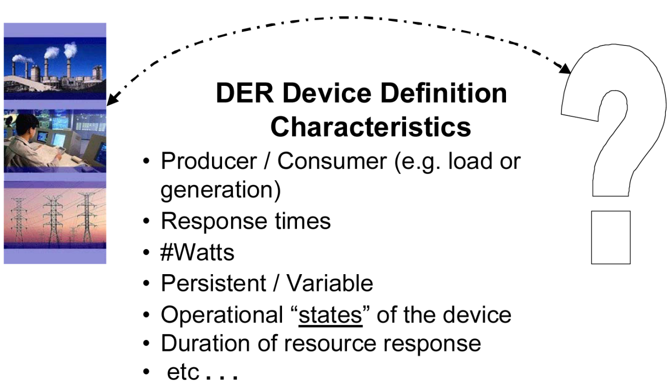


Figure 1
Device Characteristics

If I want to get from point A to point B, I don't hail a cab and ask to control the break pedal. Likewise I don't get on an airplane and insist that I control the throttle. The designers of the transportations systems know how their systems work and have designed them to meet my needs. The utility entity has requirements that can be stated in a format that makes the "how to get there" the responsibility of the systems designers who know how to operate their systems effectively to meet the needs of the utility industry.

In the past, instead of teaching those best able to affect the results by understanding what new capabilities are needed in their products, we have wanted to take hold of their controls to steer and brake their products ourselves. This has put limits on expanding these programs. Once we see how we can avoid the issues related to that approach, we will be able to economically and securely expand benefits to the next level. We need to simply describe our needs in these terms (see examples in Figure 1) to the designers of a system, building, or device who can design-in the best response. These future "smart" devices and systems will then be able to tell us if, when, and how long they can support a response. But we won't need to control their throttle or brake pedal.

An immediate advantage to this approach allows us to enfold process-oriented devices. These devices or systems are difficult to interrupt with out hindering, rendering the process ineffective, or even damaging other products or equipment. But if these devices can either report their availability dynamically, or identify themselves as being able to receive and respond to the conditions identified by specific types of smart grid messages, we can impact the end use loads without concerns for issues such as process success, status, and safety.

The REC-VEN Concept

The architecture we have been discussing refers to smart grid automation logic that can be designed to utilize the DER in accordance with the needs of the grid and individual utility entities. The utility or grid system needs to know what resources it has available. To include the resources in planning as well as operations, we want to be able to sum up groups of resources. At the grid or utility level we don't want to be burdened with managing the resource minutiae. Perhaps some other mechanism can make this easier to manage at the grid level. For example, if there are two

systems that can each provide a 1 megawatt resource for one hour each, some aggregator should be able to dynamically report this availability up to the grid as 2 megawatts of available resources for one hour. Alternatively this could be reported as 1 megawatt available for two hours. It would be responsibility of the aggregator to manage the resources down-stream to provide the requested response.

We will refer to this logical function as the *Resource Energy Controller (REC)*. At the REC we can make the determination of what resources to report as being available. The REC would also determine when and why to send specific grid messages to the resources it manages. Note that this REC concept can reappear at various levels of the architecture.

Previously we discussed our definition of a grid resource as one able to receive and respond to messages. We refer to this device or system that can receive and respond to messages and also affect end use load or energy supply as a *Virtual End Node (VEN)*. This term becomes a generic reference to what can logically be considered as the load device or entity able to define itself and meet at least the minimum qualification of being able to respond to certain smart-grid messages. In addition a VEN may also be able to inject excess power into the grid that may be sourced from devices such as PEV, battery, PV/solar, flywheel, or generator.

A VEN may define it's capabilities in various ways of interest to a REC. In one case a VEN may indicate ability to curtail a certain amount of load very quickly (Ancillary services demand response or what OpenADR terms "Fast Demand Response") for a specified maximum duration. It could also indicate ability to curtail a specified amount of electric load for a number of hours in response to a pricing or peak shifting message. The REC can utilize a number of VEN resources to accomplish the task based on the current needs of the utility entity. The REC responds without needing knowledge of the physical or functional makeup of any class of VEN devices. More simply stated, all VENs can receive and respond to a message selected from the same message set. A key part of this concept is that the REC knows what each VEN has to offer in terms of a dynamic response capability definition.

A VEN could define itself as a consumer or a producer of energy. In the case of a plug-in electric vehicle or a local energy storage system, the same VEN could be both a producer and a consumer with the ability to dynamically change. It would then report its

Figure 2
Terms: REC & VEN

consumer/producer status upstream to the REC. In the case of a battery, there are times when it could offer its services to the REC as both a consumer and a producer of energy. Once the REC calls on it as an energy producer, its reported status would change dynamically to indicate current status.

The function of a REC is defined in terms of a distributed energy resource. Its capabilities can change in real time as it tracks the capabilities its VENs are currently offering. On the other hand, the REC can be designed to manage its resources provided by the VENs in such a way that it could be considered as a fixed capacity resource. This enables the more futuristic concept of a virtual power plant (VPP). This level of logic can be encapsulated in the REC so it manages a variety of VEN resources in such a way that it has a continuous capacity. This would be the case if a VEN controlled by the REC was a device capable of producing continuous power output. This could also be accomplished by managing a number of VENs in a rotational algorithm giving the appearance up-stream that this REC is a continuous resource.

The capabilities of a REC can be called upon to meet the operational requirements of the grid or individual utilities. Information regarding what type of product is represented by the VEN (AC, Water Heater, Building, C & I load, battery, PEV etc) is no longer needed to control resources since all resources report their capability and availability in a uniform manner. Consider the example of an air conditioner. We don't need to know it's an AC unit. We only care that it can deliver the energy reduction as advertized in the discovery and reporting mechanism of the VEN. It should become apparent by now that the difference between one device and another is its energy capabilities and not the type of device. The DER capabilities being controlled by a single REC or VEN is theoretically unlimited.

The Recursive Nature of the Architecture

As noted and illustrated in Figure 3, a VEN is only aware of one upstream REC. Also notice that a VEN may also function as a REC aggregating additional resources below it. A REC may control any number of VENs residing downstream. A key point to understand is that a REC reports up-stream in simple terms what capabilities it can provide. The REC does not control any systems. It communicates down-stream to a VEN (or multiple VENs) in standard terms based on resource capabilities. The VEN is where the control of any systems and hardware takes place. In database terms, the relationship of REC to VEN is one-to-many.

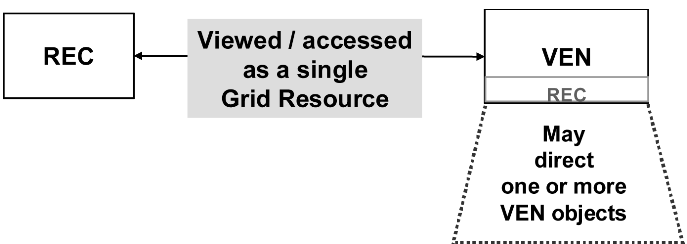


Figure 3
VEN Single point-of-focus

The VENs that are at the same level (controlled by the same REC) need not be similar since a VEN specification will present capabilities in a generic form. One could argue the advantages or disadvantages of having similar or dissimilar objects controlled by one VEN. In this architecture, we consider this as an implementation decision. As illustrated in Figure 4, the only requirement is that the VEN accurately reports its capability and dynamic operational parameters reliably. Where the VEN secures its resources is abstracted and not visible by any upstream RECs. Figure 5 and Figure 6 further illustrate the recursive nature of the configuration abstractions.

Measurement and Verification

The program designs, relative to the smart grid, seem to have several trains of thought. Verification is needed or required for some programs while others advocate that if proper messaging and response exists, it should be measurable at the meter. In the REC/VEN concept we consider that the current status is always reported up stream both in capability and response. This provides the closed-loop verification up stream. In addition, the grid system should be able to verify the response via other traditional methods

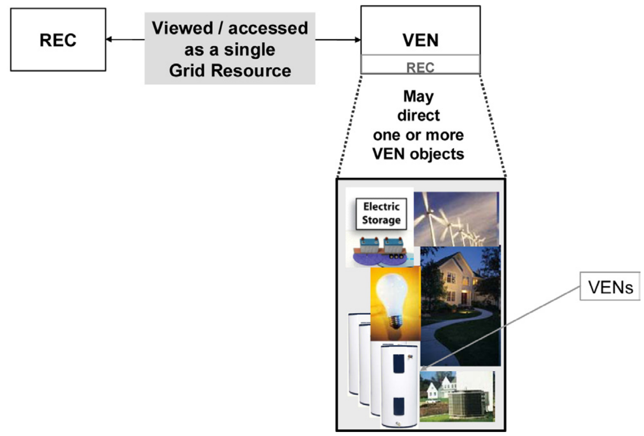


Figure 4
Recursive Master-Slave

A VEN is associated with a single REC. Whether a VEN's upstream REC is unique or a part of an upstream VEN would not be apparent to the VENs below. Reliability is the key. If a VEN reports to the REC that is can curtail a megawatt of power, this must be a reliable promise and the source is not the issue.

If a VEN is a power producer, it must be reliable and could come from various sources including battery, solar, or generators. It is reasonable to assume that a single VEN identified as having ability to provide energy, may have a variety of technologies to call upon to provide the capabilities it offers to the grid.

to double-check what the REC is reporting as there is always a desire for checks & balances. Since the REC may be aggregating capabilities it controls and reports, this aggregated amount should be easier to check and verify.

Down at the end nodes the VEN has the capability, although not obligatory, to report data to the customer. At the VEN, response could be tracked in both real-time and over time for historic display and access by the customer. In this concept we leave this decision and the creative way it can be tracked and displayed at the discretion of the innovative developers of the smart grid products and VEN devices.

The Flow of Control

A VEN is free to utilize any of the resources it can control. These could be hardware components, other devices, or identities that qualify as a VEN in their own right. They could also be resources proprietary to this particular fully qualified VEN. In reviewing this concept, it should start to become obvious that a single device (entity or appliance) controlling it's internal load-consuming resources can qualify as a VEN if it has the communication interface. In another case a device/product could be part of a VEN of an upstream device that has proprietary visibility and control of its components or operations although the device itself would not qualify as a VEN on its own.

The two basic elements, the REC and the VEN, make the architecture retain its elegant simplicity and yet remain completely flexible in the potential configurations. The fact that a VEN can act as a REC and control other VENs provides a recursive element that simplifies the overall concept and greatly empowers the possibilities. The box diagram in Figure 5 shows several optional configurations of the concept. Note that these configurations would all appear identical from the grid perspective as the configuration below the REC is abstracted at the lower level. The diagram in Figure 6 further illustrates the concept.

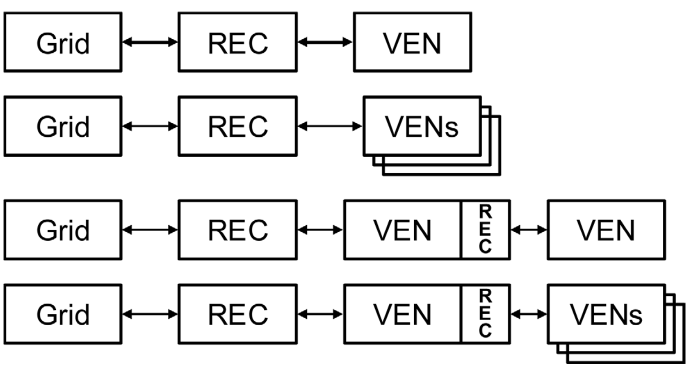


Figure 5
Valid Configurations

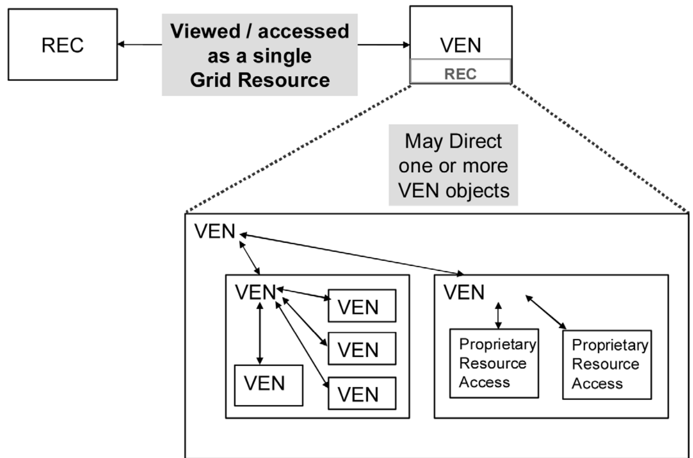


Figure 6
Nesting and Hiding

Benefits Exploration

In reviewing the principles of this concept architecture, there are a number of key understandings and benefits to consider.

1. Measurement and verification is provided at both ends. The REC is able to provide this information upstream as needed to support the various program designs. At the lower levels the VENs have the option of reporting to the end customer the grid information received, the responses invoked, and the benefits achieved.
2. The REC does not need internal knowledge of the VEN devices. It only requires knowledge of the capabilities of a VEN. These represent commitments by the REC to deliver the desired response to the utility entity up-stream.
3. A REC directs energy resources at the end nodes via one or more VENs.
4. A VEN must be able to receive, unpack, and respond appropriately to the electronic smart grid messages.
5. A VEN can also act as a REC directing the response of subordinate VENs.
6. Independent product engineers designing end load consuming devices, building controls, and systems can design their products to qualify as a VEN and maximize the response to meet grid optimization needs. Additional efficiency is gained by letting the product manufacturer optimize the product response and compete on the effectiveness of their response.

7. New smart grid enabled products/devices and systems are added seamlessly. Any device or entity designed to receive, unpack, and respond appropriately could meet the requirements of a VEN. Sophisticated process-oriented devices can be included in the smart grid system by utilizing internal knowledge of their product components and current operational state to dynamically report available capacity and respond to situational messages received.

8. Enables independent development of smart grid ready products and services. The control systems of the utility entity do not need knowledge, responsibility, or concern about internal components of a VEN device. When an entirely new device is invented, nothing upstream needs to learn of it inner workings before it can participate in the smart grid. Totally new classes of products can be *included immediately* in existing smart grid programs.

9. This concept will result in a fully scalable system. There are no minimums or maximums in the amount of energy that can be involved at the VEN. Once a device, building, or system has been implemented as a VEN it can fit into the structure at a number of levels and may add new equipment at any time.

10. This architecture removes the concern about obsolescence. A first-to-market device can participate as a VEN by itself. For example, a dishwasher could take commands directly from the grid or smart meter if it contains the VEN capability in the control system. A middleware entity, such as a home area network (HAN), may be added at a later time. This HAN now becomes the REC for the dishwasher. Now the dishwasher is a part of that system taking it's directions from the HAN. This avoids obsolescence of the utility/smart-grid messages and back-office IT design as well as the products themselves.

11. Reduces the cost of smart grid infrastructure (see Figure 7). Smart grid development cost is absorbed in the product design. We successfully retain the competitive nature that enables our society to thrive. Manufacturers compete to have grid-ready products that outperform their competitors. Safety standards and customer satisfaction remains in the product marketplace and is not burdened by utility program differences.

12. The business and reliability decisions regarding when and why to call on the energy resources remain at the utility entity.

13. Regional differences do not impact product design.

14. Opens up an "innovators sandbox" to explore the best smart grid response and most effective communication of smart grid information to the customer (see Figure 7). Consumer device manufacturers can opt to display energy information for their customer and may compete for the most effective consumer interface technology in their products.

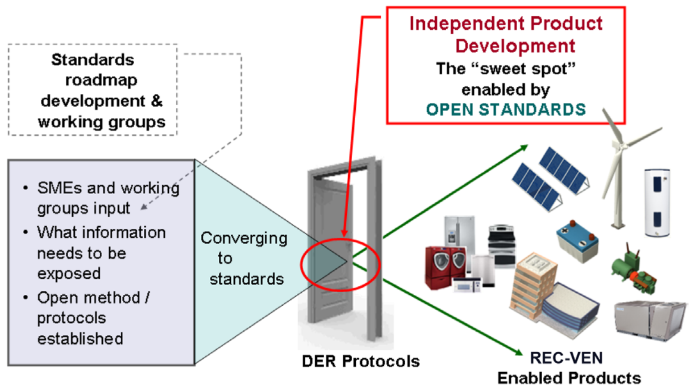


Figure 7
Door to Independent Smart-Grid product development

Summary

The issue of where the control resides is a reoccurring theme in the development of communicating devices. Much focus has been directed at what device we can add to the list of those controlled by the electric utility. With the approach presented, we let a "smart device" be truly smart and take ownership of additional grid responsibility. Rather than approaching on a component level we can assume a more encompassing perspective. Instead of asking what specific loads are being addressed, we can look at the various specifications and consider what load characteristic is being requested by the load manager and offered by the endpoint node in the system. We can remove the focus on specific devices and ask "*What situation are we seeking to manage?*"

Rather than adding communications to dumb devices and calling them "smart", this concept will also upgrade the enabling architecture. We will enable variable loads such as process-oriented

devices and variable consumer-owned renewable generation. We can *think about load and generation situational characteristics* instead of an AC program, water heater program, or commercial backup generator access etc. The parameters of a resource now describe its capability rather than the product hardware. A water heater is no longer defined by name as a "water heater". Rather it is an electricity consumer that consumes 4500 watts, can shed load within a few cycles, remain off for several hours, and could also be safely called upon to consume load if needed. The fact that it happens to be a water heater now becomes of no significance.

The REC-VEN concept opens the independent product development doorway where a device manufacturer can develop the interface that qualifies their product as a VEN. This enables it to participate in any larger smart grid entity above it without fear of obsolescence. This approach also avoids the concern over a small device lacking sufficient load or generation resources to be of interest since it can participate alone or as part of a higher level REC or VEN to provide a larger aggregate of resources.

Appendix A – REC / VEN Functions Summary

REC Summary

- The Resource Energy Controller (REC) is responsible to know both the capabilities and current availability of the resources in its domain.
- The REC manages a variety of resource types presenting their availability to the grid in a standard form. This form could appear to the grid as a virtual power plant in most respects. It could also appear as a curtailable load depending on the VEN resources below it in the domain hierarchy.
- The REC serves as an aggregator for DER functions. The REC applies logic in an automated manner to support the grid or utility entity via a standardized interface. The REC interface makes all resources appear similar to the grid.
- The REC may have the role of managing variable renewables, such as wind & solar and including consumer products that may vary in their demand response capability. The REC can manage one or more resources to be able to present the aggregated capability to the grid as a single reliable resource. For example, a REC may manage a large group of devices of a variable nature and present them to the grid as a single demand response resource. The REC reports what is available now and the duration of time the aggregated resource is available. Assume the REC has 12 megawatts of total demand response available (as reported by the VENs in its domain). If there are no time restrictions on the resources (VENs), the REC may offer these to the grid as 2 mW available for 4 hours. The REC can deliver this based on any combination and utilization of resources and components. During the 4 hour duration, the REC may manage the available resources in a round-robin fashion to sustain the resource for 4 hours even though any single resource can offer only 30 minutes. In another scenario the REC may be able to offer the resources as reliability resources, such as spinning reserves.
- The REC communicates with various resources that have each been qualified as a VEN. Via the standard VEN interface, the REC can perform the functionality needed with out unnecessary details about what is in the domain of a VEN.

VEN Summary

- The Virtual End Node (VEN) provides a standard way for any device or groups of devices to be linked into a larger domain.
- The VEN is presented up-stream in terms of its capability. This removes the need for an up-stream domain controller (the REC) to have detailed knowledge of the specific device and components.
- A VEN can be a consumer (end load), producer (distributed generation such as PV or Solar), or both (such as PEV, battery, or flywheel)
- Any end node product, new or existing, should be able to either qualify as a VEN or participate in the operation of a VEN.
- A VEN could control a device or even a group of devices in proprietary manner as long as the VEN correctly presents itself to the REC up-stream.
- The VEN must reliably report its capability dynamically. If a VEN reports that it can curtail a kW for the next hour, this must be a reliable offering. The VEN can function in a manner

similar to a REC. However, a VEN only reports up-stream to a single REC and not directly to the grid. This allows the REC to perform aggregation of multiple VENs in a way that meets the grid situational needs that also change dynamically.

- Examples of a VEN could include anything from a building or a community down to an individual appliance device.

Appendix B – Basic REC-VEN Operations

Pseudo Use Case

1. Descriptions of Function

This function utilizes a Resource Energy Controller to provide services of Virtual End Nodes to the utility entity.

Function Name

REC-VEN

Function ID

REC-VEN

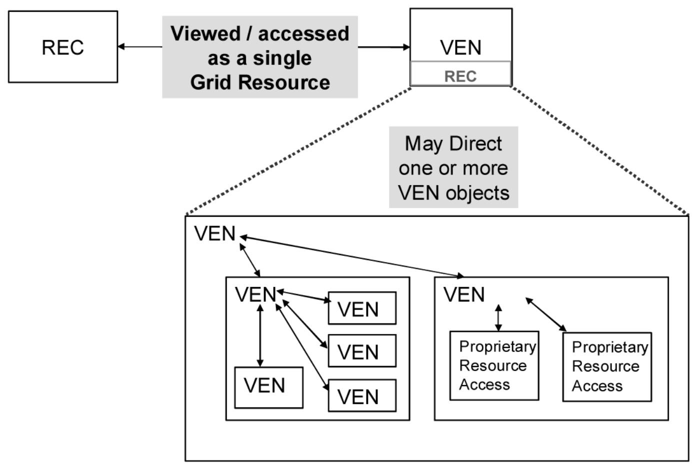
Brief Description

In recent smart pilots and proposals, sophisticated solutions have been offered that utilize smart grid technology to take over some key aspects of device control. To accomplish this, sensors were added to customer-owned devices. The live sensor data returned to the utility system was utilized to apply some business and technical logic, then return control signals to specific device components.

As an alternative, we need to give consideration to concepts that provide an elegant simplicity enabling us to work smarter at a fraction of the cost to accomplish the desired results. In the emerging smart grid system, some of the key elements to provide "smartness" for the customer and the power grid are at the end nodes of the grid. An end node that is able to utilize information exchanges with a resource energy controller (REC) is referred to as a virtual end node (VEN). Properly understanding the use of the VEN and the REC allow the customer and the power grid to interoperate with fully transparent, extensible, and scalable interoperability. This use case describes functionality to enable dissimilar grid devices to interact and represent distributed energy resources (DER) in a common manner.

Narrative

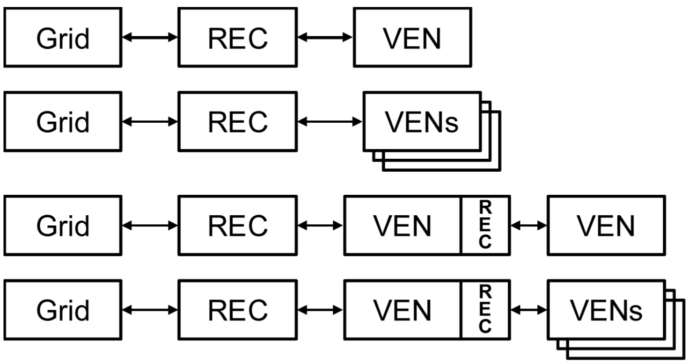
This use case describes a simple and workable approach for management of onsite or remote resources of both a similar and non-similar nature. This approach is workable for configuring, controlling, monitoring, and automating the response of distributed resources of any size or capacity. This architecture can include a broad range of coordination signals such as price, notification, control, frequency, voltage, etc. supporting customer, grid, and market needs.



In the emerging smart grid system, several key elements that will provide "smartness" for the customer and the power grid are at the virtual end node (VEN) utilizing information exchanges with a resource energy controller (REC). The VEN and REC, working together, will make it simpler for the customer to effectively use energy resources, both energy consuming and energy producing, to provide a reliable and measurable resource to the power grid.

Utilizing only a specification for the VEN and the REC we can allow the customer and the power grid to interoperate with full transparent, extensible, and scalable interoperability. The VEN and the REC are truly "smart" elements of the grid, and simplify the grid controls and accelerate development of the overall smart grid as well as the smart grid enabled products.

A VEN can be defined in basic terms as the responsible system or entity controlling an energy resource. In some cases, this could be thought of as being either the control system or a system that has visibility and appropriate communications with the system or individual device. A communicating smart appliance could be a VEN, as could a building energy management system if it has adequate interfaces to affect energy changes in the building systems. The VEN has full understanding of the resource capabilities at any given moment and can both invoke the resources as well as report status, availability, and any other necessary information to a controlling entity up-stream.



The up-stream entity, the REC, has an interface that receives information from the grid regarding status, events, optimization, real-time grid status, and pricing. The REC is the point of entry from the grid or utility operation viewpoint. It can report current resource availability of the VENs down-stream that are taking directives from the REC. The REC communicates the appropriate information to the VENs to carry out the correct actions to meet the needs of the smart grid. In effect, the REC serves as a point of aggregation for all the VEN resources it controls.

Any product, device, building, or entity can qualify as a VEN with the same standard interface as long as it has ability to provide or control energy. This enables the smart grid with absolute minimal cost and effort without fear of obsolescence. Benefits of this system architecture include:

- New products, devices, and systems are added seamlessly.
- Enables independent development of smart grid ready products and services.
- The smart grid becomes a fully scalable system.
- Business decisions regarding when and why to call on the DER remain at the utility/grid entity.
- We open up an "innovators sandbox" where optimal smart grid response and customer interfaces can be competitively explored, marketed, and added to the grid independently.

Actor (Stakeholder) Roles

Grouping (Community) ,		Group Description
Actor Name	**Actor Type (person, organization, device, system, or subsystem)**	**Actor Description**
Grid	Utility Entity	The "grid", as referenced in this use case, could be a utility, RTO/ISO, or even a control system in a community or substation.
REC	System	Resource Energy Controller – a type of server that has the role of aggregating information and capabilities of distributed energy resources. The REC is able to communicate with both the Grid and the VEN devices or systems in its domain.
VEN	System	Virtual End Node – a smart grid system or component that may be either a producer or consumer of energy. The VEN is able to communicate (2-way) with a single REC receiving and transmitting smart grid messages that relay grid situations, conditions, or events. The VEN has operational control of a set of resources and/or processes and is able to control the output or demand of these resources in affect their generation or utilization of electrical energy intelligently in response to an understood set of smart grid messages.
Customer	Persons / Industry / Systems	Consumers of the electricity

Information exchanged

Information Object Name	Information Object Description
Resources available	Current dynamic resource available updated in real-time
Call for resources	Activation of distributed energy resources via smart grid messages

Activities/Services

Activity/Service Name	Activities/Services Provided
Aggregated DER	Provides central point of aggregation for a bulk of Distributed Energy Resources

Contracts/Regulations

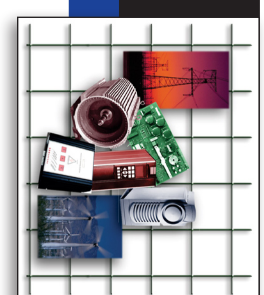
Contract/Regulation	Impact of Contract/Regulation on Function
Customer response agreement and reimbursement	A utility entity could call on DER to support any number of goals and programs. While these are an important aspect, due to the broad nature of capabilities offered by and Resource Energy Controller (REC) the contractual and regulatory issues are beyond the scope of documentation for this particular use case.

2. Step by Step Analysis of Function

Steps to implement function – Grid Calls on resources via a Resource Energy Controller

Preconditions and Assumptions.

Actor/System/Information/Contract	Preconditions or Assumptions
Grid – REC	Communication system (two way) exists between Grid and REC
REC – VEN	Communication exists between REC and VEN. This may or may not be the same communication technology as the Grid-REC communication. When a REC communicates with more than one VEN, it is not required to have the same communication system for all the VENs in its domain. Likewise, where a VEN also serves as a REC in controlling other VENs in its domain, there is not a requirement that the communications systems be similar. The way a VEN controls its domain, could be via proprietary technology.
VEN responses are reliable	The response of the VENs is reliable and may be certifiable should a certification process be developed. For VENs with process-oriented devices in its domain, the response is obviously conditional and not guaranteed. It is the responsibility of the REC to have established the statistical reliability from the variable resources.



Steps – Grid Calls on resources via a Resource Energy Controller

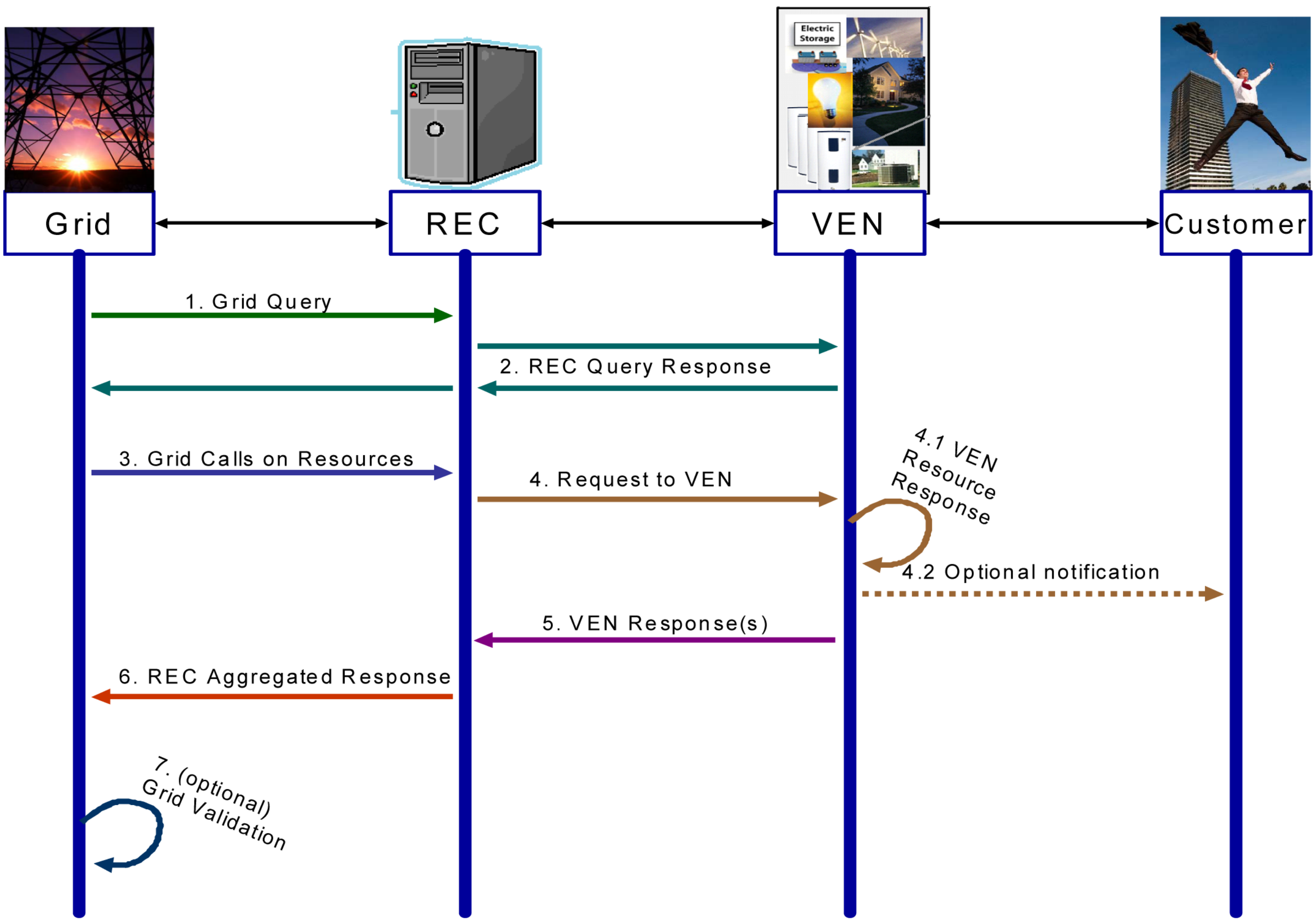
#	Event	Primary Actor	Name of Process/ Activity	Description of Process/Activity	Information Producer	Information Receiver	Name of Info Exchanged	Additional Notes	IECSA Environment
#	*Triggering event? Identify the name of the event.*[1]	*What other actors are primarily responsible for the Process/ Activity? Actors are defined in section0.*	*Label that would appear in a process diagram. Use action verbs when naming activity.*	*Describe the actions that take place in active and present tense. The step should be a descriptive noun/verb phrase that portrays an outline summary of the step. "If …Then…Else" scenarios can be captured as multiple Actions or as separate steps.*	*What other actors are primarily responsible for Producing the information? Actors are defined in section0.*	*What other actors are primarily responsible for Receiving the information? Actors are defined in section0. (Note – May leave blank if same as Primary Actor)*	*Name of the information object. Information objects are defined in section 0*	*Elaborate architectural issues using attached spreadsheet. Use this column to elaborate details that aren't captured in the spreadsheet.*	*Reference the applicable IECSA Environment containing this data exchange. Only one environment per step.*
1	Query received from Grid	Received by REC	Grid Query	Grid system needs to know what resources are available.	Grid	REC			
2	REC responds	REC	REC Query Response	REC summarizes information it continuously monitors from the VEN (or VENs) it directs.	REC using info tracked from VEN or VENs	Grid	Resources Available	REC dynamically tracks information regarding resource availability, amounts, durations, capacity etc.	
3	Grid calls on REC resources	REC & VENs	Grid calls on Resources	REC receives request from Grid and determines which resources under it's control will be utilized	Grid	REC	Call for resources and situational data	REC receives the resource request which must include the situational data to relay on to the VENs	
4	REC calls on VENs	REC & VEN	Request to VEN	VEN reacts as appropriate	Customers	VEN	Grid situational data	REC may call on all, some, or invoke a roaming response from resources if there is a need to sustain the response over a longer period of time.	
4.1		VEN resources	VEN Resource response	VEN calls on its resources. These may be either directly controlled by the VEN or at other VENs under its control	VEN and, optionally, downstream VENs	VEN	Commands / control and situational data	A VEN either controls resources or passes data on to lower VENs in the hierarchy	
4.2		Customers	Customers informed (optional)	At the option of the VEN, customers may be informed of the Grid request	VEN	Customer	Situational and proprietary operational data relative to the particular device.	The VEN may or may not involve the consumer directly at the option of the VEN device/system design.	
5	VENs respond	VENs	VEN response	VENs verify that request was received and may respond by reporting actions taken and updated status information.	VEN	REC	Verify actions	VEN will also need to update dynamic operational parameters	
6	REC response	REC	REC aggregated response	REC reports aggregated response information to Grid	REC	Grid	Response Verification	The REC updates dynamic operational parameters	
7	Grid	Grid	Grid validation	(optional) Grid observes / validates response via other traditional mechanisms					

[1] Note – A triggering event is not necessary if the completion of the prior step – leads to the transition of the following step.

Post-conditions and Significant Results

Actor/Activity	Post-conditions Description and Results
REC persistent status update	REC must maintain data regarding the availability of the resource it controls at all times. After this sequence has been invoked, the REC data should be updated. Note however, that updated REC data should be a part of normal operations for a REC and may not necessarily require special processing.
Grid status	The Grid should maintain the status of the REC and any temporary restraints should be eventually lifted. In other words, any call to a REC to limit or call on temporary resources (Demand Response for example) must be matched with an eventual message to the REC to clear the limitations.
REC fail-safe	The REC may implement (recommended) a failsafe timer that will automatically clear any temporary resources or restrictions that may be left active due to either a loss of communication or failure of the Grid system status tracking responsibility.
REC status – restriction reporting	The REC must include any restrictions currently in effect to the Grid. (These restrictions are assumed to have originated from a previous message from the Grid.)

Diagram



1020432 February 2010

Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com