Microgrids are changing the fundamental way rural electricity is produced, delivered and consumed.

The first part of this session will explain system options and different scales of microgrids.

The second part of the session will present a case study of the innovative Earth Spark microgrid in Haiti. Located in Les Anglais, this solar diesel hybrid microgrid provides power for 440 customers utilizing smart meters and a prepayment system. This session will focus on the lessons learned and best practices in developing and operating a successful community-based microgrid.
Solar integrators will play an important role in the evolution of the 21st-century smart electric grid via the deployment of utility-interactive solar-plus-storage microgrids.
Technology is fundamentally changing the way electricity is produced, delivered and consumed. The electric grid of the future will inevitably be more decentralized, interconnected and resilient than it is today. Arguably, nothing represents this trend better than microgrids, which operate in parallel with the local utility grid and have the potential to benefit a wide cross section of stakeholders. Utility-interactive microgrids can benefit consumers and facility owners through lower bills, improved power quality and increased reliability. They can also serve as controllable grid resources for utility operators, which is a value proposition with broad societal benefits.

In this article, we briefly explore different microgrid definitions and applications. We then focus specifically on distributed grid-interactive solar-plus-storage microgrids, as these are most relevant to solar developers, engineers and integrators. We explore the pros and cons of different solar microgrid configurations. We consider some of the system integration challenges associated with designing and installing solar microgrids. Lastly, we provide practical insight about managing customer expectations with regard to system capabilities and economic performance.

What Is a Microgrid?

Microgrids are a key pillar of the 21st-century electric grid envisioned by the Smart Grid Research and Development (Smart Grid R&D) Program, which the Office of Electricity Delivery and Energy Reliability at the US Department of Energy (DOE) administers. According to the Smart Grid R&D Multi-Year Program Plan (2010–2014) (see Resources), the program’s short-term goals call for commercially viable
microgrids by 2020, as well as a self-healing distribution grid with a high penetration of distributed energy resources, demand response and plug-in electric vehicles. In 2011, the Microgrid Exchange Group, an ad hoc group of subject matter experts within the Smart Grid R&D Program, put forward the closest thing to a consensus definition of a microgrid after much discussion and scrutiny.

As defined by the Microgrid Exchange Group, which comprises people researching and deploying microgrids: “A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid [and] can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.” This definition is generally consistent with one developed by a working group at the International Council on Large Electric Systems (CIGRE): “Microgrids are electricity distribution systems containing loads and distributed energy resources (such as distributed generators, storage devices or controllable loads) that can be operated in a controlled, coordinated way while connected to the main power network or while islanded.”

The similarities in these definitions belie the elasticity of microgrids in practice. Microgrids vary considerably in terms of scale, complexity and loads. They can incorporate many different types and combinations of power generation and energy storage technologies, including fossil fuel generators, microturbines, fuel cells, photovoltaics, wind, small hydro, biomass, batteries, flywheels, electric vehicles, energy management systems and controlled loads. While microgrid categories and reference architectures are fluid, the following are some examples of microgrid applications or types.

Campus microgrids. Military bases and university or corporate campuses deploy this type of microgrid. The customer or facility owner owns and maintains the microgrid assets as well as the dedicated distribution system behind the meter. Though interconnected to the local utility grid, campus microgrids typically support autonomous operation to some degree, either allowing the facility to operate independently during a utility outage or supporting critical loads. For example, Black & Veatch commissioned a microgrid at its corporate headquarters in April 2015 that incorporates combined heat and power (two natural gas microturbines), variable renewable energy (150 kW of rooftop solar), distributed energy storage (100 kWh lithium-ion battery) and controllable loads (45 electric vehicle charging stations).

Community microgrid. Community microgrids are integrated into utility networks rather than located behind a customer’s meter. Though community microgrids use the same technologies as campus microgrids, the utility controls the system and the distributed energy resources are subject to utility regulation. Customers often deploy community microgrids to improve grid resiliency or support essential community services in the event of an emergency that results in widespread power outages. The utilities that Hurricane Sandy impacted are among the early adopters of community microgrids.

Islanded microgrid. With no connection to a transmission or distribution network, islanded or off-grid microgrids provide power to remote communities, isolated industrial sites or actual islands. However, they incorporate the same types of distributed power generation, energy storage assets and advanced control capabilities as utility-interactive microgrids, often as a means of reducing dependence on diesel generators.

Nanogrid. Their function rather than their size defines microgrids. However, some microgrids serve multiple buildings or customers, whereas others serve a single building or load. The term nanogrid describes the latter, which is effectively the smallest microgrid building block.

Advanced microgrid. Researchers and analysts use the term advanced microgrid to differentiate...
between today’s commercially available microgrids and the next-generation microgrids they envision coming online in 5 or 10 years. According to the authors of the Sandia National Laboratories report *The Advanced Microgrid* (see Resources), an advanced microgrid is “loosely defined as a dynamic microgrid.” As such, the milestones along the road map to advanced microgrids have less to do with hardware than with software and regulation. To realize the 21st-century smart grid, utility operators need to be able to dynamically control variable renewable resources, distributed energy storage systems and microgrid assets. This requires new specifications, protocols, standards, qualification tests, security measures and protection schemes. It also requires new ways for asset owners to participate in electricity markets.

**Solar Micorgrids**

Though microgrids are technology neutral, they are especially well suited for integrating batteries in concert with photovoltaics. In their Clean Energy Group report, *Solar+Storage 101* (see Resources), Seth Mullendore and Lewis Milford note: “With steadily dropping costs in both solar and energy storage technologies, [solar plus storage] has become a viable and more reliable choice for emergency power. Not only do [solar-plus-storage] systems have the ability to provide power indefinitely when the grid is unavailable, they can also cut costs and generate revenue the other 99.9% of the time when the grid is functioning normally.”

For the purposes of this article, we use the term *solar microgrid* to refer specifically to a solar-plus-storage microgrid that is deployed behind the meter in a commercial or industrial application. Our intention is to distinguish solar microgrids from small-scale grid-tied battery backup PV systems on the one hand and utility-scale energy storage systems on the other. Advanced controls capable of balancing captive loads and energy resources, as well as bidirectional flows of stored energy, characterize a solar microgrid. Not only do the batteries in a solar microgrid support stand-alone operation, but the system controller can also dynamically discharge them in parallel with the grid, as a means of providing value-added services for both the utility and the customer.

By comparison, the role of the batteries in a simple grid-tied battery backup PV system is only to provide uninterruptible power to critical loads during a power outage. Otherwise, the system works in a binary utility-interactive mode, either...
on or off. Meanwhile, a utility-scale energy storage system deployed at a substation to manage or firm up variability is not a solar microgrid, as we are using the term, because the energy storage asset is installed in front of the meter, likely does not support islanded operation and interconnects at higher voltage levels than a solar microgrid.

**SYSTEM CONFIGURATIONS**
You can subdivide solar microgrids into three basic configurations or architectures: ac coupled, dc coupled and hybrid systems. There are pros and cons associated with each design approach.

**AC coupling.** In an ac-coupled configuration, the PV system and the energy storage system each have their own inverter, as shown in Figure 1 (p. 28). These separate inverters connect to one another on the ac side of the system, typically through a dedicated subpanel containing backup loads. The PV inverter is typically a standard utility-interactive inverter, albeit one capable of receiving external controls. The storage inverter controls battery charging and discharging. You would therefore more properly refer to it as a **power converter** or **power conversion system**. While some power converters have an integral grid isolation device, in our experience, it is more common to use a dedicated external grid isolation device actuated via a master system controller.

Compared to dc coupling, an ac-coupled configuration typically offers improved conversion efficiencies and equipment availability, as well as simplified system monitoring and serviceability. Conversion efficiencies are improved because the PV system connects to standard utility-interactive inverters, which are often 97% or 98% efficient. While power converter options are more limited than PV inverter options, several vendors serving the solar market—including ABB, AEG Power Solutions, Eaton, Ingeteam, Parker and Schneider Electric—also offer commercial-scale energy storage converters. Further, you can deploy any power converter suitable for dc coupling as a dedicated storage converter in an ac-coupled microgrid. Having all of these options to choose from makes it relatively easy for designers to identify a storage converter with the desired capacity rating and product features.

An additional benefit to using utility-interactive PV inverters is that you can use standard OEM or third-party PV monitoring solutions. While this may sound trivial, it is an important consideration for some applications. For example, off-the-shelf monitoring options are valuable for customers
who want to install a public lobby display to showcase their PV system. This may also be the easiest way to provide customers with a client login that enables them to track expected versus actual PV production. Meanwhile, having two separate inverters makes it easier for technicians to isolate the storage system from the PV system for maintenance and troubleshooting.

The drawbacks of ac coupling relate to costs, space requirements and system control. Because ac-coupled systems require two separate inverters, they are typically more expensive than a comparable system deployed using a single multiport converter. Systems deployed using a dedicated energy storage converter face difficulties in qualifying for the 30% investment tax credit (ITC). Two inverters also take up more physical space than a single converter. Lastly, system control and interoperability may be more limited or complicated in systems deployed using two inverters, especially if the inverter manufacturers differ. Mismatched inverters may also make it more difficult to monitor both the PV and the energy storage systems effectively.

**DC coupling.** In a dc-coupled configuration, the PV and energy storage systems share a power converter with three or more ports. As shown in Figure 2, two ports on the dc side of the converter are dedicated to the PV and battery inputs, and a third port on the ac side of the converter provides an input for the utility grid. While power from the PV array flows in one direction only, power flow on both the battery and utility ports is bidirectional.

DC coupling can reduce material and labor costs compared to an ac-coupled system since it can rely on a single power converter. DC-coupled systems are generally more compact in terms of physical space. Not only do you have to install fewer pieces of equipment, but also this approach eliminates redundant subcomponents and controls. Meanwhile, the process of qualifying the energy storage components for the 30% ITC is simplified when the solar and storage share the same converter.

In specific scenarios, dc coupling may provide unique performance benefits. For example, battery...
charging from the PV array is likely more efficient in a dc-coupled system, simply because it involves fewer power conversion steps. In addition, with some products, the battery input to the dc bus permits extended hours of operation on the PV port, allowing for additional energy harvest early in the morning or late in the evening.

The potential drawbacks of dc coupling include limitations related to product availability, weighted efficiency, shared converter capacity and energy metering. Relatively few equipment vendors—including Dynapower, Ideal Power and Princeton Power—offer multiport converters for solar microgrids. As compared to a standard utility-interactive inverter, these specialty converters have a lower CEC-rated efficiency, typically in the 94% to 96% range. You need to consider whether you are compromising system services and functionality by having two dc sources share converter capacity. For example, will PV production occupy essential converter capacity at times when the system needs to discharge stored energy? Obtaining full credit for PV-generated energy may also present a problem, since there are losses associated with energy storage system charge and discharge cycles. Further, applying revenue-grade metering to dc-coupled systems in solar renewable energy credit (SREC) markets is uncharted territory for both integrators and regulators.

**Hybrid system.** A hybrid system configuration integrates additional generator(s) into the dc- or ac-coupled microgrid. Potential renewable energy resources include wind or micro-hydro turbines or biogas digesters. However, it is most common to augment a solar microgrid with a natural gas or diesel generator. In this scenario, the generator typically connects to the backup loads’ subpanel via a controllable contactor or a transfer switch. The master controller manages operation of the entire system, including the generator and the grid-isolation device.

As a design strategy, integrating a fossil-fuel generator into a solar microgrid is a way of reducing energy storage capacity requirements and associated costs, while ensuring that you still meet customer needs. Of course, a backup generator is most valuable when a major storm or disaster results in an extended grid outage, which is also when refueling may prove problematic. Nevertheless, integrating additional generation resources is a great way to increase overall system resiliency and reliability, as well as extend autonomy during stand-alone operation.

A drawback to backup generators is that fuel is no longer carbon free or free of cost. Further, fossil-fuel generators require periodic maintenance, as well as regular cycling. A hybrid microgrid configuration also increases system complexity. In addition to requiring more sophisticated controls, these systems may also be more complicated to commission or troubleshoot.

**ENGINEERING AND DESIGN CONSIDERATIONS**

Compared to utility-interactive PV systems, solar microgrids present additional design and integration challenges. Support of stand-alone operations requires additional hardware, and some of this equipment—most notably the battery bank—is physically large. Design calculations are more complex, since these systems have bidirectional power flows and multiple energy sources. This operational complexity requires extra controls and software. Finally, solar microgrids require additional safety considerations.

**Energy storage.** To optimize system performance, longevity and cost, you must identify the right storage technology based on application-specific conditions of use. This is a complex analysis, well beyond the scope of this article. At a high level, however, battery selection is largely a function of expected discharge frequency and depth. Power-oriented batteries are better suited for applications with short charge and discharge times. Energy-oriented batteries are better suited for applications with long charge and discharge times.

Jay Marhoefer is the co-founder and CEO of Intelligent Generation, a software-as-a-service company that uses software algorithms to optimize a distributed network of storage assets for maximum market value. Marhoefer notes:
“Selecting the right type of battery requires a certain expertise, as it depends on the economic application of the energy storage system. For example, a power-oriented battery suitable for frequency regulation is not practical as a means of managing demand or capacity charges.”

In the frequency regulation market operated by PJM, a regional transmission organization (RTO), energy storage systems are categorized as a “dynamic, fast-responding resource,” and are compensated based on their ability to respond to a signal within a 4-second interval. This is not necessarily a high-energy application, but it does require a high-power battery, one that can charge or discharge very quickly. By contrast, load shifting for demand response purposes requires a high-energy battery, but is not necessarily a high-power application.

In terms of technology, lithium-ion batteries currently dominate the market. According to US Energy Storage Monitor, a report from GTM Research and the Energy Storage Association, lithium-ion batteries accounted for 70% of the grid-connected energy storage capacity deployed in 2014. Flow batteries, which have a flowing electrolyte, are another option for solar microgrids.

High-energy densities, relatively low weight and good cycle life characterize lithium-ion batteries, making them ideal for everything from cell phones to electric vehicles. These commercial applications have helped scale the technology and reduce costs. Lithium-ion batteries are available from divisions of large, well-known companies such as LG and Panasonic. Since they respond well to fast, intermittent high-power demands, they are well suited for frequency regulation and similar grid services. However, their usable capacity is limited, meaning that lithium-ion batteries perform better and last longer when they are not fully discharged. Further, large-scale lithium-ion batteries require active space conditioning, as prolonged exposure to heat reduces cycle life.

Flow batteries, on the other hand, have extremely high-cycle life—the limits of which laboratories have not fully characterized yet—and their full capacity is available for discharge without any reduction in cycle life or performance. This makes flow batteries an excellent choice for long duration and deep discharge applications, such as load shifting and backup power. Since flow batteries are not suited for mobile applications, they do not benefit from the growth of the electric vehicle industry to scale manufacturing economically. Start-up companies such as American Vanadium and ViZn Energy offer flow batteries.

**Site evaluation.** The location and layout of major system components is important to the success of a microgrid project. Equipment layout impacts construction costs, system maintenance and the host customer’s experience. Designers need to consider how major components—such as the PV...
array, energy storage system and backup loads’ subpanel—relate to one another, as well as to the point of connection and backup loads. Evaluating the time and materials required to relocate backup load branch circuits is critical, as this is a potential source of cost overruns. If the customer has a list of high-priority backup loads, verify the feasibility and practicality of extending these branch circuits to the backup loads panel. Otherwise, the customer will be disappointed to learn at a later date that the system does not back up these loads.

Energy storage components, in particular, are a significant design consideration. Containerized battery energy storage systems for commercial and industrial applications are physically equivalent to 20-foot shipping containers and often include control components, space conditioning and fire suppression systems. In some cases, you need more than one battery container. In addition to accounting for the physical footprint of the enclosure(s), designers need to consider noise, waste heat, aesthetics, accessibility, working clearances and proximity to the point of connection. Note that the proximity of the energy storage and power conversion systems relative to the PV array and point of interconnect is particularly important in dc-coupled systems. Both the physical distance of the circuits and the conduit routing have a significant impact on construction costs.

**Design calculations.** Compared to utility-interactive PV systems—or even grid-tied battery backup systems—solar microgrids require additional design calculations, and some of the nuances are not entirely obvious. With a utility-interactive PV system, for example, designers can verify the adequacy of the service simply by comparing the maximum combined inverter output capacity with the incoming utility service rating, in either amps or kilovolt-amperes. Solar microgrids, by comparison, require an additional design step because the storage system is both a load and an energy source. As a result, designers need to consider the ac rating of the power converter in both directions.

In practice, this means designers must add the power converter’s maximum input rating to the maximum expected instantaneous building load. This sum should be less than the electrical service capacity. If this sum is greater than the service capacity, designers have two options: upsize the service or limit the loads. Conceptually, upsizing the service capacity so that it exceeds the sum of the maximum possible site loads is a brute-force design solution, as it is the most expensive answer to the problem. Unless you expect a microgrid to generate a significant portion of its revenue by participating in ancillary service markets dependent on the full converter capacity, service upgrade costs are seldom justified. A more cost-effective solution is to control either site loads or charge current. The latter is generally a more practical option, as you can accomplish this using the microgrid control system.

You must perform the same type of analysis for the backup loads subpanel, as well for any electrical equipment between the microgrid point of connection and the utility transformer. In some cases, it is a good idea—if not a requirement—to install additional energy meters as a means of providing closed-loop verification of system inputs, which allows the control system to check the accuracy of any one data stream by comparing it to others.

**Point of connection.** To prevent component overloading in the electrical system, you often need to interconnect solar microgrids on the supply side of...
the main overcurrent protection device (OCPD), as shown in Figure 3 (p. 32). When considering design options, do not rule out moving the metering point upstream to clear the way for a supply-side connection. It may be more desirable to locate the point of connection outside the building, as this may lower costs, improve safety and provide emergency responders with more-direct access to the system disconnecting means.

**Backup loads.** Power converter capacity on the one hand and the amount of stored energy on the other limit the ability of a solar microgrid to autonomously support loads during a power outage. While the duration of stand-alone operation varies based on customer habits, instantaneous power requirements are a hard-stop design limit. As such, you need to pay particular attention to the continuous ac current rating of the power converter, as well as its overload or surge current rating.

At start-up, some commercial and industrial loads—most notably large motors or compressors—require a large amount of current, referred to as *locked rotor amps* (LRA). The information label for a motor typically includes its LRA rating. If this is not available, you can measure inrush current during the site evaluation. To properly operate backup loads, the power converter must support instantaneous surge currents on top of the expected base load requirements.

**Sequence of operations.** The sequence of operations is a matrix that informs the control system logic. It identifies all of the components that the local control system will interact with, as well as all of the system operating modes. It then defines the state of operation for the power converter, the status of controllable loads, the position of switches, alarm trigger set points and so forth, for every possible operating mode. In our experience, the sequence of operations is unique for each job, based on how the system integrates with the host facility, which components and energy resources are present, and how the system generates revenue.

The control system for the Konterra Microgrid project (see pp. 72–73), for example, prioritizes using power converter capacity as a current source to process PV-generated power, as this provides the most predictable revenue stream. Since the converter capacity (500 kW) is larger than the PV input capacity (402 kW), the controller uses any excess converter capacity to participate in PJM’s fast-response frequency regulation market. This allows the PV system to generate additional revenue during the day, as well as at night. In the event of a grid outage, the controller opens the isolation device and switches the power converter to island mode. In this mode, the converter acts as a voltage source and operates loads connected to the backup subpanel.

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You must develop the sequence of operations control matrix with the consensus of all project stakeholders, including the host customer, electric distribution company, AHJ, equipment vendors, engineer of record and EPC. Meet with the electric distribution company and AHJ early in the project development cycle to apprise them of the plan, and adjust it as necessary based on their feedback. Coordinate the sequence of operations with the energy storage system vendor to ensure that the battery can support the desired functions and capabilities. Clear communication is critical not only for establishing a common set of criteria by which to evaluate project success, but also as a means of managing customer expectations.

**Safety.** A 20- or 40-foot storage container filled with batteries presents inherent safety hazards, some of which utility-interactive PV systems do not pose. However, system integrators are intimately familiar with many of the commonsense safety responses to these hazards. For example, strict adherence to the access and working space requirements in *NEC* Section 110.26 is essential. You need to identify arc-flash hazards, guard live parts and ensure that system labeling meets or exceeds Code requirements. You also need to consider using fire-retardant materials and an automatic fire suppression system.

Energy storage systems also require heightened attention to incident preparedness. The authors of the *US DOE Emergency Storage Safety Strategic Plan* (see Resources) note that it is “essential to engage the first responder community early” in the process of designing and siting energy storage systems, with the goal of improving overall safety and developing hazard mitigation techniques. After meeting with first responders, you will need to produce a site-specific safety
States with Emerging Energy Storage Markets

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Early adopters While California is leading the way, as it did with the adoption of solar technologies, several other states also have emerging energy storage markets.
Wholesale Market Opportunities

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<td>ERCOT</td>
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<td>Pilot regulation program in place since 2008; implementing new frequency regulation market design in 2015</td>
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<td>MISO</td>
<td>Pay-for-performance frequency regulation</td>
<td>Implemented program to meet FERC Order 755 in 2013; working on improving dispatch signals and developing markets for new products</td>
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<td>NYISO</td>
<td>Pay-for-performance frequency regulation</td>
<td>Implemented regulation market in 2013; studying new market rules that would allow behind-the-meter generators to participate in wholesale markets</td>
</tr>
<tr>
<td>PJM</td>
<td>Pay-for-performance frequency regulation</td>
<td>Implemented regulation program to meet FERC Order 755 in late 2012; proposed a new capacity performance product for storage plus renewables for 2016/2017 delivery year</td>
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<tr>
<td>SPP</td>
<td>Fast-responding frequency regulation service pilot program</td>
<td>Southwest Power Pool implemented regulation pilot project in 2013; working on developing markets for new products</td>
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**Market-based incentives** Pay-for-performance frequency regulation programs provide premium compensation for fast-responding resources, such as energy storage systems. Transmission operators are also developing other ancillary service products that will provide additional revenue streams for energy storage assets in the future.

Companies usually program solar-plus-storage systems to support a specific and limited set of functions based on the market context, potential revenues and host customer needs. The functions selected affect stand-alone autonomy based on the energy storage system’s likely state of charge when an outage occurs. The control system also requires customization based on the market value of ancillary services, site-specific equipment configurations and individual customer needs. Developing and debugging a custom control system requires advance planning.

**Economic performance.** It is inherently more difficult for project developers to generate revenue projections and estimate return on investment for solar microgrids than for utility-interactive PV systems. This is not only true for systems that participate in spot markets for ancillary services, but also for systems that realize savings based on avoided costs. Demand charge reductions, for example, are difficult to estimate without detailed historical load data. Even when these data are available, demand charge savings are highly dependent on customer habits. If the customer’s energy consumption habits change significantly, you will need to adjust the system performance expectations.

Another factor that you need to account for with frequency response is the cost of operation. Significant energy losses are associated with using batteries as a dynamic fast-responding resource, simply due to the round-trip efficiency losses associated with the energy storage system. You must account for... CONTINUED ON PAGE 40
storage system energy losses—as well as energy that the control system or space-conditioning system consume—when running financial models. These losses effectively reduce PV system production, which will decrease energy credits or SREC payments.

Finally, you need to consider the operations and maintenance implications of solar-plus-storage systems. Battery life expectancy generally decreases the more often and more deeply the system cycles batteries, which also impacts financial performance. Specifying the wrong battery based on the conditions of use, for example, can severely curtail battery life. In addition to accounting for increased maintenance and insurance costs, you must also add transmission dispatch and scheduling fees. To set appropriate customer expectations, you need to factor all of these considerations into the customer’s financial pro forma.

Marhoefer at Intelligent Generation elaborates: “Today, project financing for energy storage is similar to where PV project finance was in the early 2000s, before the advent of power purchase agreements. A primary impediment to storage project finance is the merchant risk associated with frequency regulation, which is a spot market. It is also a thin market that will be subject to downward price pressure as cheaper storage assets saturate the market in future years. However, costs for lithium-ion energy storage systems continue to trend downward as production scales. At some point, the costs will be low enough to spur investment despite the merchant risk.”

Analysts and service providers are not the only industry stakeholders convinced of the inevitability and importance of microgrids. The authors of the California Public Utilities Commission report Microgrids: A Regulatory Perspective (see Resources) note that “this development is happening whether the utility, or regulator, encourages it or not.” The real issue, they conclude, is what utilities and regulators will do to use these technologies most effectively.

Untapped Potential

Compared to utility-interactive PV systems, solar microgrids are relatively expensive to deploy and difficult to finance. While these are meaningful market barriers today, most analysts expect rapid and significant growth in energy storage applications. Mike Munsell at Greentech Media notes (see Resources): “GTM Research likens the current commercial energy storage market to the U.S. solar market of 2005. [Though still expensive,] the technology is sophisticated enough to allow for widespread adoption, and the business models are just beginning to emerge.” Further, much of the energy storage market growth in the next 5 years is expected to come from behind-the-meter applications.
Introduction

EKo Pwòp (Elekrisite Kominote Pwop = Clean community electricity) is Haiti’s first hybrid solar powered microgrid and EarthSpark’s first endeavor in microgrid implementation and operation. The grid was turned on in 2012 and has since been expanded twice. Each phase has offered numerous lessons. As processes have improved, the grid operators continue to face challenges. Political risk, process risk, regulatory risks, and technical hurdles all challenge the financial viability of microgrid development in Haiti, EarthSpark International’s goal is to create a business model that can overcome these challenges and prove that electricity production can be financially and environmentally sustainable. EarthSpark is currently seeking grant funding for 3 additional grids that will enable us to further de-risk the process of microgrid development in Haiti. Along side development of the three additional grids, EarthSpark is putting in place an investable plan to operationalize 80 microgrids in Haiti by the end of 2020. The model focuses on off-grid towns with densely-packed ‘down town’ areas where clusters of businesses and homes demonstrate a high density of demand. People living and working in these settings are often paying exorbitant rates for electricity equivalents – diesel generators, kerosene and candles – and the arrival of a grid can both reduce individuals’ energy expenses
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while unlocking enormous rural economic potential. Approximately 60% of the population lives in rural areas and more than 70% of the total population lacks access to electricity\(^1\).

Haiti’s national grid is owned by Electricité d’Haiti (EDH), a state-owned monopoly operating with severe technical and financial inefficiencies. EDH’s power is primarily produced by diesel and HFO generators, with about a third (approx. 30% in 2006) coming from hydro\(^1\). (Note that Haiti must import all petroleum products as it does not have domestic crude oil production and refining capacities). With poor infrastructure and maintenance, old and deteriorating equipment, and an unstable network, outages are frequent and often unscheduled for the small percentage of the population that has access to the national grid. Theft is also a major problem in Haiti – it is estimated that in 2002, 64% of EDH electricity consumption was unmetered\(^1\). According to the Ministry for Public Works, Transportation and Communications (MTPTC) of Haiti, between 2002-2003, EDH produced 513.29 GWh of energy, yet only sold 238.22 GWh, thus suffering from a total loss rate of 53.6\(^%\)\(^1\) (which includes technical and non-technical losses). This trend in extremely high losses was observed as far back as 1998 and likely continues to date.

While improving EDH service for the existing grids remains national imperative, there is no coherent effort to deliver electricity to the 70% of the population that has no electricity. In that context, EarthSpark is working in off-grid towns to leapfrog the existing energy infrastructure by employing technologies that aid us in providing clean and reliable service. The EKo Pwòp grid has the following setup:

- **93 kW solar panel array** that powers the grid and charges the battery bank during the daytime.

- **30 kW backup diesel generator** which is only used during periods of inclement weather.

- **450 kWh battery bank** that powers the town at night, making Les Anglais the only town in Haiti with 24/7 electricity service.

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- **Smart meters** developed by EarthSpark’s spin-off company SparkMeter. These meters have a pre-pay functionality that enables cost assurance. Additional functionalities include:
  
  o **Time-of-use pricing**: the tariff can vary based on specific times of the day. For example, for the EKo Pwop grid, the cost of electricity per kWh is cheaper during the day, and increases at night when the cost to produce electricity is higher (see tariff structure in Table 1).

  o **Flat rate or block rate**: the base electricity rate (in cost/kWh) can be a flat rate or can depend on the amount of energy consumed each month. If the user does not consume a minimum value, a higher rate can be applied.

  o **Load limiting** – the operator can define the maximum load (from 2 W to 4.8kW) that each client can draw at any given time. Each home or business has a smart meter, which allows us to control the limit of each client.

  o **Monthly plan** – this defines a minimum payment that a customer must spend each month in order to use electricity.

To ensure that the generation system’s capacity is not exceeded, the EKo Pwèp grid employs a tiered load limiting system that depends on the load limiting functionality of the smart meters. Figure 1 illustrates the tiered structure. Five levels of service are offered, starting with the most basic service titled “Limye” (meaning “light” in Haitian Creole), which offers a maximum load of 30 Watts, enough to power cells phones, radios, and lights. Approximately 65% of the clients on the grid currently use this service. The tiers increase in load limit up to the highest service level titled “Anchor”. Using the ABC (Anchor, Business, Community) Model, EarthSpark’s grid is built to deliver high amounts of electricity to Anchors, or large consumers such as hotels or commercial clients, as well as small amounts of electricity to smaller businesses and homes. The tariff structure reflects different levels and different times of use. Large consumers pay less per kWh since their overall consumption is much greater, and each kWh costs more at night in
order to incentivize lower consumption when electricity production costs are higher, i.e. when batteries are in use. Table 1 provides the cost/kWh for each service level in Haitian gourdes.

![Figure 1 - Service Levels for the EKo Pwòp microgrid.]

<table>
<thead>
<tr>
<th></th>
<th>Limye</th>
<th>TV</th>
<th>Freezer</th>
<th>Gwo Bagay</th>
<th>Anchor</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Daytime tariff (₲/kWh)</strong></td>
<td>40</td>
<td>40</td>
<td>30</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td><strong>Night time tariff (₲/kWh)</strong></td>
<td>60</td>
<td>60</td>
<td>45</td>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 1 - EKo Pwop tariff structure and time-of-use pricing example

In enabling the Monthly Plan option of the smart meters, those who do not use a predefined amount of electricity each month will be downgraded to a lower tiered load limit. This ensures that customers do not take advantage of lower tariffs for higher service levels. Since there is a limited number of connections with high load limit services, the Monthly Plan ensures that people are using their service. For example, if a customer is on the Freezer level, they may have to spend 500 Haitian gourdes per month in electricity to keep their service level. If they do not use this amount, they will be downgraded to the TV level. Another client can then sign up for the freezer service that just opened up.

The way people pre-pay for electricity is the same as how they pre-pay for cell phone minutes. Customers must pay in advance for their electricity credits before they can use them. The pre-pay mechanism relies on vendors who can sell from any location using a smart phone or tablet with internet service. A client simply finds a vendor, pays the vendor to add credit to their account in any monetary value they can afford, and the vendor then enters the information on their smart device. The customer can use this value in kWh of electricity until their credit runs...
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out. All customers on the grid use the pre-pay system except for the anchor, who is post-pay and requires monthly bill collection.

Challenges and Lessons learned:

Since the launch of the initial grid pilot in 2012, EarthSpark has encountered many challenges that are informing the deployment of our next microgrids in rural Haiti. These challenges are outlined below:

- **Electricity theft**: While electricity theft from EDH is common and even viewed as a clever way to ‘beat the system’, in rural towns the reaction is often the opposite. “Stealing form Enèji Pwòp is stealing from the community!” one customer roared recently in a community meeting in Les Anglais. Nevertheless, the normalization of electricity in Haiti is a widespread problem in Haiti and unfortunately EKo Pwòp is not immune! We have made several attempts to discourage theft, including community pressure, enforcing a fine and disconnection, and involving the justice system. Our current method of checking for theft is to evaluate the service connection at each home on the grid, which is a time consuming process. We are also in the process of implementing totalizer meters (provided by SparkMeter) at each distribution transformer that will monitor the total usage of a subnetwork, which can then be compared to the total payment. We have realized that a major drawback of our current method of home installations is the placement of the meters. They are installed on the exterior of the home (Figure 2), making it easy to tap into the service drop line to steal electricity.

Figure 2. Typical home in Les Anglais, Haiti. The SM smart meter is installed at a location that is easy for our technicians to access (center column), but also easy for the residents to access if they want to steal electricity.
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Lesson learned – place multiple meters together on power poles at a high elevation. This will make it more difficult for customers to access the service drop yet make it easier to check for theft if multiple meters are collocated.

Figure 3. The image shows the location where a theft offender tapped into the service drop line to steal electricity. A nail was placed directly in the service line, upstream of the meter. A wire was then tied to the nail and used to power an appliance.

(A quick anecdote: One of our recent theft offenders told us that it is worse to steal a cow than to steal electricity! We disconnected the client by removing his meter but the service drop could not be completely removed because it was being used for a neighbor’s connection. We found the offender stealing a second time and he said that he was too tempted by the fact that the service drop was still accessible. He insisted that we quickly find a way to remove the service line so that he is no longer tempted to steal.)

- **Lack of efficient appliances in the Haitian market:** While it is difficult to completely foresee how consumers will use electricity and which appliances will be adopted when electricity becomes available for the first time in a town, some common themes are very predictable. Unfortunately finding deeply efficient appliances to meet the needs of newly-electrified homes and businesses remains a challenge. For Eko Pwòp, electricity access fostered a new business throughout town: freezers could now be used to sell cold drinks, ice cream, and ice. Thus freezers and Freezer service became a highly desired commodity. Unfortunately inefficient chest freezers are sold in Haiti and the instructions are not provided in the local language. Therefore our customers are not using the proper
settings and are burning through a lot of electricity due to inefficient use of the freezers (constantly opening the doors and filling the freezers up to a point that they are completely filled with products). This leads to unnecessary pressure on the grid, waste, and unhappy customers. EarthSpark is working on sourcing efficient freezers, fans, and televisions that can be imported to Haiti and will also conduct tests to determine how the clients can use the freezers in a more efficient way.

- Internet service and smart devices required:
  - The SparkMeter system does not require internet to function, but internet access enables vendors to sell electricity from outside of the ‘energy store’ hub where local Wi-Fi enables transactions. With an internet-enabled smart phone or tablet, electricity vendors can sell electricity credits directly from their personal home or store which is the strong preference of vendors. Less than 20% of Haitians have access to the internet and are not accustomed to paying for this service. Internet based sales require smart devices, such as smart phones and tablets, which are not commonly used in rural areas. One of our current challenges is finding vendors who are willing to purchase smart devices and to pay for internet service.
  - Internet is also slow – 2G is the only service that is available in Les Anglais. This presents a challenge in remote monitoring of our generation system. EarthSpark is currently searching for low-bandwidth solutions to remote monitoring.
Lessons learned and best practices approach to microgrid management

(Challenges continued…)

- **Lack of regulatory framework for private utilities:** Despite laws to the contrary, Haiti’s Electricité d’Haïti (EDH) is often perceived as having exclusive legal authority to sell electricity. EarthSpark and other microgrid operators are in discussion with the Ministry of Public Works (MTPTC) and other stakeholders to clarify the framework. Our focus rests on a decree that gives municipalities the authority to provide electricity and/or delegate that authority to a third party.

- **Skilled lineman are not readily available:** EarthSpark contracted a Dominican company to install the distribution system. Our local grid technician has been trained for basic distribution system work, but for larger trouble shooting and work we are currently relying on the Dominican firm’s linemen. This is not a feasible long-term solution, and stronger local capacity and local partners is needed.

- **Equipment and supplies not available in country:** Many supplies are not found in Haiti and must be acquired in the U.S. Unfortunately Haiti has high customs fees and shipping services are not reliable.

- **High maintenance measures needed for power electronics in harsh environment:** Rural Haiti can be very dusty (due to lack of paved roads and landscaping) and the climate is hot year-round. Our inverters and site controller reside in a modular shipping container that was not designed for the harsh climate. EarthSpark is currently working on climate control measures to mitigate any consequences that the environment may have on the electronic devices. The inverters were also designed with specially sized filters that can only be purchased in the U.S. or other countries.

- **Pre-pay method – important to guarantee timely, and efficient payment.** Billing is a challenge in Haiti, therefore pre-pay metering is important in ensuring that payment is received. Our only post-pay client is the anchor customer, which is a hotel owner. Receiving payment from this one customer is in itself a challenge. In the future, all customers will be on pre-pay service.
Lessons learned and best practices approach to microgrid management

Best practices:

- Operating in areas that are rural yet characterized by a dense population, i.e. a small footprint, promote operational efficiency! A smaller footprint:
  
  - Reduces the time needed to deploy employees when grid issues need to be addressed. This in turn reduces operational costs.
  - Reduces distribution system costs, and thus capital costs
  - Community engagement and education are critical! Information is easy to disseminate, and news spreads quickly by word of mouth.

- When introducing the community to the concept of the microgrid, inform them that
  
  - The systems must not be tampered with or manipulated, or there will be penalties, which may include a fine, service disconnection, and possibly involvement of the law. These penalties must be immediately enforced. Recently experienced events that prompt this action:

    - After the mayoral elections, a group of protesters damaged the smart meter at the home of the old mayor of Les Anglais. EarthSpark must replace this meter. Staff communicated that this act is considered an assault to the community microgrid, not to the former mayor.
    - While doing construction work on his home, a customer removed our smart meter and reinstalled it at another location on his home. This is a dangerous act that should not be tolerated.
    - A client drew too much current, blowing an external fuse that accompanies the smart meters, which serves to protect the installation. Rather than paying our technician to replace the fuse, the customer jumped the fuse to resume service.
  
  - Theft will not be tolerated.
GLOSSARY of Terms

**Anti-islanding:** Safety protocols intended to ensure that distributed energy resources can’t feed power onto utility distribution lines during a system outage. IEEE 1547 includes anti-islanding standards to protect the safety of utility line workers. (See also “islanding.”)

**Backup power system:** A generation system designed and operated to provide emergency backup power during utility grid outages. A microgrid can be defined as a sophisticated backup power system.

**Balancing:** Active efforts to match energy supply and demand to maintain stable system operations. Both microgrids and large-scale utility grids perform balancing operations.

**Campus microgrid:** A microgrid serving assets within the perimeter of a discrete campus -- e.g., a university, corporate, or government campus, a prison, or a military base. Campus microgrids generally do not cross public rights of way or incorporate public utility infrastructure.

**Combined heat and power (CHP) (a.k.a., "cogeneration," "trigeneration" or "waste heat to power"):** CHP systems supply both electricity and thermal energy, and can comprise the generation foundation of an efficient and economical microgrid.

**Community microgrid (a.k.a., "cluster" or "segment" microgrid):** Microgrids serving a group of customers, likely with municipal or other public facilities as anchor tenants. In general, community microgrids cross public rights of way and incorporate public utility infrastructure.

**Demand response (DR):** Energy loads capable of being reduced, deferred, or curtailed in response to signals regarding such conditions as energy prices or system constraints.

**Distributed energy resource (DER):** Generally any form of decentralized generation, storage, or demand management capability.

**Distributed generation (DG):** A small power plant located near an end-use customer, often interconnected with the low-voltage utility distribution grid (versus the high-voltage transmission system).

**District energy system:** A local system that provides thermal energy for multiple facilities -- usually heating and domestic hot water, and sometimes thermal processes and cooling. District energy strategies can produce substantial energy savings and emissions reductions, as well as greater local resilience.

**Energy improvement district (EID):** A vehicle used by local and state governments to promote planning, development, and funding activities supporting energy infrastructure improvements in a defined geographic area or community. Community leaders are considering microgrids as part of energy improvement district planning.

**Energy management system (EMS):** Software and hardware for balancing energy supply (including storage) and demand to maintain stable operations.

**Energy service company (ESCO):** A non-utility entity that provides retail, commercial, or industrial energy services.

**Green building and smart building:** High performance building designs can incorporate microgrid technologies and control structures.
IEEE 1547.x: A set of industry standards for interconnecting distributed energy resources to electric utility systems. IEEE 1547 is being amended to accommodate microgrids and higher penetrations of DERs.

Interconnection: at the point of common coupling, interconnected systems are synchronized to the grid -- their frequency, voltage, and phase angles are matched up.

IPP: Independent power producers are non-utility companies that generate and sell energy to one or more customers.

Islanding: Intentional islanding is the act of physically disconnecting a defined group of electric circuits from a utility system, and operating those circuits independently. Islanding capabilities are fundamental to the function of a microgrid. (See also “anti-islanding.”)

Microgrid: A small energy system capable of balancing captive supply and demand resources to maintain stable service within a defined boundary. There's no universally accepted minimum or maximum size for a microgrid.

MUSH: Military installations, universities, schools, and hospitals. Many of the first commercial microgrids are being installed for customers in MUSH applications.

Nanogrid: A microgrid serving a single building or asset, such as a commercial, industrial, or residential facility, or serving a dedicated system, such as a water treatment or pumping station.

Net-zero: The condition in which a building, campus, or complex is capable of generating energy equal to its aggregate annual consumption.

Off-grid microgrid: A microgrid that's not interconnected with a local utility network. Off-grid microgrids generally are located on islands and remote sites, such as isolated rural communities and mining camps.

Photovoltaics (PV): Solar-electric energy cells in any of numerous forms and configurations.

Plug-in electric vehicle (PEV): Transportation vehicle with an onboard electricity storage system and the ability to charge from an outside power source.

Smart city: A community that plans and develops infrastructure, buildings, and operations to intentionally optimize efficiency, economics, and quality of life.

Smart grid: A energy system characterized by two-way communications and distributed sensors, automation, and supervisory control systems.

Transactive energy: A market system in which services are priced dynamically for individual nodes and resources, on the basis of system constraint conditions.

UPS (uninterruptible power supply): A power system that maintains continuous electricity service for specific systems or circuits, avoiding even momentary interruptions in service. UPS systems generally rely on storage batteries, with backup generators for larger systems and those that need to ensure power supply for a longer duration.

V2G: Vehicle-to-grid technology, integrating PEVs together for dispatchable electricity storage for grid support and ancillary services.

Virtual power plant (VPP): Aggregated power generating capacity that's provided by multiple, real DG facilities operating in different locations.