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Micro grid for Disaster Preparedness and Recovery

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ABSTRACT— Microgrids are a solution to many of the issues identified in the disaster review. A microgrid is a collection of controllable and physically close generators, managed in careful collaboration with local loads. By relying on a variety of generators, a microgrid system avoids many of the single-point- of-failure issues of the traditional electricity grid. Similarly, by closely managing local supply and demand, the microgrid can ensure that essential services are met, despite constraints that may exist on electricity supply. Whilst often viewed as a means of encouraging the uptake of renewable energy, or addressing challenges of peak demand, micrograds can make a significant contribution to helping with disaster preparedness and recovery.the penetration of microgrids and the fundamental challenges that need to be addressed before they become commonplace. Microgrids are not without their challenges, both technical and non-technical, and this White Paper considers a wide range of issues limiting microgrid uptake, from regulatory barriers to the deployment of distributed generation, to the technical challenges of operating a microgrid with a large amount of renewable energy.

Keywords- Renewable energy, Microgrid, Distributed Generation, Anti-Islanding, Demand Management, Peak Demand, Stability, Utility Grid

I. INTRODUCTION

Electricity systems have undergone significant changes in the past 10 years. For example, there has been a rapid uptake of new, relatively small generation technologies referred to as distributed generation, and in many countries electricity load has continued to grow dramatically. These changes are often considered a challenge to electricity system operation. However, one of the most recent concepts, that of the microgrid, can actually be an asset to system operation, particularly when considering disaster preparation or recovery. One way of managing the increasing complexity of our electricity systems is to group distinct distributed resources such as generators or loads, so that they represent a single generator or load to the wider electricity system. When such loads and generators are located within close geographical proximity of each other, such a system is often referred to as a microgrid. More specifically, in this work we define a microgrid as a collection of controllable and physically proximate distributed generator and load resources, where there are multiple sources of AC power and at least one of these is based on a renewable energy technology such as wind or solar energy.

A microgrid may or may not be connected to the wider electricity grid. We define an isolated microgrid as one that is not connected to the utility grid in any way, shape or form, but is a distinct island for which no PCC exists. We define a connected microgrid as a microgrid that can be connected to the utility grid. It may operate as a distinct island, but features a PCC that allows interaction with the utility grid (most typically to facilitate import/export of power). There are a number of reasons microgrids are now receiving significant attention. They are a way of coordinating the growing number of sites with local on-site generation. For example, an industrial estate with roof-mounted solar cells and a gas- powered back-up generator can be transformed into a microgrid by adding intelligent control systems to the generators, then linking these to load controllers to form a dynamic self-contained energy system. Microgrids also represent an entirely new way of powering remote or rural communities – rather than one centralized (often diesel- powered) generating station, these communities can be powered by a large number of low-emissions generators, linked with appropriate load control. As the range of possibilities between these two examples is quite wide, to assist with any ambiguity regarding what is a microgrid, Table. 1. provides some examples of what, in this work, is not considered a microgrid.

Commonly used name	Typical example	Why this is not a microgrid
Local renewable energy system	A single building with a local renewable energy system (for instance, a solar generator)	The loads and generators in such a system rarely exhibit any form of inteliger dynamic control. There are rarely multiple sources of AC power in such systems.
Local back-up power supply	A single building with a local back-up power supply (such as batteries or a fossil-fuel generator)	Typically such systems operate using a single generation source or battery suppl so do not fit our definition of a microgrid having multiple AC sources.
Grid-connected peaking plant	Relatively large (>1 MW) generators interspersed throughout a distribution network for meeting peak demand	Connected to a broader distribution system, there are multiple points of connection to the wider grid, violating ou definition that a microgrid has one single point of connection.

Table.1.

An example is a connected microgrid system deployed at an industrial campus. Power is obtained from the grid to supply loads (the offices), as a conventional site, but can also be obtained from embedded generation, including a wind turbine, solar photovoltaic panels and a micro-turbine. All these feed power to the site via inverters. A battery is equipped with a special two-way power inverter that can both absorb power when excess is available or supply it when there is a shortage. If embedded generation is greater than the required load, excess power can be exported to the grid via the two-way PCC. The site can also be isolated from the grid at the PCC, in which case the loads are supplied from the embedded generation only. In these circumstances, the EMS must carefully control which loads are allowed to draw power, in order to complexes. balance supply with demand.

Fluctuations in the renewable generation caused by changing weather conditions are balanced by judicious charging and discharging of the batteries, under the control of the EMS.

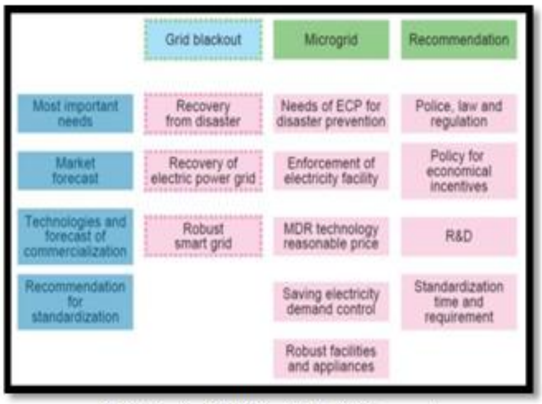

Fig. 1. Needs of MDR on Market Environment

Some of the key features of this microgrid that set it, and microgrids in general, apart from more traditional power distribution systems are:

- The use of distributed generation sources, including renewable and CHP generators
- The introduction of dynamic load control systems
- The use of multiple inverters
- The ability to island the system, and
- A point of common connection (for connected microgrids)

These features may occur in isolation in traditional electricity systems, but combine to form a unique set of opportunities and hurdles when deployed as a microgrid. These are explored in the following sections.

Benefits of microgrids

A.To end users

One of the major benefits of microgrids is that they typically reduce emissions associated with electricity generation, and/or increase the efficiency of generation. Such benefits come from the distributed generators used in microgrids, which are often based on low or zero-emission generation sources – from highly efficient gas turbines through to renewable energy systems. As well as the efficiency of the generator itself, their close proximity to loads means the efficiency of distributed generators can be further improved by utilizing their waste heat – for example, to heat or cool nearby buildings. The overall efficiency is also improved because the transmission losses are reduced as well.

Microgrids also allow end users to become autonomous in their energy provision. By operating their own network of local generators and coordinated loads, microgrid owner/operators can end their reliance on the wider electricity grid. By maintaining the ability to island from the wider grid, a microgrid can ensure robust and reliable supply for its enclosed loads, isolated from faults on the wider electricity system. The microgrid can also provide enhanced power quality compared with the wider grid, useful in critical applications such as semiconductor manufacture. This additional resilience is one of the main benefits of microgrids

in relation to the challenge of disaster relief, and will be further explored in later sections of this White Paper.

B.To utilities/distribution companies

One of the recent changes in modern electricity networks has been the increasing uptake of distributed generation. Whether it is solar cells for renewable supply or reciprocating engines providing CHP solutions, distributed generators are now quite common in a modern electricity system. Distributed generation poses a number of challenges to the operation of electricity systems. It can reverse the direction of power flow in certain parts of the network. This can cause problems in networks designed on the assumption power will flow in one direction only. Further, to maintain power quality in the network, it may be necessary to individually manage each of the operating generators. With large numbers of generators possibly operating at any one time, centralized management of individual distributed generators across the entire electricity system can be a cumbersome task.

Microgrids ease the challenge of controlling large numbers of distributed resources by making distributed generation control an internal process, operating within the microgrid. For example, by managing a large number of distributed generators on an industrial campus as a microgrid, we are able to abstract the challenges of coordinating and controlling multitudes of distributed resources away from the wider utility grid. Each generator is managed internally to the microgrid, and the entire microgrid appears as only one single generator to the broader electricity system. Here the microgrid, with its single point of connection to the wider electricity system, implicitly aggregates all the resources within the microgrid to appear as a large, single controllable resource. Ultimately, with microgrid technologies, today's electricity networks can operate with large amounts of distributed generation yet can use conventional command and control techniques.

	Responsibilities	Requirements
Public administration	Community-wide disaster avoidance and response planning	An understanding of best practices and assessment of prevention plans for disaster resilience or recovery
Standards organizations	Development of standards to assist with disaster preparedness or recovery	Technical standards to ensure technical goals or benefits can be realized Classification standards to allow evaluation and comparison of disaster-preparedness strategies
Private companies	Company-specific disaster response planning	Plans to ensure business is appropriately prepared for major disasters and rapid recovery from disaster
	New products and technologies for disaster resilience or recovery	Products and technologies that can assist with disaster preparation or recovery, and that adhere to current technical standards to ensure maximum widespread benefit
End users/ Consumers	Education and training related to disaster preparedness and recovery	Detailed planning to minimize the impacts of a major disaster

Fig.2. Target Audiences and their Needs

Microgrids can also assist with peak electricity demand – the spikes in consumption that result in under-utilized electricity distribution infrastructure and often drive electricity price increases. In an attempt to better manage peak demand, load management technologies are being developed that coordinate a variety of electrical loads so the total electrical consumption adheres to a set of constraints. This technique is particularly beneficial in a microgrid situation, where loads can be managed to match time-varying distributed generation capacity, as well as network throughput capacity. An example is where load management on a building air-conditioning system is used to match the electricity consumption of the load with the supply available from the renewable energy sources, reducing the need for fossil-fuel generators while maintaining occupant comfort in the buildings. Ultimately, such active load management means that the microgrid can be operated with less generation held in reserve, improving broader system utilization and reducing capital costs. Microgrids can also assist power systems to operate with significant renewable electricity generation. The traditional view of electrifying remote areas was that whilst some renewable sources could be included, a large centralized fossil-fuelled generator was needed to provide "spinning reserve" and act as inertia for the generation system. Microgrids challenge this theory: they are designed around multiple small generators, without any single large source of inertia. It is not uncommon now to find microgrids operating with greater than 50 % of the electrical load being met by renewable generation supply.

C. Microgrids for disaster relief

Microgrids are inherently suitable for maintaining electricity provision during or after a disaster. It is first worthwhile reviewing what electrical outages typically mean for power system infrastructure, and then how microgrids can help. Faults on power distribution systems can occur for a variety of reasons, from hardware failure through to physical interruptions from storms or animal intrusion. Protecting system assets from such faults are devices such as circuit breakers, reclosers and fuses, which isolate faulty network components and allow re-routing of power in an attempt to maintain the function of remaining assets. While some aspects of power system operation and fault response are automated, all systems still require significant manual oversight and intervention. In short, even today, often the only way a utility knows there has been an outage in the distribution system is when a customer calls to report it.

One of the core challenges to the reliable operation of contemporary power systems is their radial, centralized nature. Essentially, system-wide failures can occur if there is a failure at any central point of the system, and there are significant limits to the dynamic reconfiguration possible. Though some reconfiguration can occur at the edges of the network, the core structure remains in place, is difficult to change in situ and is at risk of failure.

As stated earlier, despite the best efforts of engineers to maximize system reliability, modern centralized power systems remain prone to unexpected failure, whether from cascading failures or widespread geographical disasters. Microgrids can dramatically improve the reliability of such power systems. The first instance of such reliability improvement occurs at the local site of the microgrid. In times of disaster, an islanded microgrid can continue operation, maintaining local power supply autonomously. Microgrids can also improve the reliability of supply more broadly than their immediate vicinity. If the wider grid is operational but strained, a microgrid can assist by reducing the load on the wider grid, or even exporting power from the microgrid to a broader area. As well as power management, microgrids can also help with voltage and frequency control in such situations. If the wider grid is not functioning, a carefully managed local microgrid may be able to restore power supply to its immediate neighborhood by, in essence, temporarily broadening the region of the microgrid to create a larger islanded region around the microgrid. Such scenarios need particularly careful management to ensure electrical safety and maintain the reliable operation of the microgrid itself.

Microgrid associated technologies

Technologies associated with microgrids range from particular types of generation, through to energy storage devices, load controllers, and the underlying control and coordination systems. Common technologies are listed below:

i. Microturbines are a fixed generator based on gas turbine technology. These typically operate in the 25 kW to 100 kW range, and consist of a turbine, electricity generator and inverter interfacing the turbine with the wider electricity grid. Microturbines have relatively clean exhausts, usually operate on natural gas, and may be part of a CHP system.

ii. Batteries are increasing in prevalence as a way of providing reserve power during outages and for smoothing the output of renewable energy sources. There is an increasing range of battery technologies available for deployment into electricity grids, from traditional lead-acid technologies through to newer flow-battery designs. Batteries are interfaced to the electricity grid through an inverter/charger.

iii. Flywheels/super capacitors offer an alternative to battery storage, with very high power outputs possible at a lower cost. The focus on such systems is the power available, rather than the total energy stored – batteries can supply power for longer, but flywheels and super-capacitors can supply very large amounts of power in a short time, more cheaply and with a longer lifetime than a battery.

iv. Fuel cells produce electricity from an input fuel and oxidant, but without the combustion of typical fuel generators. They offer very high efficiency and low emissions, but are currently very expensive.

v. Renewable generators such as solar PV or wind turbines are growing in prevalence as their reliability improves and price of generated electricity approaches that of non-renewable sources.

vi. CHP systems improve the efficiency of distributed generators by capturing waste heat and utilizing it in a downstream process. Typical applications of CHP systems are in heating buildings, where the waste heat from the generator is used to directly heat a building, or cooling, where the waste heat is used in a heat-driven-cooling process to cool a building.

As well as the key generation and load technologies introduced above, a number of "infrastructure" technologies are required to fully realize the features described in our earlier microgrid vision:

- Advanced high-speed control methods to maintain microgrid stability and provide intelligent and dynamic operation, despite having no central point of grid "inertia"
- Advanced sensing, diagnostics, forecasting and adaptation technologies to provide the microgrid control system with detailed and up-

to-date information on the status of the microgrid. Care must be taken to ensure that a minimum number of sensors are used and that the total capital outlay is also minimized

- Integrated communications systems to link the various resources in the microgrid to ensure reliable operation, even during typical communication outages

IV. Challenges and barriers

Whilst microgrid technologies hold great promise as a transition path to low-emissions electricity networks, and as a way of improving the reliability or resurrection of supply during disasters, a number of fundamental challenges need to be addressed before they become commonplace. These challenges are both technical and non-technical.

A. Technical challenges

Below are some of the fundamental technical challenges to be addressed to enable wide scale microgrid uptake.

i. Synchronizing multiple small generators

The use of multiple distributed generators can pose significant challenges in a microgrid that is not currently connected to a functioning wider grid. In short, without the “inertia” provided by the wider grid, the multiple small generators lose any form of central stabilizing force. This can cause problems, particularly with frequency and voltage stability. Such issues are solved by developing intelligent control schemes that synchronize the various devices. But there are trade-offs. They typically rely on having a relatively fast and ubiquitous communications network available to link the various microgrid components. Ultimately, although solutions exist, the operation of a power system based on many small components rather than one large generator is a more complex task than current engineering approaches are accustomed to.

ii. Intermittent generation sources

Distributed generation based on renewable sources, such as wind or solar, can pose an extra challenge to microgrid development. The intermittency in the power supply available from renewable generation (caused by, for example, wind gusts or clouds passing overhead) means that not only is power flow bi-directional, but the power being fed into the system from such sources at any one time can vary randomly. Solutions here range from the use of batteries or other energy storage to smooth out generation intermittency, through to tighter coupling of supply and demand to ensure demand matches intermittent supply, and forecasting techniques that can aid system management by predicting the profile of future generation.

iii. The use of inverters

In a microgrid, inverters convert the DC output of the generator to AC, control the frequency of this supply, monitor power flows in the network, and provide basic fault and isolation protection. The challenge to successfully integrating inverters into the microgrid is being able to facilitate parallel operation of inverters serving potentially heterogeneous sources, without loss of synchronization, propagation of harmonics or loss of stability in general. Having a small number of inverters presents a challenging, but well-studied, dilemma. If the inverters use centralized or master-slave control, current sharing is enabled but high-bandwidth links are required to facilitate the distribution of error signals [9]. In contrast, distributed, on-board (to the inverter) control reduces the bandwidth but at the cost of synchronization difficulties [9]. Though such techniques appear well understood, they focus upon systems with very few inverters. For larger microgrids with numerous inverters, the available literature is less comprehensive and doubts remain as to the scalability of those techniques proposed for small-scale systems. In particular, given the complex interactions that may occur between inverters [9], there is increasing potential for problematic emergent phenomena to appear as the size grows. Predicting and controlling such behavior is difficult and has not been sufficiently explored in earlier work.

iv. Planning and design of microgrids

A large number of quite different devices make the design of microgrids quite complex. Issues of installation cost, environmental impact, line loss, grid connectivity, reliability, resource longevity, reuse of waste heat, capacity for intentional islanding and physical constraints all affect the decision-making process. Often, a goal such as maximized reliability will confl ict with another such as minimized operating costs. Overall, the complexity means heuristics or rules-of-thumb for microgrid design are inappropriate if an optimal or near-optimal system configuration is required. Sophisticated design tools using artificial intelligence approaches are needed for optimal microgrid planning, and such tools are only now being realized.

v.Islanding

A central benefit of the connected microgrid, particularly in disaster relief, is the capacity to ride through failures which occur on the utility grid, with limited loss of localized service.

By rapidly disconnecting from a faulting system (intentional islanding), adjusting local generation and shedding non priority loads, particularly high levels of reliability can be guaranteed for priority resources on the microgrid. However, achieving this goal is not straightforward. First, the fault condition on the wider grid must be detected. Then, the microgrid must transition to island mode in a controlled manner – with the variety of distributed resources cooperating, and the loads being batched to the available generation capacity, which may include shedding some low-priority loads. Finally, when the fault on the wider grid is cleared, the microgrid must be able to make the transition back to normal service. Managing each of these phases is a significant technical challenge, and much

work remains to develop reliable, flexible and affordable microgrid controllers that can realize these goals.

vi.Microgrid modelling

Microgrids are expensive to install and set up for research purposes. Researchers and developers often rely on software tools to model and then predict the performance of microgrids but there is no single tool available that is immediately suitable. Further, in spite of the fact that many DER have existed for some time, there are few accurate models of wind turbines, solar PVs and fuel cells, along with their associated controllers, currently available [10] to use in existing modelling tools. There is likewise no consensus on models used for the economic planning of microgrids. Research is currently underway to develop various models that serve the needs of the particular research interests of the modeller, for example, optimal operation based on 30-minute demand data [11], [12]. Models of real time markets are being developed [13] to investigate how microgrids can operate as autonomous entities within the wider market. Ultimately, the entire area of microgrid modelling, from engineering to economic, is relatively immature, and needs significantly more work.

vii. Microgrid protection

In general, devices, such as circuit breakers, that detect and isolate faults in electricity systems are specified assuming that the source has an available fault current much higher than the load. In a microgrid, electricity can often flow in multiple directions, depending what state the microgrid is in at a particular time. This makes the planning and operation of protection systems quite a challenge. Compounding these challenges, faults may be difficult to detect in microgrids, which often do not have high fault currents, unlike the traditional macrogrid. In such circumstances, a short circuit scenario may be difficult to detect, as the short circuit current was similar to the regular operating state of the microgrid.

B.Non-technical barriers

As a new technology that represents a fundamental shift in how we operate our power systems, a number of non- technical barriers to microgrid operation also exist.

i. Cost of microgrids

A barrier to the uptake of microgrids is often the perceived higher financial cost of DER compared with generation in centralized power stations. In particular, the higher per-kilowatt price of distributed generators is often cited as a drawback, while doubts remain about the on-going maintenance and operation costs. Recent studies however have found that the cost of generating power in a microgrid is comparable with present electricity supply, as long as support for PV is available [10]. Moreover, in developing countries without infrastructure, DERs may be more likely to be cost effective, since their installation cost must be compared with that of installing high voltage transmission lines [14].

Financial cost features regularly in optimization studies of microgrids, typically offset against other desired properties, such as CO2 reduction. A great deal of effort is being given to developing microgrid models that will help calculate this offset. A case study of the hypothetical installation of DERs in a hotel reveals a 10 % cost saving and 8 % CO2 saving [15]. Behind these models are assumptions about the cost of electricity sourced from traditional power stations, which may prove incorrect when a CO2 tax (or a similar mechanism) is imposed or costs change as a result of new technologies.

ii. Business models

Compounding the cost challenges of microgrids is the broader problem of calculating their returns, in order to justify their commercial benefi ts to a business. In a simple analysis, a microgrid may only operate as a system to provide uninterruptible power after a wider electricity outage. Calculating the financial benefit from this service, versus the cheaper and less complicated option of insurance can be a challenging prospect. More sophisticated uses of microgrids may in fact earn the owner a return – as discussed earlier in this White Paper, microgrids may participate in demand side response or similar programmes, earning a return for the response they provide. Whilst conceptually relatively simple, estimating the actual returns from such concepts is quite difficult – currently, the returns from participation in demand side markets vary dramatically based on jurisdiction, location and what incentive programmes are currently in place. Add complications such as varying fuel prices, and the risks inherent with new technology, and calculating a business return from microgrids is a challenging task.

iii.Risk evaluation

Whilst one of the key benefits of microgrids is to help with preparedness and recovery from major electricity outages, the actual risk a particular plant faces against such disasters is often poorly understood. As shown in many of the case studies in this Paper, humans are generally poor at estimating risks and their consequences, the likelihood of major electrical outages, their length, and subsequent effects on business. It is understandable that stakeholders may also underestimate the benefits a microgrid may offer.

iv.Policy, regulation and standards

The microgrid concept is relatively new, so it is not surprising that the regulatory framework for integration of microgrids into the wider grid is still developing [16]. Getting this framework right is crucial, as it deeply affects the economic benefi ts of microgrids [17]. It is clear that the current framework poses some barriers for the uptake of microgrids [15]. For example, IEEE Standard 1547 requires that grid-connected power inverters can detect a grid fault and will shut down in that event. Consequently, commercial inverters are designed to do just that, and there is no incentive for them to offer island transition and support of uninterruptible supply in microgrids. This standard is driving research into the static switch, which can disconnect and reconnect in sub-cycle times [18]. At the operational level, there is no agreed policy relating to the way microgrids should behave under different operating conditions, such as with light or heavy loads, with or without grid connection or after communication failure (see, for example, [19]). Research into standards is being conducted for the operation of microgrids [20] and a new generation of energy management systems is being designed to meet the challenges, in particular to meet the requirements of International Standard IEC 61970 [21]. The work as yet is in

its early stages. The potential for a microgrid to be owned by different entities with conflicting interests is also problematic. Policies should address how investment and maintenance costs should be apportioned between parties, what loads are to be disconnected in the event of faults and what (if any) compensation should be due in the event of a loss of power.

v. Training

Perhaps one of the greatest challenges to the widespread acceptance and uptake of microgrid technologies is the general lack of familiarity with the basic concepts behind them. As a relatively new technology, there is a lack of confidence in dealing with the concept and in some cases illinformed preconceptions about their challenges. This concern exists among legislators, electricity systems operators and even technical personnel responsible for microgrid design and installation. Perhaps the latter category is the most worrying – currently, in many countries and jurisdictions, there is a general lack of awareness around the design and construction of electrical systems with embedded generation, two-way power flows, islanding and other key characteristics. Such issues can certainly be addressed by professional development programmes, and need to be a key consideration for the widespread uptake of these technologies.

C. Future trends

As a rapidly developing technology, it is always difficult to predict how the broader industry around microgrids may develop. When considering the use of microgrids for disaster relief, it is worth exploring some of the possibilities. The following sections introduce some of the most recent concepts being considered.

i. Virtual microgrids

This Paper defines a microgrid as having a number of generation sources located geographically close to each other. Intuitively, to have any benefit, generators must be connected to the same electrical network, yet some of the benefits of microgrids are possible with generators remaining geographically distant. Such a scenario can be referred to as a virtual microgrid. One commercial example of a virtual microgrid is with deregulated energy markets, where an electricity retailer may benefit from distributed generation sources. When a retailer is exposed to volatile electricity markets, it may use demand management, or distributed generation, to help manage its financial risk. In this situation, the retailer benefits simply by being able to dispatch generation to reduce its total overall load profile. It does not matter where the generators are located, or how they are electrically connected, as long as they are customers of this particular retailer. In the context of disaster preparedness or relief, virtual microgrids may be relevant because they bring a situation in which the entity controlling the microgrid may have to manage a number of disparate devices, residing in geographical locations that have experienced quite different conditions during the electricity outage.

ii. Resource networks

This Paper has focused on microgrids as a network of electricity generators, yet in many applications, electricity is only one of the key resources at play. Water, gas and other resources have their own distribution networks, and these may interact with that of the microgrid. Ideally, when considering broader resource management questions, it is important to consider the interplay between these various resources. Recent research suggests that a microgrid should not be studied as a network of electrical devices, but, rather, as a network of key resources and functions. This might include the provision of reliable electricity and water supply, the use of natural gas, and perhaps the provision of heating or cooling. Whilst research or development around microgrids of multiple resources is relatively immature, for now we can make one key conclusion regarding microgrids for disaster relief and preparation. As was seen in the Roppongi Hills case study, for an electrical microgrid that may be dependent on other resources, such as gas fuel supplies, factoring in such dependencies will be critical to reliable microgrid operation.

iii. Clustered microgrids

In this Paper, microgrids have generally been considered as a standalone entity, with the focus being on how a single microgrid can restore or maintain electricity supply within itself or (for example) the challenges of managing multiple resources within one microgrid. When microgrids proliferate, a number of microgrids could possibly be coordinated together. Such coordination would involve using a hierarchical structure. With no hierarchy, large numbers of microgrids being controlled by one entity essentially face the same challenges as in operating today's macrogrid. On the other hand, adding too many levels of hierarchy adds overheads to the system, wasting resources and slowing responsiveness. In relation to disaster relief or preparedness, clustered microgrids would have an impact similar to that of the concept of virtual microgrids discussed earlier. They would add to the management complexity, but at the same time bring additional flexibility to the power system.

II. CONCLUSION

One technology that can play a significant part in planning for more resilient and reliable electricity supply systems is the microgrid, which builds on the benefits of distributed generation technology. Distributed generation, in the form of local gas or diesel engines, through to rooftop solar systems or even energy storage devices, is a relatively common part of today's electricity systems. Distributed generators are now an accepted means to improve the reliability of electricity supply at their host site, acting as uninterruptable power supplies. Yet today we are failing to realize the full potential of distributed generators. By coordinating multiple distributed generators, and integrating control of loads with this function, we realize the concept of a microgrid. Microgrids bring additional benefits, such as improved reliability (no single point of failure), lower emissions through providing for renewable energy supply, and even allowing for the export of power to wider areas of the electricity system.

As a new technology, microgrids are not without their challenges. As well as detailing the potential benefits from microgrid technology, this Paper also examined some of the challenges to their operation, from technical challenges such as the lack of standards that specify common control interfaces between devices in microgrids, through to non-technical challenges such as appropriate business models to support the business case for microgrid development. Following the examination of the recent major electrical disasters, the response to these disasters, and the availability of new technologies such as microgrids, several recommendations can be made for policy-makers, industry and standardization organizations, aimed at improving the resilience of our communities against electrical failure.

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