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Review of Microgrid Development in the United States and China and Lessons Learned for China

Jiancheng Yu[a], Chris Marnay[b *], Ming Jin[b,c], Cheng Yao[a], Xu Liu[b], Wei Feng[b]

[a]Tianjin Electric Power Co., Tianjin, 200001, China
[b]Lawrence Berkeley National Laboratory, Berkeley CA, 94720, USA
[c]University of California Berkeley, Berkeley CA, 94720, USA

Abstract

The U.S. has emerged as the microgrid development leader with around 40% of worldwide capacity. Over the last decade, demonstrations have been executed by a mix of civilian federal, military, private, and local government entities. While their motivations are mixed, resilience became the focus following Superstorm Sandy in 2012, especially in the highly active northeast states. This paper describes U.S. microgrid demonstrations. Then it shows China's effort to develop microgrids and compares the difference between U.S. and Chinese projects. Finally, based on U.S. experience, recommendations are provided for Chinese microgrids.

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1. Introduction and Background

The U.S. is the world's single biggest microgrid (MG) market by far, accounting for approximately 40% of the total capacity either in place or under development [1]. A widely used *microgrid* definition developed by the U.S. Department of Energy is given below. The entire Asia Pacific totals a similar sized market, including China, and significantly, Japan. Reasons for U.S. this dominance are somewhat unclear, but its relatively unreliable and aging legacy electricity megagrid is certainly one driver. The low cost and wide availability of natural gas is another, especially in the northeast and California, where electricity prices are relatively high, i.e. the *spark spread* is attractive. Other key drivers are the push towards high renewable penetration and equivalent low carbon footprint, which together with other environmental objectives are a particularly powerful motivation in California. Open access to power markets, as is widespread in these same two areas could also be a motivator, especially access to various demand response and ancillary service market opportunities. More generally, it may be that the potential of coping with supply- and demand-side variability locally is a potentially valuable service to the megagrid that can generate attractive revenue streams [2]. Finally, resiliency merits a special mention. The entire eastern seaboard of the U.S. is prone to hurricanes, and the trauma of several serious ones experienced from Andrew in 1992 to Sandy in 2012 particularly sensitized policymakers to the dangers, and MGs became recognized as a proven way to harden electricity supply. The recent 2017 hurricanes, Harvey, Irma, and Maria, will surely intensify this effect, and extend it to the southeast U.S. and the Caribbean. Finally, since the military are especially concerned with secure energy supply, it has been influential in the development of MGs in the U.S.. In this paper, the research underpinings for U.S. MG development are described, and some case study MGs examined. An example from China, the Animation Park at Tianjin Eco-City, is also covered, and finally, lessons for MG development in China are drawn.

2. Overview of U.S. MG policies and research

2.1. Federal level policies and research

The Office of Electricity Delivery and Energy Reliability (OE) within the U.S. Department of Energy (DOE) has invested in a portfolio of MG research and development activities over the last decade, many of them in conjunction with the Department of Defense (DOD) [3]. OE developed a definition of MG in 2010, which has become widely accepted in the U.S. and internationally, and others are similar [4,5]. The final sentence was added in 2017.

A MG 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.
A MG can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode.

A *remote* MG is a variation of a MG that operates in islanded conditions. [6]

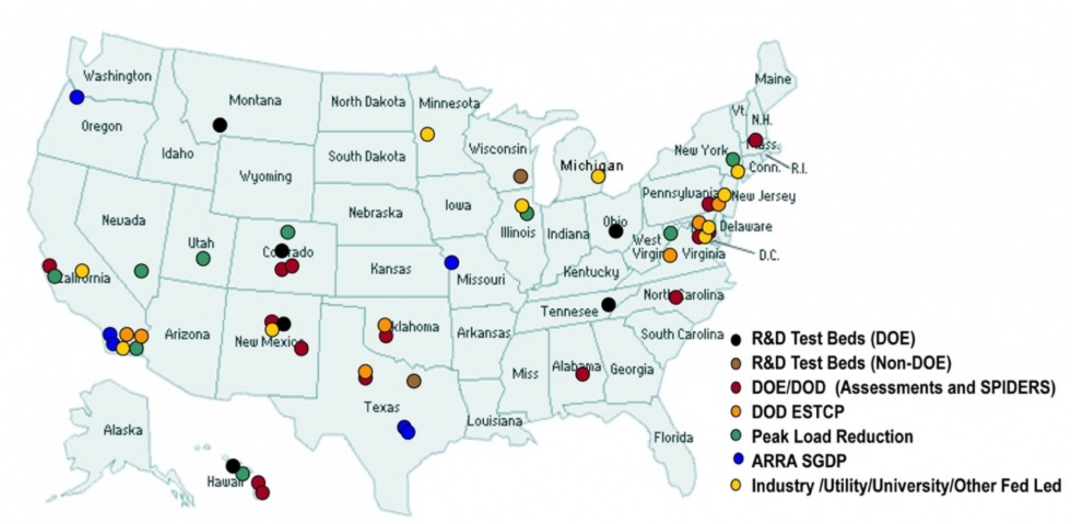

Fig. 1. Select U.S. Federal MG assessment and demonstration projects (source: OE)

OE's first major program began in 2008, and the nine Renewable and Distributed Systems Integration (RDSI) initiated are shown in green on Figure 1. Projects totalling $100M, typically with 50-50 DOE and co-funder financing, were primarily intended to achieve a minimum 15% peak load reductions. The two California projects, Santa Rita Jail and Borrego Springs both received subsequent California Energy Commission (CEC) funding, became exceptional MG examples, and are still operating. They are described in more detail below. The red projects are joint DOE-DOD projects developed under the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS) program, which began in 2010 [7]. Since military bases are often in remote locations poorly served by the megagrid, highly reliable and resilient power is often needed. The first three SPIDERS demonstrations were at Hickam Air Force Base and Camp Smith, both in Hawaii, and Fort Carson, Colorado, but MG principles were rapidly adopted and have been applied at many sites, effectively making them the default power system for military facilities [8]. Under the (approximately $4B) American Recovery and Reinvestment Act of 2009 (ARRA) smart grid (SG) program, numerous projects were conducted, including one at Borrego Springs and one neighbouring the U.C. Irvine (UCI) campus MG, both described below. Many of these projects demonstrated technologies critical to MGs, e.g. battery storage; however, only one complete MG project was executed under ARRA by Portland Gas and Electric, in Salem, Oregon as part of the Pacific Northwest SG Demonstration Project [9,10,11].

OE designated next-generation MG systems with goals: "to develop commercial-scale MG systems (capacity <10 MW) capable of reducing outage time of required loads by >98% at a cost comparable to non-integrated baseline solutions (uninterrupted power supply plus diesel genset), while reducing emissions by >20% and improving system energy efficiencies by >20%, by 2020." These goals have remained consistent, and consequently, OE research moved from demonstrations towards systems integration, particularly focused on MG controllers and standards for Advanced Microgrids [12,13]. This pivot coincided with a desire for MG standardization to speed deployment, and for more sophisticated operations, as described in an influential 2014 Sandia report [14]. OE funded 8 MG controller projects covering a wide range of MG types and widely spread across the U.S.

While the Federal programs described above were the main engine of early U.S. MG research, there has always been significant private sector activity in the area, often arising from self-generation projects, typically at large commercial, campus, medical, or industrial sites, typically built around central plant combined heat and power (CHP) facilities. The 2011-2012 period when OE research was redirected was a pivotal year in MG development for much more dramatic reasons, and exactly these facilities, e.g. the New York University campus, played central roles. During the Great East Japan Earthquake in March 2011, two MG projects, the longstanding Sendai MG and the Roppongi Hills district of Tokyo, both performed magnificently, reorienting the research direction of this early MG powerhouse towards resilience [15]. In late October of the following year, Superstorm Sandy hit the northeastern states. In a similar manner, some existing MGs performed well, and state policymakers took notice too, leading to a similar reorientation of research in that part of the U.S. [16]. The great interest by state and local government in the resilience benefit of MGs has spawned programs of varying size and complexity in all the states affected by Sandy, but the State of New York's Prize (NY Prize) program, managed by the State Energy Research and Development Administrations (NYSERDA), is the most extensive.

The NY Prize is an ambitious $70M grant program with additional leverage opportunities designed in 3 stages. The first, Feasibility Study stage, completed in 2016, produced 83 studies of possible MGs to protect public facilities, especially emergency services [17]. The second stage is now in progress and will lead to the production of 11 detailed engineering and financial studies, while the final stage beginning in 2019 will see build out of some projects. Outside of the northeast, other states have also achieved notable MG research and demonstration successes, notably California, whose MGs grew from the CEC's Renewable Energy Secure Communities program [18]. Interestingly, New York has a different MG definition reflecting its resilience focus: MGs are local energy networks that are able to separate from the larger electrical grid during extreme weather events or emergencies, providing power to individual customers and crucial public services such as hospitals, first responders, and water treatment facilities. [19]

2.2. Utilities and Independent System Operator (ISO) activity

Utilities have themselves developed microgrids, sometimes called *milligrids*, e.g. Borrego Springs, which is discussed in the next section [20]. Also, under their regulatory regimes, utilities provide financial incentives and rebates for some MG technologies, notably for small-scale renewables, batteries, and load control through programs like California's Self-Generation Incentive Program (SGIPs), which covers various technologies. *Net metering* programs enable MG owners to sell excess energy, although the terms vary widely across states. Open electricity markets in much of the U.S. interact with MGs by encouraging demand response and ancillary services provision to the megagrid. Because of their wide spectrum of energy technologies and (often) advanced control systems, MGs can participate in a variety of markets, e.g. ancillary services such as fast frequency response. In other words, MGs can serve as an integrator and aggregator of local capabilities, and can offer them to the local electricity distribution company or grid operator, as their programs and markets allow.

3. U.S. MG case studies

To show the diverse landscape of existing MGs in the U.S., four representative projects are listed in Table 1 below. They cover a range of funding sources, technologies, and primary functions, e.g., institutional, campus, utility owned, and brown field development. 1. Funded by DOE, Alameda County, and the CEC over the past decade, the Santa Rita Jail demonstrates the Consortium for Electric Reliability Technology Solutions (CERTS) technology, which allows the Jail to seamlessly and quickly disconnect from the grid and run islanded for extended periods [21]. 2. Owned and operated by the UCI, this campus MG aims at testing internal operation as well as interface with the rest of the future SG. UCI has recently partnered with Southern California Edison to test advanced SG technologies, such as phasor measurement units, to enable transmission substation-level situational awareness [22]. 3. The Borrego Springs demonstration, supported by San Diego Gas and Electric, OE, and the CEC serves a community of 2,800 customers and exemplifies an *unbundled utility microgrid*, wherein distribution assets are owned by the utility, but some or all of the distributed energy resources are owned by independent power producers and customers [23]. 4. The historic Philadelphia Navy Yard base now owned and operated by the Philadelphia Industrial Development Corp (PIDC) ranks among the largest non-municipal distribution systems in the nation in terms of area served and electricity consumption. Also, being a former Federal facility, The Navy Yard is exempt from price regulation, which provides a particularly interesting testbed for innovative tariffs. The current commercial and industrial campus hosts over 120 companies and 3 legacy Navy activities totalling more than 10,000 employees [24]. More generally, MGs are now entering the culture, and are widely recognized both technically and institutionally as platforms that can enhance reliability and resilience as well as create a fertile environment for renewable adoption, load control, and active electricity and ancillary service markets [25].

4. Microgrid development in China

Energy and Environment is a key issue for the Chinese government. China has long since overtaken the United States as the world's leading CO_2 emitt**er**. The central government plans to peak China's CO_2 emission by 2030. Relying on coal as its major energy source caused not only large CO_2 emissions, but also unhealthy air quality. Thus, finding alternative energy resources is the government's first environmental priority for future sustainable development. China has ample renewable energy resources in the west: however, the majority of energy use is concentrated in the Eastern coastal area. Given the intermittency of renewable energy and the challenge of long-distance transmission, harvesting clean and renewable energy at the local level is attractive, and developing MGs has become an important research area.

China started its MG research and development in the 12^{th} Five Year Plan [*] (FYP). The National Energy Administration (NEA) targeted 100 clean energy demonstration cities and 1000 clean energy demonstration campuses. In those demo projects, comprehensive energy service to combine electricity with cooling and heating is encouraged. China also expected to build 30 national level MGs demonstrations by 2015. In the 13^{th} FYP[†], the NEA further developed policies for distributed clean energy development. The targets now call for 55 smart energy and *energy internet* demonstration projects and 28 MG demonstration projects.

	Santa Rita Jail	UC Irvine	Borrego Springs	The Navy Yard	Tianjin Eco-city Animation Park
Funders	Alameda county, DOE	UC Irvine	SDG&E, CEC	PIDC	Chinese government
Projects	CERTS, RDSI	SGDP	RDSI, CEC	AM	Sino-Singapore Smart Grid Integrated Demonstration Project
Site	Dublin CA	Irvine CA	Borrego Springs CA	Philadelphia PA	Tianjin China
Capacity	4 MW	24MW	4 MW	34 MW	4.5 MW
Generation technology	PV (1.2MW), diesel generation (2.4MW), molten carbonate fuel cell (1MW)	gas turbine (13.5MW), PV (3.5MW), steam turbine (5.6MW)	Diesel generators (3.6MW), PV (700kW)	Gas/diesel turbines (9MW), PV (2MW), fuel cell (600kW)	CCHP (1.5 MW), PV (1 MW), ground-sourced heat pump (1 MW)
Storage technology	Li-ion battery (2MW/ 4MWh)	thermal storage (17000 m^3, 211 $MWht_h$), Li-ion battery (2MW/ 0.5MWh)	Li-ion battery (1.5MW/ 4.6MWh), three community batteries (75kW/ 150kWh), six home storage (4kW/ 8kWh)	Community solar and energy storage (125kW)	batteries (700 kWh), thermal storage (45.7 MWh for heat, 24.3 MWh for cooling)
Electric vehicle	NA	eight level 2 chargers, H_2 station 180kg/day	NA	small demo	charging stations
Control system	distributed energy resources management system	MelRoK EnergiStream, interfacing with MG model for real time data	SCADA on all circuit breakers and capacitor banks, feeder automation	coordinated distributed control, automated demand response	comprehensive multi-stage energy coordination and control system
Connection interface with utility	reverse power relay, seamless islanding (in < 8 ms)	69kV to 12kV using two 15 MVA transformers	Borrego substation 69kV to 12kV	two main substations through 13.2 kV feeders, 15 MW&19 MW	standard substations
Operation	seamless islanding	islanding	manual islanding	grid connected	grid connected

Table 1. Summary characteristics of example U.S. and Chinese MGs

The overall objectives for NEA MG development policies promote clean and renewable energy adoption at the distributed level and decarbonizing energy use for campuses and facilities. This is the main driver of current MG development. To support these policies, research has focused on the technical specification of different MG types [26].

* From 2011 to 2015

† From 2016 to 2020

China's specification categorizes MGs into off-grid, grid-connected and grid-assisted. It further specifies system configurations and technologies for each type and possible technologies budgets.

One of China's most successful MG demonstrations is the Tianjin Eco-City MG. This demo project features a new energy model for sustainable development, enhances renewable energy penetration, and demonstrates an energy system takes action against climate change. Tianjin Eco-City has a land area of 34.2 km^2 and will be completed over 10-15 years. It will accommodate a population of 50,000, and had a maximum load of 39.6 MW in 2016. Research focuses on the fields of intelligent power distribution and utilization, including distributed generation, microgrid planning, distribution network operation and utilization efficiency, energy dispatching, smart homes, big data analysis, and smart grid evaluation. The Animation Park microgrid component is designed to supply energy for seven office buildings, and includes a 1.5 MW gas-fired CHP system with a 1 MW ground source heat pump that supplies both heating and cooling. Thermal storage tanks are installed so the heat pump can be dispatched during early morning to produce heating and cooling ahead of building requirements. A 1 MW solar PV array is also integrated into the MG together with a 700 kWh battery bank. Together with the U.S. examples, the technical features of the Animation Park MG are summarized in Table 1, demonstrating its high level penetration of distributed generation and storage. More research could be done on the MG's resiliency and islanded operation, as well as advanced communication and controls for demand response and export. With the future establishment of Chinese electricity markets, this type of MG could play a bigger role in demand response, and provide ancillary serveries to the megagrid.

Comparing U.S. and Chinese MGs, in the U.S., development is typically driven by multiple parties including multiple levels of government, research institutes, distribution utilities, and the private sector. Comprehensive incentives and policies are found at the federal, state, and local government levels, and at utilities, while in China, central government policies and local utility initiatives are the main driving forces. U.S. and Chinese MGs also exhibit some technical differences. One is that U.S. MGs are more grid integrated and capable of providing grid ancillary services, and MG demonstrations for resiliency have become more and more common in the U.S., but much less so in China.

5. Recommendations for China

China has made considerable effort to develop MGs; however, current demonstrations tend to focus on showcasing technologies rather than operation models, and understanding the benefits is also underplayed. Recommendations for developing demonstration projects in the future in China follow:

- Define clear goals and targets for various types of demonstration projects.
- Articulate the spectrum of expected benefits to MG members, the megagrid, and society as a whole.
- Shift from technology-oriented demonstrations to technology plus market mechanisms and business model demonstrations and enable projects scalable to current markets.

Analyze MG demonstrations and associate demonstrated benefits with government incentives received. From the policy perspective, China has established a good framework to encourage distributed renewable interconnection; however, there are still many areas that U.S. experience could China's MG development, such as:

- Establish national and provincial MG research programs to encourage development and application of new technologies entering into market.
- Remove barriers to interconnection, and develop a clear procedure for non-PV distributed generation to connect
- Foster electricity markets in China and create demand response and electricity ancillary service signals to enable distributed energy assets to supply grid services
- Utility companies will not only participate MG development but also act as the incentive providing agencies for MG developers and users.

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Biography

Chris Marnay has worked for 18 years in the MG space, mostly at Berkeley Lab., where he remains affiliated within the China Energy Group. In 2001, he proposed the principles on which DER-CAM are based, and led its development until his retirement. He currently leads the independent consultancy, MgDoM LLC.