A Larger Role for Microgrids

Are Microgrids a Viable Paradigm for Electricity Supply Expansion?

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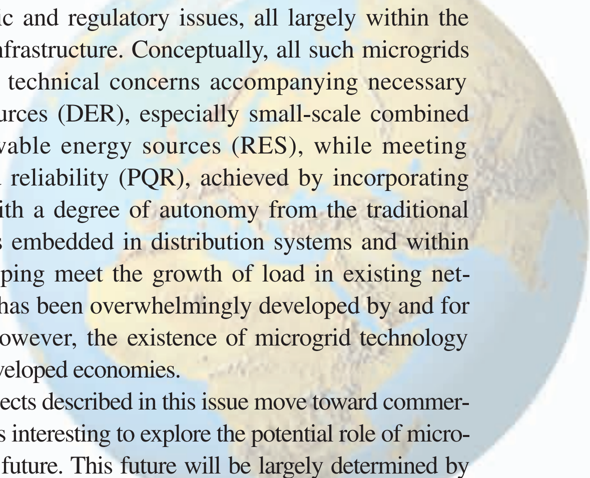

THE OTHER ARTICLES REGARDING MICROGRIDS APPEARING IN THIS ISSUE OF *IEEE Power and Energy Magazine* have discussed various architectures, demonstration projects, operational and control principles, and economic and regulatory issues, all largely within the context of an existing highly developed utility infrastructure. Conceptually, all such microgrids may be viewed as a framework that addresses technical concerns accompanying necessary growing deployment of distributed energy resources (DER), especially small-scale combined heat and power (CHP) and small-scale renewable energy sources (RES), while meeting demanding requirements for power quality and reliability (PQR), achieved by incorporating modern controls that enable them to operate with a degree of autonomy from the traditional macrogrid. This conceptualization of microgrids embedded in distribution systems and within customer commercial or industrial facilities helping meet the growth of load in existing networks has evolved because microgrid capability has been overwhelmingly developed by and for applications in highly developed economies; however, the existence of microgrid technology might also alter the trajectory of progress in less-developed economies.

As the microgrid technology demonstration projects described in this issue move toward commercial developments in diverse future applications, it is interesting to explore the potential role of microgrids in a wider emerging global electrical energy future. This future will be largely determined by population growth and the rapidly expanding resource requirements of newly industrializing economies, environmental concerns (particularly climate change), and dwindling fossil-fuel reserves, together with the geo-political instability these forces are creating. The only element that may be confidently forecast is that electricity demand will grow. Despite more efficient technology, in general, development has led to an increasing share of end-use energy being electricity, and this link is unlikely to be broken. Our growing requirements for the energy services provided by electricity are unlikely to abate, and they will be met using a collage of approaches, technologies, and solutions. Examination of the electricity demand growth problem indicates that, conceptually, microgrids are well suited to play a significant role in the future evolution of energy service provision.

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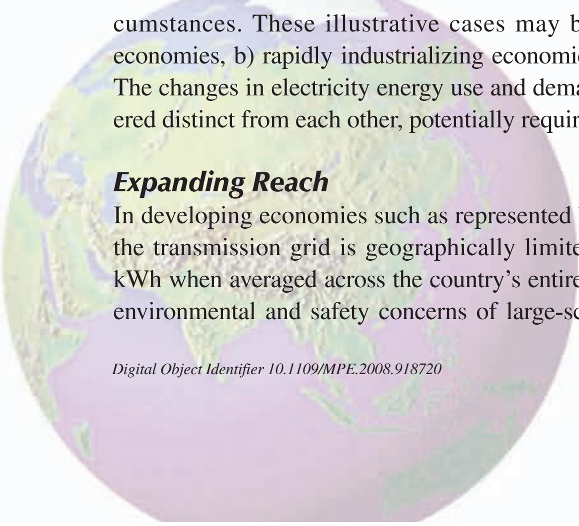
Three Faces of Change

The level of electrification within a geographical region may be estimated by considering the number of circuit kilometers of transmission lines per unit area of the region. The circuit kilometers of high voltage (>132 kV) transmission lines for a square kilometer of land area for Zambia, India, and Germany are illustrated in Table 1. Corresponding data on the population percentage with access to domestic electricity in 2000 and annual per capita energy consumption in 2000 and 2003 are also provided in Table 1, along with average growth of annual per capita electrical energy consumption for the three countries. The amount of electricity consumption per capita and the percentage of population with access to grid electricity clearly indicate the structure of the economies in these countries, and they are typical of others in similar circumstances. These illustrative cases may be considered representative of a) developing economies, b) rapidly industrializing economies, and c) postindustrial economies, respectively. The changes in electricity energy use and demand in these classes of economies may be considered distinct from each other, potentially requiring diverse solutions.



Expanding Reach

In developing economies such as represented by countries in Sub-Saharan Africa, the reach of the transmission grid is geographically limited. Daily per capita electricity use is about 1–2 kWh when averaged across the country's entire population. In this stage of development, even if environmental and safety concerns of large-scale electrification using fossil fuels and nuclear

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energy are set aside, the capital investment required to expand the traditional centralized power system to reach most of the population makes such a proposition prohibitive. Development is hampered by lack of purchasing power and low levels of average consumption among the unserved populations.

On the other hand, the concept of a micro-utility pioneered by Grameen Shakti in Bangladesh (see Figure 1) offers evidence of the relative ease with which grass-roots solar electrification projects can be carried out without heavily subsidized large capital development assistance, when appropriately integrated with community economic development. Similar applications of renewable energy technologies such as micro-hydro, photovoltaic cells, and small-scale wind turbines are well developed and have been deployed widely in the developing world. Technologies and operational models for conventional combustion engine generators based on renewable fuels like biomass, bio-diesel, and agricultural waste are also becoming viable through various demonstration projects. Furthermore, small hybrid systems based on operating diesel engine generators together with solar and/or wind power systems have been put to use extensively in residential off-grid applications. Even in nonremote locations, rather than expanding the macrogrid, an autonomous microgrid is already a preferred option to extend the reach of electricity to populations with limited purchasing power. Access to electricity at this stage of development is accompanied by modest levels of per capita consumption and low equipment capacity factors, but at the same time, electricity supply is a key enabling factor for realizing broader developmental goals including education, healthcare, and trade. Further, initial local autonomous microgrid deployment does not preclude future macrogrid expansion. Most interesting from an electrical engineering perspective is the question of how might the macrogrid evolve differently in such an environment. Specifically, how would a macrogrid look if engineered to deliver large quantities of carbon-free generated electricity to local microgrids that control their PQR locally?


USAID/GRAMEEN SHAKTI

figure 1. A rural Bangladeshi family enjoys the benefits of solar power, including lights and television (source: www.usaid.gov/stories/bangladesh/pc_bd_solar.html).

Managing Growth

When electricity access becomes broader, as in the rapidly industrializing economies, represented by countries such as India, the reach of the transmission grid becomes more balanced. However, there tends to be a large deficit in generating capacity due to rapid growth in demand; i.e., electricity demand grows rapidly despite falling birth rates. The daily per capita electricity use is about 1 to 2 kWh when averaged across the country's entire population but more of the population has access to electricity. Considering the fact that in 2000 only 43% of the population in India had electricity service, the average daily per capita electricity use is about 2 to 3 kWh for the connected population. At this stage of development, the major challenge in developing electrical energy includes: a) expanding access to electricity for those sections of populations not reached by the grid, and b) meeting increased demands from sections of populations within the reach of the grid. Microgrids can meet those goals cost effectively because they can be deployed where needs are greatest without the necessary prerequisite of huge investments.

Transforming Growth

Returning to postindustrial economies, such as Japan, Europe, and North America, the reach of the transmission grid is essentially universal. The daily per capita electricity use is in the rage of 20–35 kWh, or higher. The major challenge in engineering electrical energy systems for the future in such economies is to meet the relentlessly increasing demands of

table 1. Electricity access and use in illustrative countries.

Country	Circuit km of >132 kV Transmission Lines/sq km	Percentage with Access to Electricity in 2000	Per Capita kWh Use in 2000	Per Capita kWh Use in 2003	Average Annual Change in Per Capita kWh Use in 2000–2003 (%)
Zambia	0.0048	12	582	662	4.6
India	0.021	43	402	435	2.7
Germany	0.234	100	6,682	6,900	1.1

Sources: *Energy Balances of OECD Countries (2006 edition); Economic Indicators and Energy Balances of Non-OECD Countries (2006 edition); World Energy Outlook: Energy and Poverty (2002), Paris: IEA; . http://www.sapp.co.zw/; http://www.powergridindia.com/powergrid/; http://www.eon-netz.com/.*

populations with universal access to electricity, while simultaneously addressing climate change and maintaining PQR. However, since the level of electricity use is high in comparison with global average norms, there is significant incentive to transform energy use to increase overall energy efficiency, to change the resource mix to reduce greenhouse gas emissions from both the electricity and transportation sectors, and to meet increasing peak loads and variations in seasonal and daily load swings. Thus, our discussion has come full circle back to microgrids as an enabling agent for realizing the transformation of highly developed power systems.

Features of the Growth Model

It may be observed that in preparing for growth in electricity use globally, microgrids are a favorable compliment to the legacy growth paradigm based on expansion and reinforcement of the centralized grid. There is no ex ante reason to preclude the possibility of multiple types of microgrids coexisting within a given macrogrid. Various architectures might be appropriate for different requirements and opportunities. However, given microgrid research completed to date, some range of possible characteristics might be assumed and the consequent benefits explored. The following features of such an alternative paradigm show microgrids as attractive for accommodating a wide range of growth needs, mechanisms, and paths.

Autonomy

Microgrids allow for generation devices from a wide variety of primary energy sources, often renewable, along with storage devices and controlled loads operating in an autonomous fashion, hopefully without need for fast real-time communication and control, as has been demonstrated by the Consortium for Electric Reliability Solutions (CERTS) microgrid, and others.

Stability

The control approaches based on appropriate droop in frequency and voltage at the terminals of each of the devices in a microgrid can allow the entire network to operate in a stable manner during nominal operating conditions and during transient events.

Compatibility

Microgrids compliment and participate as a functional unit within the existing centralized legacy grid whose expansion is inhibited. This combination ensures that there are no stranded assets and that resources are utilized to their design capacity for their planned lifetime.

Flexibility

The rate of expansion and growth of microgrids need not be precisely forecast. Devices can be added as the need arises and presuming they are compatible with operating protocols, with neighboring microgrid(s), or with the macrogrid, as appropriate. Microgrids might be entirely technology neutral and accommodate diverse sources such as solar, wind, conventional fossil fuel, storage devices, and end-use equipment.

Scalability

Sections of microgrids can be expanded within, or additional microgrids may be established to meet growth. It allows for many small devices to operate together in a parallel and modular manner to scale to higher power levels.

Efficiency

Energy management layers can be accommodated within the framework to allow for concerns such as operating efficiency, environmental emissions, heat harvest, etc., to be optimized in a systematic manner.

Economics

The droop control technique allows for behavioral properties in response to costs, and market signals can be programmed into the operating protocol of the microgrid. The technical conceptualization does not dictate any particular pricing, market, or settlement mechanism within the microgrid, or in the transactions with the central grid.

Peer-to-Peer Model

This paradigm requires a true peer-to-peer model be adopted for operation and control of the microgrid and its interactive energy transactions with the centralized utility grid. The conceptualization does not dictate the size, scale, number of peers, or the growth rate.

Barriers

Not surprisingly, there are many barriers that may prevent delivery and capture of the benefits of microgrids as listed above. As is typical, the regulatory barriers and their economic consequences tend to be more discouraging than technical challenges, so they are the focus here. No effort is made to provide an exhaustive list of regulatory barriers, and they may differ across jurisdictions, but short descriptions of three critical U.S. examples follow; i.e., standby charges, interconnection rules, and lost utility revenues. These are all problems that can create high hurdles for microgrids but which have feasible solutions.

Standby Charges

One of the more contentious issues concerns standby charges. These are typically levied on any installed on-site generation at the site of a connected customer that is not intended solely for emergency use. The logic behind such charges asserts that infrastructure must be in place to serve the site's load in the event of its self-generating capacity being unavailable, and the site should pay this cost. This would occur if the on-site capability were shut down; e.g., for maintenance, because economics dictate, or as a result of equipment failure. In such a circumstance, the site's full load must be served by the macrogrid, so some argue that the cost of establishing and maintaining capacity for this purpose must fall on the site. The debate over such charges in the United States has been acrimonious. On the one hand, if capital expenditures are normally collected in volumetric charges on electricity sales, then it is true that a self-generator has avoided the burden of these costs. On the other hand, the use of these facilities by the site might well be rare, in which case they are serving other customers the vast majority of the time. New York state has an interesting approach to this dilemma. Some parts of utility costs that are deemed close enough to the customer to be only usable to serve it are fully charged to one demand charge, while more versatile assets further away are made available on a contract basis to the customer. Note that this problem could be eliminated if customers were charged an energy-only real-time market price for electricity. In this case, the high capital cost recovery required for deliveries at peak times are included in the price of the electricity. Only if the microgrid purchased during such times, e.g., in the event of equipment failure, would it be responsible for significant capital cost recovery, and clearly there would be a strong incentive for it to avoid such costly purchases. Further, correct incentives would be created for equipment sizing and operation.

Interconnection

It remains far from clear what organizational structure will dominate microgrid development and indeed whether there will or should be a dominant form. Microgrids may develop along quite diverse lines for various applications and equally may function under quite diverse business models and arrangements with the legacy grid. But under any relationship, one of the most contentious issues that will arise for microgrids is surely interconnection; i.e., the rules by which generation not owned by the utility is attached to the macrogrid. Absent clear rules, utilities would be able to discourage interconnection of generation they do not control, and the regulatory environment makes this likely, if, for example, lost revenues directly affect the utility's bottom line. Several U.S. states have implemented interconnection rules that dramatically lower this barrier and its associated costs. An example is California's Rule 21. Further development and adoption of IEEE 1547.4 is a necessary prerequisite for U.S. microgrid development.

Lost Utility Revenues

One of the classic problems with energy efficiency arising out of electricity utility regulation concerns the issue of lost revenues. Electricity utilities are natural monopolies; i.e., they exhibit such strong economies of scale that it would not make sense to have active competition between multiple smaller less-efficient suppliers. Given this cost structure to avoid abuse of market power, electricity is typically subject to some form of price regulation. Where wholesale supply is competitive, such cost-based regulation might be applied solely to the distribution portion of delivered electricity costs. This regulatory approach impedes policies intended to expand adoption of energy efficient equipment if the utility loses revenue as a result of sales falling short of expectations, while it cannot increase prices without regulatory approval, or at least, only after a lag. In these circumstances, the lost revenues can have a big effect on the bottom line because in a high fixed-cost business revenues fall more steeply than costs; i.e., a utility is unlikely to look favorably on any innovations that result in unforeseen sales loss. A common hypothesis is that utilities raise barriers to interconnection of self-generation and also discourage energy efficiency investments because of this possible consequence for its revenue and profits.

Pioneered by California back in 1982, revenue balancing accounts track revenue shortfalls to effectively eliminate the lost sales disincentive problem. When tariffs are set, they are based on forecasts of sales and costs. If sales exceed or fall short of the forecasts, the surplus or shortfall of revenues accrues to a balancing account in the company's accounts. Periodically, the balancing account is zeroed out by amortizing the balance into future tariffs. In principle, this mechanism makes utilities indifferent to their sales volume and neutral to customer self-generation. Nonetheless, whether the critical importance of this accounting construct, often known as revenue decoupling, is understood by staff throughout the utilities is certainly open to question. Similar schemes are now in place in approximately six other U.S. states, with about ten others considering them.

Conclusions

Given the technical constraints imposed by the growing needs of distributed generation, DER, and demanding PQR requirements, the microgrid concept is evolving toward a potentially versatile solution. The growing body of technical publications includes analytical modeling that defines the theoretical basis; computer simulation studies that verify operation and performance; and laboratory-scale, community-scale, and utility-scale demonstrations and pilot projects that add field experience to theory and simulation. Similarly, vigorous efforts are underway to expand microgrid economic and regulatory analysis capability, but challenges remain. At the policy level, significant changes will be needed to facilitate capture of the benefits of microgrids.

For Further Reading

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Biographies

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Chris Marnay is a staff scientist at Berkeley Lab and leads its End-Use Forecasting Group.