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microgrids

the key to unlock distributed energy resources?

MODERN SOCIETY CRITICALLY depends on a secure supply of high-quality electrical energy. Increasing concerns for primary energy availability, the aging infrastructure of current transmission and distribution electrical networks, the need to connect nontraditional generation such as intermittent renewables, and active open wholesale markets are increasingly challenging security, reliability, and quality. Very significant amounts of investment will be required to develop and renew the electrical infrastructure, and the most efficient way to meet social demands will likely be by incorporating innovative solutions, technologies, and grid architectures. According to an International Energy Agency estimate, global investments required in the energy sector over the period 2003–2030 are about US$16 trillion.

Future electricity grids have to adapt to changes in technology while matching societal values for the environment and commerce. Thus, system security, safety, environment, power quality, cost of supply, and energy efficiency are examined in new ways in response to changing requirements in a liberalized market environment. Technologies should also demonstrate reliability, sustainability, and cost-effectiveness. At the distribution level, the new requirements call for the development of:

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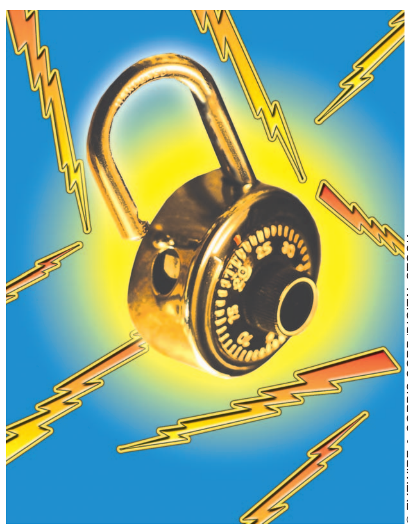
- ✔ distribution grids accessible to distributed generation (DG) and renewable energy sources (RESs), either self-dispatched or dispatched by local distribution system operators
- ✔ distribution grids enabling local energy demand management interacting with end users through smart metering systems
- ✔ distribution grids that benefit transmission dynamic control techniques and overall level of power security, quality, reliability, and availability.



In summary, distribution grids are being transformed from passive to active networks in the sense that decision making and control is distributed and the power flows bidirectionally. This type of network eases the participation of DG, RESs, demand response (DR), and energy storage and creates opportunities for novel types of equipment and services, all of which would need to respect common protocols and standards. The function of the active distribution network is to efficiently link power sources with consumer demands, allowing both to decide how best to operate in real time. Power flow assessment, voltage control, and protection require cost-competitive technologies and new communication systems with information and communication technologies (ICTs) playing a key role.

The realization of active distribution network technologies will allow radically new system concepts to be implemented. Perhaps the most promising novel network structure is the microgrids paradigm. Microgrids comprise low voltage (LV) distribution systems with distributed energy resources (DERs) such as microturbines, fuel cells, photovoltaic (PV) arrays, etc., together with storage devices (i.e., flywheels, energy capacitors, and batteries) and controllable loads (Figure 1), offering considerable control capabilities over the network operation. These systems are interconnected to the medium voltage (MV) distribution network, but they can be also operated isolated from the main grid in case of faults in the upstream network. From the customer point of view, microgrids provide both thermal and electricity needs and in addition enhance local reliability,

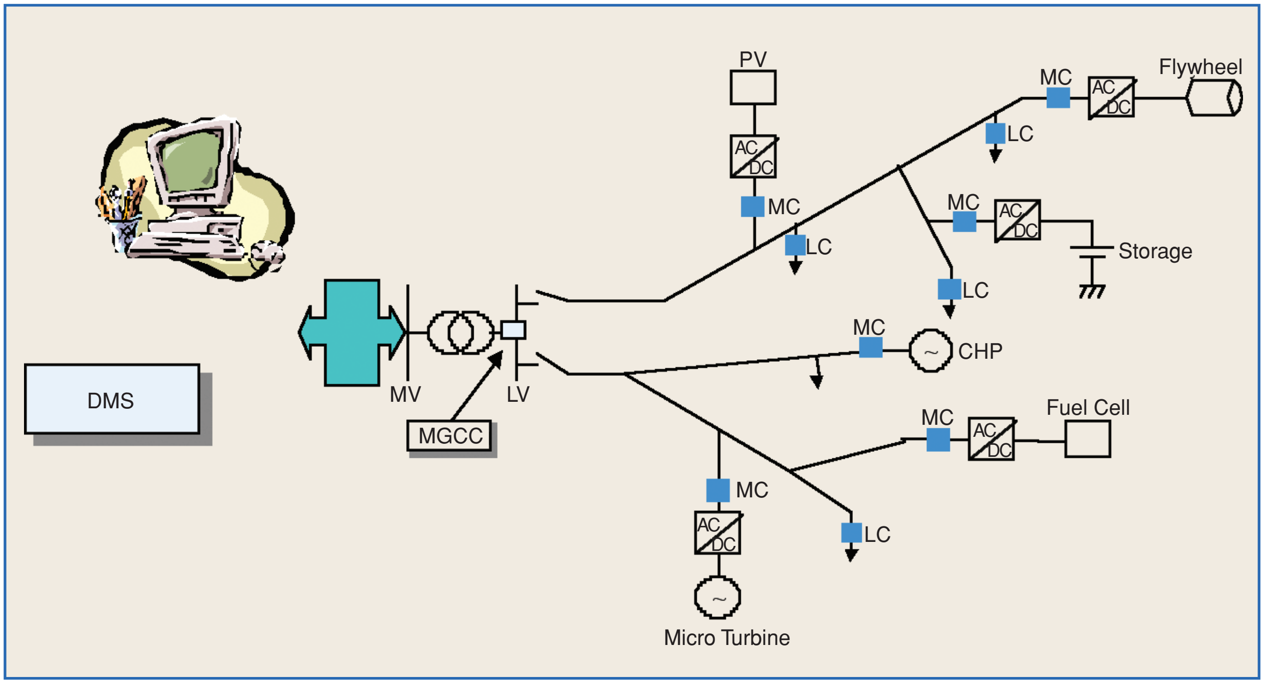


figure 1. Typical microgrid structure coordinated by the microgrid central controller (MGCC) and interfaced to the distribution management system (DMS).

reduce emissions, improve power quality by supporting voltage and reducing voltage dips, and potentially lower costs of energy supply. From the grid's point of view, a microgrid can be regarded as a controlled entity within the power system that can be operated as a single aggregated load or generator and, given attractive remuneration, as a small source of power or ancillary services supporting the network. Thus, microgrids comprise the coordinated behavior of DERs and DR, maximizing their benefits to customers and grids.

The key economic potential of the application of DERs at customer premises lies in the opportunity to locally utilize the waste heat from the conversion of primary fuel to electricity. There has been significant progress in developing small, kilowatt-scale, combined heat and power (CHP) applications. These systems are expected to play a very significant role in the microgrids of northern countries. On the other hand, PV systems are anticipated to become increasingly deployed in countries with sunnier climates. The application of micro CHP and PV potentially increases the overall efficiency of utilizing primary energy sources and consequently substantially lowers carbon emissions, which is another critically important benefit given worldwide efforts to combat climate change.

From the utility point of view, application of DERs can potentially reduce the demand for distribution and transmission facilities. Clearly, DG located close to loads will reduce flows in transmission and distribution circuits with two important effects: loss reduction and ability to potentially substitute for network assets. Furthermore, the presence of generation close to demand could increase the service quality seen by end customers. Microgrids can provide network support in times of stress by relieving congestion and aiding restoration after faults.

There are tremendous opportunities and challenges for the development and operation of microgrids in the technical, economic, and regulatory sectors. Consequently, they have been the subject of extensive research development and dissemination activities in the United States, Japan, Europe, and Canada in order to provide efficient solutions and to demonstrate microgrid operation concepts in laboratories and in pilot installations, as was outlined in the July/August 2007 issue of *Power & Energy Magazine*. This current special issue on microgrids features five excellent articles, listed as follows and presented in sequence:

- ✔ "Design for Distributed Energy Resources: Microgrid planning and architectures for improved reliability and integration," by Johan Driesen and Farid Katiraei
- ✔ "Making Microgrids Work: A look at microgrid technologies and testing projects from around the world," by Benjamin Kroposki, Robert Lasseter, Toshifumi Ise, Satoshi Morozumi, Stavros Papathanassiou, and Nikos Hatziargyriou
- ✔ "Microgrids Management: Controls and operation aspects of microgrids," by Farid Katiraei, Reza Iravani, Nikos Hatziargyriou, and Aris Dimeas
- ✔ "Policymaking for Microgrids: Economic and regulatory issues

of microgrid implementation," by Chris Marnay, Hiroshi Asano, Stavros Papathanassiou, and Goran Strbac

- ✔ "A Larger Role for Microgrids: Are microgrids a viable paradigm for electricity supply expansion?" by Giri Venkataramanan and Chris Marnay.

The article by Driesen and Katiraei gives a systematic overview of the different types of microgrids starting from their architecture and operation mode. It deals with the problem of planning the transition toward microgrids in an open environment, taking into account the uncertainties regarding electricity production, load, and market evolution. Finally, it discusses some adaptations that have to be made in the protection systems to allow microgrid operation of a distribution system.

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The article by Kroposki et al. describes the technologies used in microgrids including DG, energy storage, interconnection switches, and control systems. This article also highlights testing experience and demonstrations with microgrids around the world, focusing on the United States, Japan, Canada, and Europe. Testing ranges from the component level to fully integrated systems at the megawatt scale.

The article by Katiraei et al. provides a general overview of the existing control methods of DG units with emphasis on electronically coupled units. The article highlights the importance of power management and energy management strategies for sound technical and economical operation of the microgrid. Finally, it describes possible architectures for microgrid supervisory control and highlights potential features of centralized and decentralized controls in an open environment.

The article by Marnay et al. explores the economic and regulatory challenges to widespread microgrid deployment. As is so often the case in this industry, many would agree that the technical challenges are not the most daunting, but rather the economic and regulatory hurdles are actually higher. The article addresses both the bigger philosophical and smaller project-level aspects of economic evaluation of microgrids and discusses examples of the regulatory barriers as they have been described on three continents. The economics of microgrids is somewhat consistent around the world, with similar analysis methods emerging from more traditional areas of utility planning and project finance, albeit with some notable differences. Conversely, the regulatory picture is much more complicated, involving as it does many different areas of public intervention; i.e., utility rate making, environmental regulation, building codes, etc.

Finally, the concluding article by Venkataramanan and Marnay expands the horizon beyond the postindustrial countries to consider the possible role of microgrids in the expansion of electricity supply to residents of countries at various levels of development. Some of the key challenges to further microgrid deployment are also recapped.

For Further Reading

European Technology SmartGrids Platform, "SmartGrids: Vision and strategy for European electricity networks of the future," [Online]. Available: http://www.smartgrids.eu/documents/vision.pdf

N. Hatziargyriou, A. Asano, R. Iravani, and C. Marnay, "Microgrids," *IEEE Power Energy Mag.*, vol. 5, no. 4, pp. 78–94, July/Aug. 2007.

Microgrids [Online]. Available: http://microgrids.power.ece.ntua.gr

DER at LBNL[Online]. Available: http://der.lbl.gov

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