NIKOS HATZIARGYRIOU

Microgrids
Architectures and Control

Contents

MICROGRIDS

ARCHITECTURES AND CONTROL

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Foreword

The idea of microgrids is not new. However, as new technologies are coming into existence to harve renewable energy as well as more efficient electricity production methods coupled with the flexibili of power electronics; a new industry is developing to promote these technologies and organize the into microgrids for extracting the maximum benefits for owners and the power grid. More than 1 years ago, the Department of Energy has sponsored early research that laid the foundations f microgrids and explored the benefits. One key aspect is the ability and promise to addre environmental concerns that have been growing in recent years. Today the microgrid concept ha exploded to include a variety of architectures of energy resources into a coordinated energy entity th its value is much greater than the individual components. As a result the complexity of microgrids ha increased. It is in this environment of evolution of microgrids that the present book is very welcom It is written in a way that provides valuable information for specialist as well as non-specialists.

Chapter 1 provides a well thought view of the microgrid concept from the various forms implementation to the potential economic, environmental and technical benefits. It identifies the ro of microgrids in altering the distribution system as we know it today and at the same time elaborat on the formation of microgrids as an organized entity interfaced to distribution systems. In refreshingly simple way identifies the enabling technologies for microgrids, that is power electronic communications, renewable resources. It discusses in simple terms the ability of microgrids minimize green house gases, help the power grid with load balancing and voltage control and assi power markets. While it is recognized that participation of the microgrids in power markets is limite by their size, it discusses possible ways that microgrids can market their assets via aggregators ar opens the field for other innovations.

The book addresses two of the great challenges of microgrids: control and protection. Four chapte are devoted to these complex problems, three on control (Chapters 2, 3 and 5) and one on protectio (Chapter 4). The multiplicity of control issues and their complexity is elaborated in a clear ar concise manner. Since microgrids comprise many resources that are interfaced via power electronic the book presents the organization of the control problems in a hierarchical architecture that consis of local controllers that control specific resources, their operation and their protection as well as out loop controllers that perform load-generation management, islanding operation as well as th interaction with up-stream controllers including power system control centers. It provides a goo overview of approaches as well as the role of state estimation in controlling and operating microgrid. In addition to conventional control methods, recent intelligent control approaches are als discussed. The specific issues and challenges of microgrid control are clearly elaborated. As a example, because the microgrid typically comprises many inverters connecting various resources the microgrid it is possible to trigger oscillations due to inverter control interactions. Methods f solving these issues are clearly discussed in an easy to follow way. It is recognized that multip microgrids can exist in a system and the issue of controlling and coordinating all the microgrids very important from the point of view of managing the microsources as well as providing services the power grid by coordinating all the resources. The services can be any of the ancillary services th are typically provided by large systems: frequency control, voltage control, power balance, capaci reserves. The hierarchies involved in the control and operation of multi-microgrid systems eloquently presented as a hierarchical control problem.

Protection of microgrids is a challenging problem due to the fact that microgrid resources provi ~~limited fault currents. Detection of faults in microgrids is problematic at best because the grid~~ si fault current contribution may be very high while the contribution from microsources is limite Present protection schemes and functions are not reliable for microgrids. The book describes clev methods for providing adequate protection functions such as adaptive protection schemes, addition components that will provide temporarily high fault currents to enable the operation of protectiv relays, increasing inverter capacity and therefore fault current contribution. While the book provid some solutions it also makes it clear that there is much more work that needs to be done to reliab protect microgrids.

The basic approaches in designing, controlling and protecting microgrids are nicely compliment by a long list of microgrid projects around the globe that provide a picture of the evolution microgrid design and lessons learned. Specific microgrid projects in Europe, United States, Japa China and Chile are described and discussed. These projects provide an amazing insight into th lessons learned, challenges faced and issues resolved and issues outstanding. The examples span sma capacity microgrids as well as some very large microgrids; grid-connected microgrids as well stand-alone or island microgrids. The information provided is extremely useful and enabl appreciation of the challenges as well as the rewards of these systems.

Finally, the last chapter elaborates on the technical, economic, environmental and social benefits microgrids. The discussion is qualitative as well as quantitative. While the quantitative analysis very much dependent upon specific areas and other conditions, the qualitative discussion is applicab to microgrids anywhere in the globe. Indirectly, this discussion makes the case for microgrid comprising mostly renewable energy resources as a big component in solving the environmenta economic and social issues that are facing a society that relies more and more in electric energy. Th technical issues are solvable for transforming distribution systems into a distributed microgrid. Th work presented in this book will be a fundamental reference toward the promotion and proliferation microgrids and the accompanied deployment of renewable resources.

This book is a must read resource for anyone interested in the design and operation of microgri and the integration of renewable resources into the power grid.

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Preface

The book deals with understanding, analyzing and justifying Microgrids, as novel distribution netwo structures that unlock the full potential of Distributed Energy Resources (DER) and thus form buildi blocks of future Smartgrids. In the context of this book, Microgrids are defined as distributi systems with distributed energy sources, storage devices and controllable loads, operated connected the main power network or islanded, in a controlled, coordinated way. Coordination and control DER is the key feature that distinguishes Microgrids from simple distribution feeders with DER. particular, effective energy management within Microgrids is the key to achieving vital efficien benefits by optimizing production and consumption of energy. Nevertheless, the technical challeng associated with the design, operation and control of Microgrids are immense. Equally important is th economic justification of Microgrids considering current electricity market environments and th quantified assessment of their benefits from the view of the various stakeholders involved.

Discussions about Microgrids started in the early 2000, although their benefits for island a remote, off-grid systems were already generally appreciated. Nowadays, Microgrids are proposed vital solutions for critical infrastructures, campuses, remote communities, military applicatio utilities and communal networks. Bright prospects for a steady market growth are foreseen. The boo is intended to meet the needs of practicing engineers, familiar with medium- and low-volta distribution systems, utility operators, power systems researchers and academics. It can also serve a useful reference for system planners and operators, technology providers, manufacturers and netwo operators, government regulators, and postgraduate power systems students.

The text presents results from a 6-year joint European collaborative work conducted in th framework of two EC-funded research projects. These are the projects “Microgrids: *Large Sca Integration of Micro-Generation to Low Voltage Grids*,” funded within the 5th Framework programm (1998–2002) and the follow-up project “More Microgrids, Advanced Architectures and Contr Concepts for More Microgrids” funded within the 6th Framework Programme (2002–2006). T consortia involved were coordinated by the editor of this book and comprised a number of industri partners, power utilities and academic research teams from 12 EU countries. A wealth of informati and many practical conclusions were derived from these two major research efforts. The boo attempts to clarify the role of Microgrids within the overall power system structure and focuses on th main findings related to primary and secondary control and management at the Microgrid and Mult Microgrid level. It also provides results from quantified assessment of the Microgrids benefits fro an economical, environmental, operational and social point of view. A separate chapter beyond the E projects, provided by a more international authorship is devoted to an overview of real-wor Microgrids from various parts of the world, including, next to Europe, United States of Ameri Japan, China and Chile.

Chapter 1, entitled “The Microgrids Concept,” co-authored by Christine Schwaegerl and Liang Ta clarifies the key features of Microgrids and underlines the distinguishing characteristics from oth DG dominated structures, such as Virtual Power Plants. It discusses the main features related to the operation and control, the market models and the effect of possible regulatory settings and provides exemplary roadmap for Microgrid development in Europe.

Chapter 2, entitled “Microgrids Control Issues” co-authored by Aris Dimeas, Antonis Tsikalaki George Kariniotakis and George Korres, deals with one of the key features of Microgrids, name their energy management. It presents the hierarchical control levels distinguished in Microgri operation and discusses the principles and main functions of centralized and decentralized contro including forecasting and state estimation. Next, centralized control functions are analyzed an illustrated by a practical numerical example. Finally, an overview of the basic multi-agent system concepts and their application for decentralized control of Microgrids is provided.

Chapter 3, entitled “Intelligent Local Controllers,” co-authored by Thomas Degner, Nikos Soultani Alfred Engler and Asier Gil de Muro, presents primary control capabilities of DER controllers. Th provision of ancillary services in interconnected mode and the capabilities of voltage and frequen control, in case of islanded operation and during transition between the two modes are outline Emphasis is placed on the implications of the high resistance over reactance ratios, typically found LV Microgrids. A control algorithm based on the fictitious impedance method to overcome the relate problems together with characteristic simulation results are provided.

Chapter 4, entitled “Microgrid Protection,” co-authored by Alexander Oudalov, Thomas Degne Frank van Overbeeke and Jose Miguel Yarza, deals with methods for effective protection i Microgrids. A number of challenges are caused by DER varying operating conditions, the reduce fault contribution by power electronics interfaced DER and the occasionally increased fault level Two adaptive protection techniques, based on pre-calculated and on-line calculated settings a proposed including practical implementation issues. Techniques to increase the amount of fau current level by a dedicated device and the possible use of fault current limitation are also discussed.

Chapter 5, entitled “Operation of Multi-Microgrids,” co-authored by João Abel Peças Lopes, Andr Madureira, Nuno Gil and Fernanda Resende examines the operation of distribution networks wi increasing penetration of several low voltage Microgrids, coordinated with generators and flexib loads connected at medium voltage. An hierarchical management architecture is proposed an functions for coordinated voltage/VAR control and coordinated frequency control are analyzed an simulated using realistic distribution networks. The capability of Microgrids to provide black sta services are used to provide restoration guidelines. Finally, methods for deriving Microgri equivalents for dynamic studies are discussed.

Chapter 6, entitled “Pilot Sites: Success Stories and Learnt Lessons” provides an overview of rea world Microgrids, already in operation as off-grid applications, pilot cases or full-sca demonstrations. The material is organized according to geographical divisions. George Kariniotaki Aris Dimeas and Frank van Overbeeke describe three pilot sites in Europe developed within the mo Microgrids project; John Romankiewicz and Chris Marnay provide an overview of Microgrid Projec in the United States; Satoshi Morozumi provide an overview of the Japanese Microgrid Project Meiqin Mao describes the Microgrid Projects in China and Rodrigo Palma Behnke and Guillerm Jiménez-Estévez provide details of an off-grid Microgrid in Chile. These projects are of cour indicative of a continuously growing list, they provide, however, a good impression of the on-goin developments in the field.

Chapter 7, entitled “Quantification of Technical, Economic, Environmental and Social Benefits Microgrid Operation,” co-authored by Christine Schwaegerl and Liang Tao attempts to quantify th Microgrids benefits using typical European distribution networks of different types and assumi various DER penetration scenarios, market conditions, prices and costs developments for the yea 2020, 2030 and 2040. Sensitivity analysis of the calculated benefits is performed. Although, th precision of these quantified benefits is subject to the high uncertainties in the underlyi assumptions, the positive effects of Microgrids operation can be safely observed in all cases.

Next to the co-authors of the various chapters, there are many researchers who have contributed
the ~~material of this book by their knowledge, research efforts and fruitful collaboration~~ during th
numerous technical meetings of the Microgrids projects. I am indebted to all of them, but I fe
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1

The Microgrids Concept

Christine Schwaegerl and Liang Ta

1.1 Introduction

Modern society depends critically on a secure supply of energy. Growing concerns for primary energ availability and aging infrastructure of current electrical transmission and distribution networks a increasingly challenging security, reliability and quality of power supply. Very significant amounts o investment will be required to develop and renew these infrastructures, while the most efficient way meet social demands is to incorporate innovative solutions, technologies and grid architecture According to the International Energy Agency, global investments required in the energy sector ove the period 2003–2030 are estimated at $16 trillion.

Future electricity grids have to cope with changes in technology, in the values of society, in th environment and in economy [1]. Thus, system security, operation safety, environmental protectio power quality, cost of supply and energy efficiency need to be examined in new ways in response changing requirements in a liberalized market environment. Technologies should also demonstra reliability, sustainability and cost effectiveness. The notion of **smart grids** refers to the evolution electricity grids. According to the European Technology Platform of Smart Grids [2], a smart grid an electricity network that can intelligently integrate the actions of all users connected to it generators, consumers and those that assume both roles – in order to efficiently deliver sustainabl economic and secure electricity supplies. A smart grid employs innovative products and servic together with intelligent monitoring, control, communication and self-healing technologies.

It is worth noting that power systems have always been "smart", especially at the transmission leve The distribution level, however, is now experiencing an evolution that needs more "smartness", order to

- facilitate access to distributed generation [3,4] on a high share, based on renewable energy sources (RESs), either self-dispatched or dispatched by local distribution system operators
- enable local energy demand management, interacting with end-users through smart metering systems
- benefit from technologies already applied in transmission grids, such as dynamic control techniques, so as to offer a higher overall level of power security, quality and reliability.

In summary, distribution grids are being transformed from **passive** to **active networks**, in the sen that decision-making and control are distributed, and power flows bidirectional. This type of netwo eases the integration of DG, RES, demand side integration (DSI) and energy storage technologies, a creates opportunities for novel types of equipment and services, all of which would need to conform common protocols and standards. The main function of an active distribution network is to efficient link power generation with consumer demands, allowing both to decide how best to operate in rea time. Power flow assessment, voltage control and protection require cost-competitive technologi and ~~new communication systems with information and communication technology (ICT) playing~~ key role.

The realization of active distribution networks requires the implementation of radically new syste concepts. **Microgrids** [5–11], also characterized as the “building blocks of smart grids”, are perhap the most promising, novel network structure. The organization of microgrids is based on the **contr** capabilities over the network operation offered by the increasing penetration of distributed generato including microgenerators, such as micro-turbines, fuel cells and photovoltaic (PV) arrays, togeth with storage devices, such as flywheels, energy capacitors and batteries and controllable (flexibl loads (e.g. electric vehicles [12]), at the distribution level. These control capabilities allo distribution networks, mostly interconnected to the upstream distribution network, to also opera when isolated from the main grid, in case of faults or other external disturbances or disasters, th increasing the quality of supply. Overall, the implementation of control is the key feature th distinguishes microgrids from distribution networks with distributed generation.

From the customer's point of view, microgrids provide both thermal and electricity needs, and, addition, enhance local reliability, reduce emissions, improve power quality by supporting voltage ar reducing voltage dips, and potentially lower costs of energy supply. From the grid operator's point view, a microgrid can be regarded as a controlled entity within the power system that can be operate as a single aggregated load or generator and, given attractive remuneration, also as a small source power or ancillary services supporting the network. Thus, a microgrid is essentially an aggregatio concept with participation of both supply-side and demand-side resources in distribution grids. Base on the synergy of local load and local microsource generation, a microgrid could provide a larg variety of economic, technical, environmental and social benefits to different stakeholders. comparison with peer microsource aggregation methods, a microgrid offers maximum flexibility terms of ownership constitution, allows for global optimization of power system efficiency ar appears as the best solution for motivating end-consumers via a common interest platform.

Key economic potential for installing microgeneration at customer premises lies in the opportuni to locally utilize the waste heat from conversion of primary fuel to electricity. There has bee significant progress in developing small, kW-scale, combined heat and power (CHP) application These systems have been expected to play a very significant role in the microgrids of colder clima countries. On the other hand, PV systems are anticipated to become increasingly popular in countri with sunnier climates. The application of micro-CHP and PV potentially increases the overa efficiency of utilizing primary energy sources and consequently provides substantial environment gains regarding carbon emissions, which is another critically important benefit in view of the world efforts to combat climate change.

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

In the following sections, the microgrid concept is clarified and a clear distinction from the virtu power plant concept is made. Then, the possible internal and external market models and regulatio settings for microgrids are discussed. A brief review of control strategies for microgrids is given and roadmap for microgrid development is provided.

1.2 The Microgrid Concept as a Means to Integrate Distributed Generation

During the past decades, the deployment of distributed generation (DG) has been growing steadil DGs are connected typically at distribution networks, mainly at medium voltage (MV) and hig voltage (HV) level, and these have been designed under the paradigm that consumer loads are passiv and power flows only from the substations to the consumers and not in the opposite direction. For th reason, many studies on the interconnection of DGs within distribution networks have been carrie out, ranging from control and protection to voltage stability and power quality.

Different microgeneration technologies, such as micro-turbines (MT), photovoltaics (PV), fuel cel (FC) and wind turbines (WT) with a rated power ranging up to 100 kW can be directly connected the LV networks. These units, typically located at users' sites, have emerged as a promising option meet growing customer needs for electric power with an emphasis on reliability and power qualit providing different economic, environmental and technical benefits. Clearly, a change interconnection philosophy is needed to achieve optimal integration of such units.

Most importantly, it has to be recognized that with increased levels of microgeneration penetratio the LV distribution network can no longer be considered as a passive appendage to the transmissio network. On the contrary, the impact of microsources on power balance and grid frequency ma become much more significant over the years.

Therefore, a control and management architecture is required in order to facilitate full integration microgeneration and active load management into the system. One promising way to realize th emerging potential of microgeneration is to take a systematic approach that views generation an associated loads as a subsystem or a microgrid.

In a typical microgrid setting, the control and management system is expected to bring about variety of potential benefits at all voltage levels of the distribution network. In order to achieve th goal, different hierarchical control strategies need to be adopted at different network levels.

The possibility of managing several microgrids, DG units directly connected to the MV network ar MV controllable loads introduces the concept of multi-microgrids. The hierarchical control structu of such a system calls for an intermediate control level, which will optimize the multi-microgr system operation, assuming an operation under a real market environment. The concept of mult microgrids is further developed in Chapter 5.

The potential impact of such a system on the distribution network may lead to different regulato approaches and remuneration schemes, that could create incentive mechanisms for distribution syste operators (DSOs), microgeneration owners and loads to adopt the multi-microgrid concept. This further discussed in Chapter 7.

1.3 Clarification of the Microgrid Concept

1.3.1 What is a Microgrid?

In scope of this book, the definition from the EU research projects [7,8] is used:

> Microgrids comprise LV distribution systems with distributed energy resources (DEI (microturbines, fuel cells, PV, etc.) together with storage devices (flywheels, energy capacitors an batteries) and flexible loads. Such systems can be operated in a non-autonomous way, interconnected to the grid, or in an autonomous way, if disconnected from the main grid. Th operation of microsources in the network can provide distinct benefits to the overall syste performance, if managed and coordinated efficiently.

There are three major messages delivered from this definition:

1. Microgrid is an integration platform for supply-side (microgeneration), storage units anc demand resources (controllable loads) located in a local distribution grid.

- In the microgrid concept, there is a focus on local supply of electricity to nearby loads, thus aggregator models that disregard physical locations of generators and loads (such as virtua power plants with cross-regional setups) are not microgrids.
- A microgrid is typically located at the LV level with total installed microgeneration capacity below the MW range, although there can be exceptions: parts of the MV network can belong to a microgrid for interconnection purposes.

2. A microgrid should be capable of handling both normal state (grid-connected) and emergency state (islanded) operation.

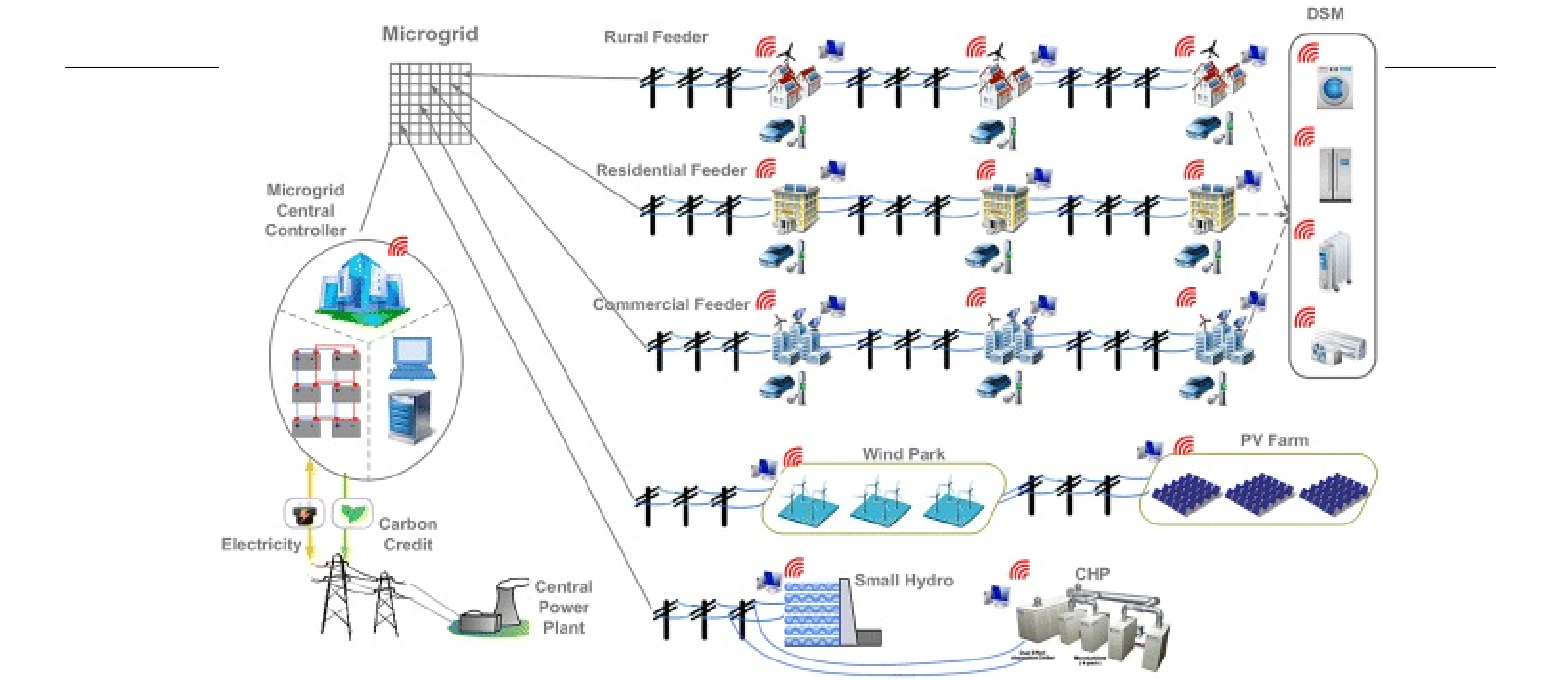
- The majority of future microgrids will be operated for most of the time under grid-connection – except for those built on physical islands – thus, the main benefits of the microgrid concep will arise from grid-connected (i.e. “normal”) operating states.
- In order to achieve long-term islanded operation, a microgrid has to satisfy high requirement on storage size and capacity ratings of microgenerators to continuous supply of all loads or i has to rely on significant demand flexibility. In the latter case, reliability benefits can be quantified from partial islanding of important loads.

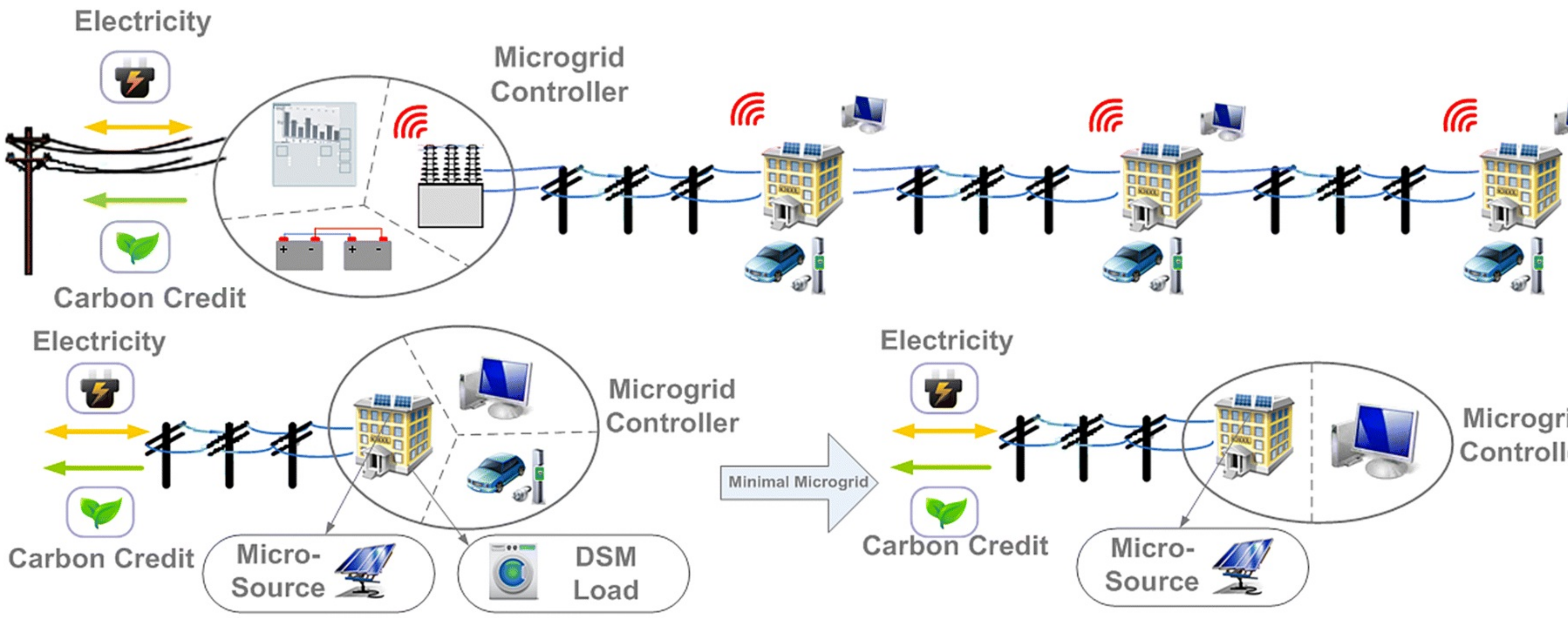
3. The difference between a microgrid and a passive grid penetrated by microsources lies mainly in terms of management and coordination of available resources.

- A microgrid operator is more than an aggregator of small generators, or a network service provider, or a load controller, or an emission regulator – it performs all these functionalities and serves multiple economic, technical and environmental aims.
- One major advantage of the microgrid concept over other “smart” solutions lies in its capability of handling conflicting interests of different stakeholders, so as to arrive at a globally optimal operation decision for all players involved.

A microgrid appears at a large variety of scales: it can be defined at the level of a LV grid, a L feeder or a LV house – examples are given in Figure 1.1. As a microgrid grows in scale, it will likel be equipped with more balancing capacities and feature better controllability to reduce th intermittencies of load and RES. In general, the maximum capacity of a microgrid (in terms of pea load demand) is limited to few MW (at least at the European scale, other regions may have differe upper limits, see Chapter 6). At higher voltage levels, multi-microgrid concepts are applied, implyin the coordination of interconnected, but separate microgrids in collaboration with upstream connecte DGs and MV network controls. The operation of multi-microgrids is discussed in Chapter 5.

Figure 1.1 (a) Microgrid as a LV grid; (b) Microgrid as a LV feeder; (c) Microgrid as a LV house

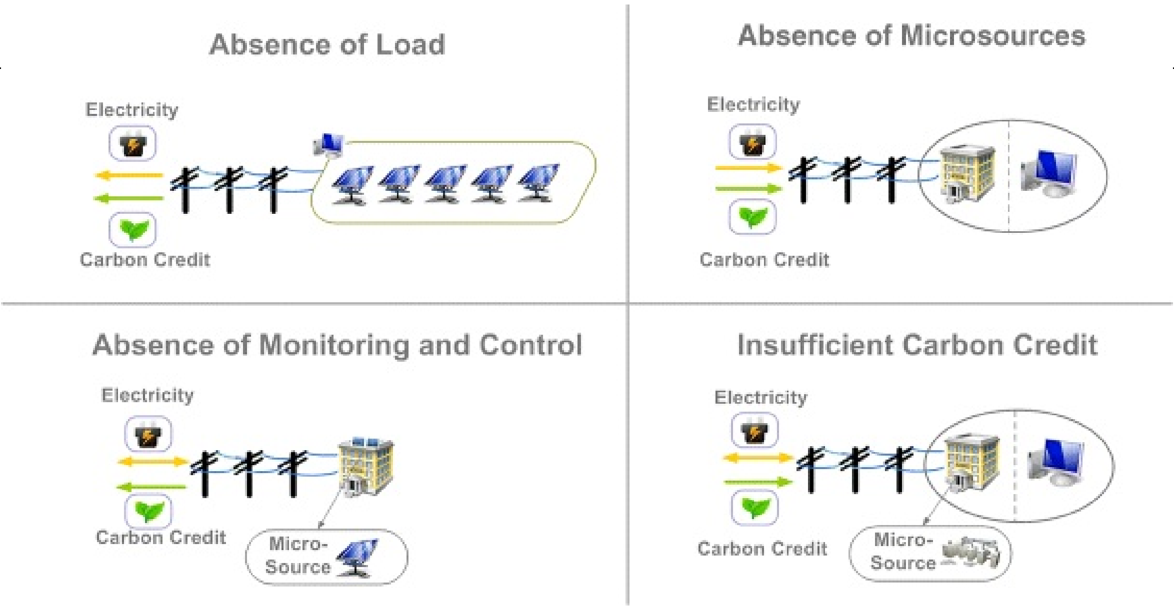




1.3.2 What is Not a Microgrid?

In Figure 1.2, the microgrid concept is further clarified by examples that highlight three essenti microgrid features: local load, local microsources and intelligent control. In many countri environmental protection is promoted by the provision of carbon credits by the use of RES and CH technologies; this should be also added as a microgrids feature. Absence of one or more featur would be better described by DG interconnection cases or DSI cases.

Figure 1.2 What is not a microgrid? Sample cases



In the following section, some typical misconceptions regarding microgrids are clarified:

- Microgrids are exclusively isolated (island) systems.

  ⇒ Microgrids have the capability to shift to islanded operation in emergency situations, thus increasing customer reliability, but they are mostly operated interconnected to the upstream distribution network. Small island systems are inherently characterized by coordinated control of their resources, thus, depending on their size and the extent of DER penetration and control, they can be also termed as microgrids.

- Customers who own microsources build a microgrid.

  ⇒ DG penetration is indeed a distinct microgrid feature, but a microgrid means more than passive tolerance of DG (also known as “fit and forget”) and needs active supervision, control and optimization.

- Microgrids are composed of intermittent renewable energy resources, so they must be unreliable and easily subject to failures and total black-outs.

  ⇒ A microgrid can offset RES fluctuation by its own storage units (when islanded) or external generation reserves (when grid-connected). Moreover, the microgrid's capability of transferring from grid-connected to island mode actually improves security of supply.

- Microgrids are expensive to build, so the concept will be limited to field tests or only to remote locations.

  ⇒ DER penetration is increasing worldwide. Financial support schemes for RES and CHP have already ensured the basic profitability of such distributed resources; future cost reductions of microgeneration and storage can make microgrids commercially competitive. In any case, the additional cost for transforming a distribution line with DER into a microgrid involves only the relevant control and communication costs. These are easily compensated by the economic advantages of coordinated DER management.

- The microgrid concept is just another energy retailer advertising scheme to increase his income.

  ⇒ Even if an end-consumer chooses not to install photovoltaic panels on his rooftop or hold a share in the community-owned CHP plant, he can still benefit from having more choice of energy supply and of sharing carbon-reduction credits in his bill.

- The microgrid controllers will force consumers to shift their demand, depending on the availability of renewable generation, e.g. to switch on the washing machine at home only when the sun is shining or the wind is blowing.

⇒ Demand side integration (DSI) programs in normal commercial and household applications should apply a "load follow generation" control philosophy only to long-term stand-by appliances (such as refrigerators and air-conditioners) or time-insensitive devices (such as water heaters).

- A microgrid is such a totally new idea, that system operators need to rebuild their entire network

⇒ Although new metering, communication and control devices would need to be installed, conversion of a normal "passive" distribution grid to a microgrid does not actually incur too much infrastructure costs on the network operator side – on the contrary, a microgrid can actually defer investment costs for device replacement.

- Microgrid loads will never face any supply interruptions.

⇒ "Smooth" (i.e. no loss of load) transition to island operation is only possible with large storage or generation redundancy within a microgrid, thus an islanded microgrid will very probably have to shed non-critical loads according to the instantaneous amount of available resource.

1.3.3 Microgrids versus Virtual Power Plants

A **virtual power plant** (VPP) is a cluster of DERs which is collectively operated by a central contr entity. A VPP can replace a conventional power plant, while providing higher efficiency and mor flexibility. Although the microgrid and the VPP appear to be similar concepts, there are a number o distinct differences:

- Locality – In a microgrid, DERs are located within the same local distribution network and they aim to satisfy primarily local demand. In a VPP, DERs are not necessarily located on the same local network and they are coordinated over a wide geographical area. The VPP aggregated production participates in traditional trading in normal energy markets.
- Size – The installed capacity of microgrids is typically relatively small (from few kW to several MW), while a VPP's power rating can be much larger.
- Consumer interest – A microgrid focuses on the satisfaction of local consumption, while a VPP deals with consumption only as a flexible resource that participates in the aggregate power trading via DSI remuneration.

Following on from the definition of a VPP as a commercial entity that aggregates differe generation, storage or flexible loads, regardless of their locations, the technical VPP (TVPP) has bee proposed, which also takes into account local network constraints. In any case, VPPs, as virtu generators, tend to ignore local consumption, except for DSI, while microgrids acknowledge loc power consumption and give end consumers the choice of purchasing local generation or generatio from the upstream energy market. This leads to a better controllability of microgrids, as shown Figure 1.3, where both supply and demand resources of a microgrid can be simultaneously optimize leading to better DG profitability.

Figure 1.3 Microgrid benefit over commercial and technical VPP due to supply side integration