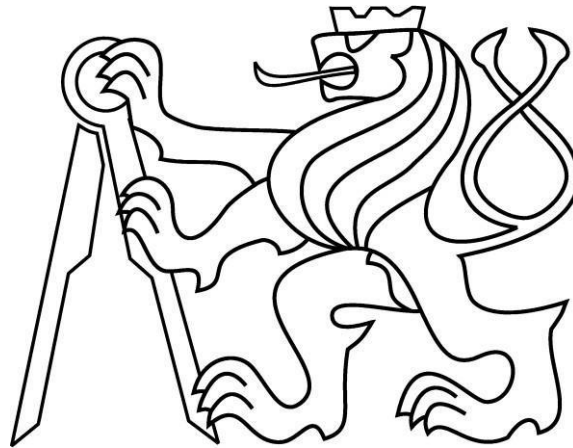


**CZECH TECHNICAL UNIVERSITY  
IN PRAGUE  
FACULTY OF ELECTRICAL  
ENGINEERING**



**TECHNICAL ANALYSE OF  
MICROGRIDE**

Master's Thesis

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3. Project More microgrids
4. Case study for selected type of renewable energy sources in microgrid

Bibliography / sources:

- [1] Energy outlook 2016
- [2] Projekt More Microgrids, CIGRE 2014
- [3] Schlabbach, J. D Blume a T Stephanblome, Voltage quality in electrical power systems, IEE London
- [4] Distribution network code
- [5] Application manual eVlivy

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## **Abstract**

The master thesis is focused on technical analysis mikrogrids. In the text are listed the basic elements of microgrids, ways to control microgrids, architecture of microgrids. Ways of operating are listed in detail the microgrids parallel to the distribution network, and Island operation. The following are the parameters of the quality of the electricity that have great importance when in operation. The author lists a number of pilot project of microgrids in Europe. In the final part of the work is presented a case study of small microgrid and the necessary calculations are made, in particular in the voltage profiles in microgrid.

## **Key words**

Microgrid, architecture of microgrid, microgrid operation, power quality, case study

## **Abstrakt**

Diplomová práce je zaměřena na technickou analýzu mikrosítí. V textu jsou uvedeny základní prvky mikrosítí, způsoby řízení mikrosítí, architektura mikrosítí. Podrobně jsou uvedeny způsoby provozování mikrosítí paralelně s distribuční sítí a ostrovní provoz. Dále jsou uvedeny parametry kvality elektřiny, které mají při provozu mikrosítí velký význam. Autor uvádí několik pilotních projektů mikrosítí v Evropě. V závěrečné části práce je představena případová studie malé mikrosítě a jsou provedeny potřebné výpočty, zejména profily napětí v mikrosíti.

## **Klíčová slova**

Mikrosíť, architektura mikrosítě, provoz mikrosítí, kvalita elektřiny, případová studie

## **Declaration**

I hereby declare that this thesis is the result of my own work and all the sources I used are in the list of reference, in accordance with the Methodological Instructions on Ethical Principles in the Preparation of University Theses.

Ahmad Alshammari

In Prague, 23. 5. 2018

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# 1. Generation and Distributed Infrastructure

## I. INTRODUCTION

This theesis explores some of the issues surrounding the apparent ongoing reorganization of the power system into units employ distributed energy resources (DER) and that enjoy some measure of control independence from the traditional grid, entities that will here be referred to as microgrids. Symmetrically, macrogrid will be used to describe familiar traditional electricity supply involving large central station generation, long distance energy transmission over a network of high voltage lines, then distribution through medium voltage radial, or occasionally meshed, networks. Most industry analysts today agree that some form of less centralized supply and control is desirable and expected;

The nature of locally controlled systems is far from determined, and indeed many forms of microgrids may emerge to meet their own local requirements, and such diversity is probably desirable. While addressing some of the wider issues, the main focus here is on three major benefits of microgrids internal to participants in it, namely 1. application of combined heat and power (CHP) technology. opportunities to tailor the quality of power delivered to suit the requirements of endues, here called heterogeneous power quality and reliability (PQR), and the more favorable environment microgrids potentially establish for energy efficiency and small-scale renewable generation investments

## II. A SHORT HISTORY OF THE U.S. POWER SECTOR

The Industry's Roots The historic progress of the electricity industry is here described in the context of the U.S.; however, parallels can likely be found in the histories of many countries. The industry began in the U.S. with a period of isolated systems, beginning when Thomas Edison opened Manhattan's Pearl Street station in 1882 . Since early systems were naturally isolated, many microgrid enthusiasts suggest that microgrids are no more than a return to our engineering roots. While this is strictly true, the picture is clouded by two features of early power systems. First, they truly were isolated, whereas modern microgrid concepts generally incorporate an interruptible grid interconnection of some kind.

Second, the era of independent systems was fairly short-lived. The birth of large interconnected systems was marked by the opening of the first remote alternating current (ac) system commissioned by Westinghouse in 1896 to serve Buffalo NY by a hydro station at Niagara Falls, about 35 km distant. In other words, the era of purely isolated systems

lasted only a decade or two. B. Unfettered Competition Following was a chaotic period (1901-1932) of consolidation and growth led by privately owned utility companies that quickly resulted in the emergence of state regulation, beginning with the establishment of public service commissions in Georgia, New York, and Wisconsin in 1907. The availability of electricity grew spectacularly over this period, ultimately reaching two-thirds of all households. Total production increased 12 %/a on average, despite declines during the Great Depression at the end of the period, and prices fell by two-thirds. Centralized control over larger regions became increasingly practical and the electricity industry because a highly capital intensive pursuit. C. New Deal Reform, the Golden Age, and Problems The early frantic period was closed by various pieces of New Deal legislation intended to spread access to electricity service, develop the vast Federal dam projects, and limit the excesses of the private electricity utility sector.

Increased Federal involvement and rapid expansion of electricity usage characterized the following era, and of equal importance, reliability improved significantly. The rapid demand growth of the World War period continued into the golden post-war period, with residential sector applications and consumption growing most spectacularly. The Federal role was further expanded through encouragement of nuclear power beginning with the Atomic Energy Act of 1954. The 1960's saw the industry reach its zenith, while at the same time, the first signs of problems were emerging. Demand grew as rapidly as ever, and yet environmental concerns, limits on efficiency improvements, and reliability concerns following the northeast blackout of 1965 signaled the coming end of the golden age. During the 1970's some problems became serious. Decades of falling costs reversed as a result of increased fossil fuel prices, all of which increased dramatically. Even domestically produced coal increased in cost by almost 16 %/ a over the decade. Following the Three Mile Island Number 2 accident in 1979, the cost of nuclear generation also escalated, and no new reactors have been ordered since.

This period also saw the beginnings of the philosophical questioning of large-scale systems that is now so familiar, especially large energy systems [2,3]. D. Reversal Typical trends in the growth of per capita energy consumption in postindustrial economies are illustrated .While advanced economies become more electricity efficient, i.e. produce more income with less electrical energy. prosperity and new uses for electricity consistently outstrip this improvement so per capita electricity use actually grows, substantially in some cases. The problems of centralized power supply make consideration of alternatives an imperative. In the U.S., perhaps 1979 was the actual tipping point because it was both the year that the utility share of generation peaked at 97 %, and it was also the year in which the Public



Utility Regulatory Policies Act (PURPA) that revitalized independent generation was passed. Although competition in generation alone was contemplated and then only under limited circumstances at first, the process of decentralization accelerated dramatically in the mid 1990's with the establishment of independent system operators (ISO's) in various parts of the country during the years 1996-1998. This process of industry restructuring not only established competitive patterns of generation competition, but also contemplated retail competition in some cases.

This process is still in motion, but at a much-reduced rate following the California market meltdown of 2000 and 2001, and restructuring has not progressed as far in the U.S. as in some other regions. E. Whither from here, This then is the starting point for this study. As asserted above, most in the industry see some merit in moving towards a more decentralized form of power system, but there is little consensus on the exact nature of that system. To be sure, the technical features of today's macro grid reflect the legacy of centralized planning, operation and control. Even in the postISO controlled regions, a high degree of centralized decision-making is retained to ensure system adequacy, stability, security, and robustness, while accommodating contractual commitments between market entities. Also, rules extend well beyond the meter, for example, requiring generator shutdown during blackouts. Per Capita Electricity Consumption in Three Developed Countries

	0.0	0.1	0.2	0.3	0.4	0.5	1970	1975	1980	1985	1990	1995	2000	kWh/US\$GDP	Japan	U.S.
France																

Electricity Intensities of Three Developed Countries

### III. DISADVANTAGES OF EXTREME CENTRALIZATION

Much has been said and written from many perspectives about the advantages of smaller scale generation and local control, but before addressing the key issues from that perspective, it is illustrative to consider the push towards microgrids, i.e. to consider what problems came along with the emergence of the familiar highly centralized grids of today. Restrictions on power system expansion – Electricity demand continues to grow in the developed economies and the macrogrid may not be expandable to meet the requirement. In the U.S., demand is predicted to increase by about 50 % over the current quarter century. Siting all the necessary generating stations, transmission lines, substations, etc. to meet growing demand will pose a major political challenge.

Limitations of centralized power system planning – Even if growing demand can be met by the macrogrid, it is not clear that this can be achieved in a timely and organized way. In the U.S., investment in the grid has been falling behind demand growth for a quarter century,

and investment in generating capacity has been erratic. Risks of volatile bulk power markets – For some good economic reasons, establishing vigorous competitive wholesale generating markets is a high priority, and yet they might prove to be counter to reliable supply. Threats to an insecure system – Concerns about malicious attacks to the infrastructure haunt us, and unfortunately, the macrogrid poses a particularly attractive target. Consequences of infrastructure interdependencies – The increasing interdependencies of our complex infrastructures may be recognized as a mistake.

Modern communication systems typically fail in blackouts, and vice-versa utility operations are highly dependent on communications. And the interdependence extends to public transportation, water and sewage service, etc. Each of these services might be more dependable if it self-provided power independent of the grid. Limits to the qualities of power delivered – Finally, the universal power quality paradigm of the macrogrid may be too costly to support, as described in more detail below.

#### **IV. THREE ADVANTAGES OF MICROGRIDS?**

Much has been said and written about the many possible benefits of a distributed power system. See [6] for example. Here, the focus is on just three aspects of microgrids, combined heat and power, heterogeneous PQR, and the role of the microgrid decisionmaker.

A. CHP CHP is likely to occur in microgrids, be it fired by renewable or non-renewable fuel. While the simple cycle efficiency of generation at modern central station power plants will normally exceed any likely competing technology available in small scales, CHP can change the overall efficiency competition considerably, potentially handing microgrids a lower overall carbon footprint. Since transporting electricity is much more convenient than transporting heat, placing generation where economically attractive heat sinks exist may be a desirable generation configuration, and one that suggests a high degree of dispersion. In fact, optimal dispersion might suggest generators be small and deeply embedded with demand, e.g. residential rooftop photovoltaics or thermal generation on multiple building floors collocated with heat loads such as domestic water heaters.

B. Heterogeneous PQR Various indices for measuring power quality and power reliability are often used in quantifying levels of electrical . Outages may be scheduled for periodic maintenance operations on the electrical system, but unscheduled outages are generally much more disruptive and threatening to people and property. Outages effects include unavailability of certain services and processes, such as refrigeration, manufacturing, plus dependence on on-site backup generation which is typically costly and environmentally damaging. In contrast, deterioration in power quality has mixed and less dramatic effects. It is caused by deviations in the features of the electrical power delivered to the load such as voltage sags, swells, harmonics, imbalances,

which are triggered by periodic switching operations or by faults in the electrical systems due to weather-events, wildlife, user errors, etc. If power quality events do not lead to service loss, they become important only when they trigger degradation in the end-use service or equipment performance or durability. Thus, from an end-user perspective, power quality and reliability cause similar consequences and costs, while the scale and drama of events might be wildly different. While the ideal is rarely achieved in practice, the prevailing macrogrid paradigm is to provide a universal level of PQR to every load in the network.FIG

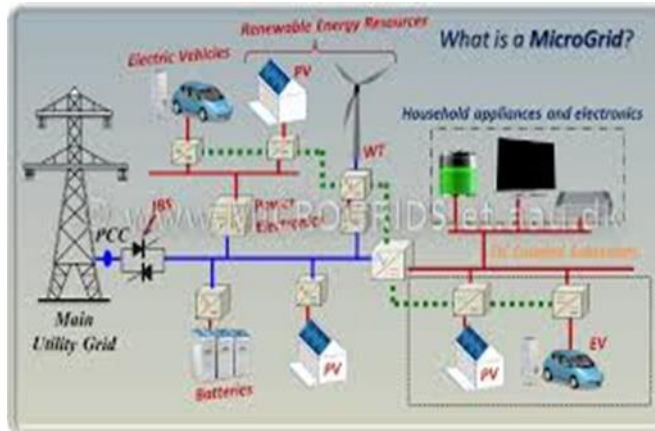


Fig. 1 – Principle scheme of the microgrid  
(source: Google.com\_AUICigB&biw=1920&bih=97)

conceptually shows an approach to picking the optimum universal target PQR level for the economy to adopt. The horizontal axis shows increasing service availability on a pseudo-log scale, with approximately the lowest reliability we can currently imagine as acceptable to the left and perfection to the right. The vertical axis shows societal cost of providing reliability. This cost has two components, the cost of providing reliability and the cost of the residual unreliability, i.e., of unserved requirements, with the sum representing the total societal cost. The optimum is clearly at the point of minimum total social cost, which in this case occurs to the left of the current U.S. target of about 99.99%. Developed economies have chosen to push reliability as far to the right in Fig 3. as possible, with relatively little consideration of the tradeoffs implicitly involved. Furthermore, the push to the right has resulted in system interdependency with possibly unnecessarily costly consequences when failures occur. One might also consider the effect of making systems more resilient to power outage, and local provision of electricity by DER is one potential method. It is pure speculation at this point what the net effect would be, but one possibility is that the societal optimal could be pulled leftwards. While technical analysis of electricity service PQR can be

highly sophisticated, by contrast analysis of the economics of the PQR of end uses is at best rudimentary. If the universal PQR is inadequate, backup or power conditioning provision is applied, and often backup is a code requirement, e.g., at hospitals, but otherwise the universal quality is accepted. Consider the pyramid shown in Fig 4, which illustrates how various electricity uses might be classified according to their PQR requirements. Some common loads are widely agreed to have low PQR requirements and appear at the bottom of the pyramid, and vice-versa. Other loads can be much harder to classify, e.g., refrigeration is re-schedulable in many applications, but might be critical in others, such as medication storage. At the top of the pyramid the exposed peak shows that not all requirements are currently met, i.e., a cut off exists. Analysis of PQR in a form like the pyramid could potentially lead to the clustering of like PQR loads on certain circuits and the provision of electricity of appropriate quality to that circuit. At the same time, the effective provision of high PQR locally to sensitive loads could potentially lower the societal optimum for grid service, as mentioned above. While space limitations preclude extensive consideration of the implications of power systems that deliver heterogeneous PQR, four observations are offered: 1. Little analysis or data collection has been done to establish the parameters of the pyramid shown in Fig. 4. 2. Matching the PQR delivered to the requirements of the end use can potentially meet our goals at lower cost than universal PQR. 3. A wise approach would disaggregate loads such that the peak of the pyramid is as narrow as possible, and the base as wide because the former are the costly ones to serve.

**V. WHAT ARE SMART MICROGRIDS?**

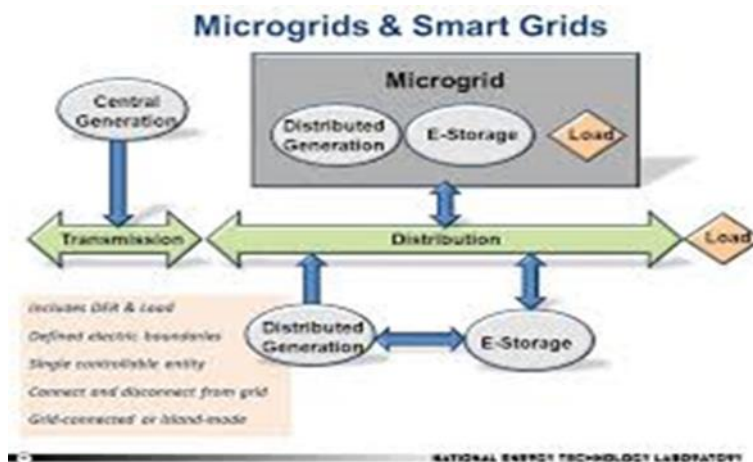


Fig. 2 Main features of the smart microgrid

Microgrids are modern, small-scale versions of the centralized electricity system. They achieve specific local goals, such as reliability, carbon emission reduction, diversification of energy sources, and cost reduction, established by the community being served. Like the bulk power grid, smart microgrids generate, distribute, and regulate the flow of electricity to consumers, but do so locally. Smart microgrids are an ideal way to integrate renewable resources on the community level and allow for customer participation in the electricity enterprise. They form the building blocks of the Perfect Power System.

Here at the Galvin Electricity Initiative's Microgrid Hub, you will find a comprehensive set of resources on microgrids, collected from our partners and from across the web. Use the navigation system at the left to browse through all of our microgrid materials, and if you have suggestions for additional content, please let us know. If you are a member of the media seeking information on microgrids, be sure to view our press kit in addition to the other resources. The Microgrid Hub was launched on May 20th to coincide with our Capitol Hill briefing, "Microgrids: A Critical Component of U.S. Energy Policy." The May 20th briefing, hosted by the the House Select Committee on Energy Independence and Global Warming, featured presentations from the Galvin Electricity Initiative's John Kelly, Guy Warner of Pareto Energy, and Intel's Fiona Sim.

## **VI. MICROGRID CONTROL**

### Hierarchical Control

In regards to the architecture of microgrid control, or any control problem, there are two different approaches that can be identified: centralized and decentralized. A fully centralized control relies on a large amount of information transmittence between involving units and then the decision is made at a single point. Hence, it will present a big problem in implementation since interconnected power systems usually cover extended geographic locations and involves an enormous number of units. The fully centralized control is currently considered infeasible. On the other hand, in a fully decentralized control, each unit is controlled by its local controller without knowing the situation of others.[17] The fully decentralized control is also irrelevant in this context due to strong coupling between the operations of various units in the system. A compromise between those two extreme control schemes can be achieved by means of a hierarchical control scheme consisting of three control levels: primary, secondary, and tertiary.[10]

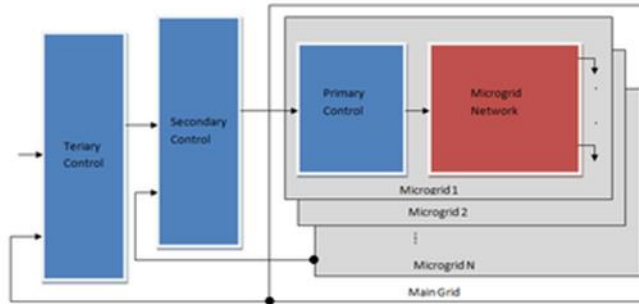


Fig. 3 – Scheme of the hierarchical microgrid control

[https://www.google.com.sa/search?q=Microgrid+control&tbm=isch&source=lnms&sa=X&ved=0ahUKEwiJlbWWrpjbAhVGLVAKHf7oA5sQ\\_AUICigB&biw=1920&bih=974&dpr=1#imgrc=MhI5yom38QYyYM:](https://www.google.com.sa/search?q=Microgrid+control&tbm=isch&source=lnms&sa=X&ved=0ahUKEwiJlbWWrpjbAhVGLVAKHf7oA5sQ_AUICigB&biw=1920&bih=974&dpr=1#imgrc=MhI5yom38QYyYM:)

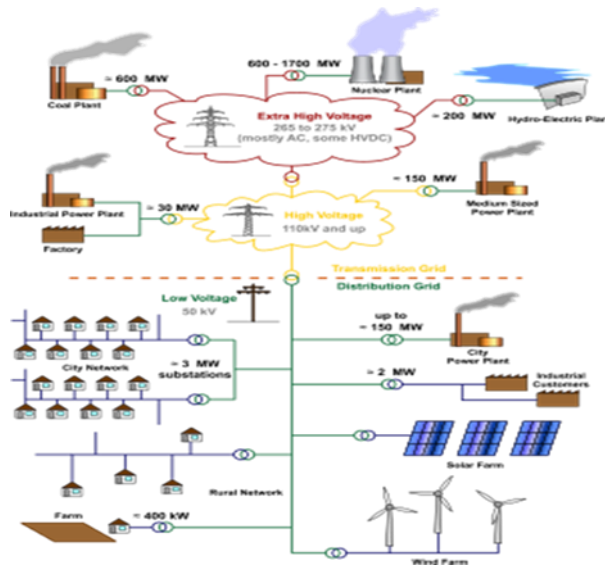


Figure 4 – Scheme of the microgrid connected to distribution network

General layout of electricity networks. Voltages and depictions of electrical lines are typical for Germany and other European systems.

An electrical grid is an interconnected network for delivering electricity from producers to consumers. It consists of generating stations that produce electrical power, high voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers.

Power stations may be located near a fuel source, at a dam site, or to take advantage of renewable energy sources, and are often located away from heavily populated areas. They are usually quite large to take advantage of economies of scale. The electric power which is generated is stepped up to a higher voltage at which it connects to the electric power transmission network.

The bulk power transmission network will move the power long distances, sometimes across international boundaries, until it reaches its wholesale customer (usually the company that owns the local electric power distribution network).

On arrival at a substation, the power will be stepped down from a transmission level voltage to a distribution level voltage. As it exits the substation, it enters the distribution wiring. Finally, upon arrival at the service location, the power is stepped down again from the distribution voltage to the required service voltage(s).

Electrical grids vary in size from covering a single building through national grids which cover whole countries, to transnational grids which can cross continents.

ABB will provide an innovative microgrid, combining battery and flywheel based storage technologies, designed to test scalability and improve power stability for around 300,000 people in Anchorage, Alaska, USA. The small scale project, initiated by Chugach Electric Association, Inc., aims to identify technologies that will enable the integration of more renewables, including wind power from a 17 megawatt (MW) wind farm on Fire Island, located about 4 km off the coast of Anchorage, which will work in concert with the innovative storage solution.

ABB's modular and containerized microgrid solution PowerStore™ will blend the complementary capabilities of two storage technologies, flywheel and battery storage. The flywheel will facilitate the integration of fluctuating wind power and the battery will be used for long-term storage. The battery has a capacity of 500 kilowatt hours with a maximum performance of 2 MW.

"We are delighted to partner with a visionary utility like Chugach Electric, to build this microgrid which incorporates a hybrid storage solution to enhance reliability of power supply", said Massimo Danieli, Managing Director of ABB's Grid Automation business unit, a part of the company's Power Grids division. "Integration of renewables is a key element of the Energy Revolution and a major focus area of our Next Level strategy."

ABB's advanced Microgrid Plus control system will monitor the hybrid storage solution and ensure proper load sharing between the two storage mediums. It is also equipped for remote service and maintenance.

"This innovative solution shows how energy storage technology can boost renewable energy penetration in Alaska and have far reaching implications for new renewable projects on the

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Railbelt as well as in smaller Alaskan communities,” said Paul Risse, Senior Vice President, Power Supply at Chugach Electric.

Chugach Electric Association is a leading electric utility, headquartered in Anchorage, Alaska's largest city, and home to half the people in the largest, most sparsely populated state in the US.

ABB is a pioneer in microgrid technology with around 40 installations all over the world, across a diverse range of applications serving remote communities, islands, utilities and industrial campuses.

ABB (ABBN: SIX Swiss Ex) is a pioneering technology leader in electrification products, robotics and motion, industrial automation and power grids, serving customers in utilities, industry and transport & infrastructure globally. Continuing more than a 125-year history of innovation, ABB today is writing the future of industrial digitalization and driving the Energy and Fourth Industrial Revolutions. ABB operates in more than 100 countries with about 135,000 employees.



## 2. Microgrid structure

### 2.1 MICROGRID CONCEPT STRUCTURE

Microgrid is the local small energy network of distributed energy resources with local loads, which is connected in parallel with the grid to provide a high reliability. It is independent of local electrical power grid and act as single controllable utility with respect to power grid. It is used to deliver the electricity to colleges, hospitals, factories, military bases or entire communities. There are two operation like Grid connected and island mode during the emergency operation. In control strategy, protection and control are big problem in the microgrid. Usually microgrid connect with Low voltage distribution network with different type of energy sources like (PV, fuel cell, etc.), energy storage system, storage battery, and variable loads. There are several distinct advantages to customers and utilities i.e. lesser overall energy consumption, reduction of environmental impact, increase reliability and resilience, most cost efficient power infrastructure.[28]

By supporting voltage and reducing voltage dips and lower cost of supply energy, it reduce emission and improve power quality. From customer point of view, it provide power and thermal needs. Demand for distribution and transmission facility has been reduced by use of MG from the utility point of view. It connect usually with MV distribution network.[28]

Research project FP5 Project MI-CROGRIDS (ENK5-CT-2002-00610) mainly deal with the single microgrid operation through laboratory experiments. This project's main objectives are describe as:

- Inventing new techniques for different control of maximum number of distributed sources.
- Development of storage and load controller and smart micro-energy sources.
- Testing of new technologies and concepts in real pilot sites.

Microgrid offers Maximum flexibility in terms of ownership constitution compared to central generation concepts. Microgrid can be built by grid operator or by consumer or by free market player platform. There are benefits to use of microgrid as power supply having emission reduction power supply and lower tariff to end consumers. For future evaluation of energy service provision, Microgrids play a significant role to overcome the demand growth of electricity. Distribution generation and distributed storage are located near the consumer location which provide improved reliability. Integration of various DG technologies with the utility power grid is an important pathway to a clean, reliable, secure, and efficient energy

system for developed economies with established levels of quality and reliability of electrical service. Various studies have found that a large number of utilities as well as consumers that have installed DGs at their facilities realize benefits like local waste heat capture, improved reliability and reduced cost. Microgrid is created by connecting a local group of small power generators using advanced sensing, communications, and control technologies.[29]



*Figure 5: Simple concept of Microgrid*

Microgrids can be operated as two modes like off grid mode (standalone mode) or main grid connection mode. Usually generation and loads are connected at low or medium voltage level .microgrids has several generation renewable sources like solar cell, fuel cell,wind energy and power storage system(battery). Maximum number of power system are connected to microgrid due to this operator should be very alert.

The followings are parameter of Microgrid:

- Small microgrid have 1-5 km radius.
- It can produce power unto to 1-5 MW to deliver the customers.
- There in no requirements of long distance transmission lines and free from transmission power losses.

Dc microgrid concept could be implemented in recent year for power generation and utilization system. DC microgrid can be placed at minimum distance between electricity

generation and loads., DC storage devices such as batteries, capacitors, and fuel cells also fulfill the requirements of local DC power. In essence, the self- network of power generation and energy storage devices, known as the Microgrid is basically a small network of the larger power grid. This self-sufficient PV-based" Nanogrid" can generate, store and distribute its own power, which is ideally suited for rural electrification.

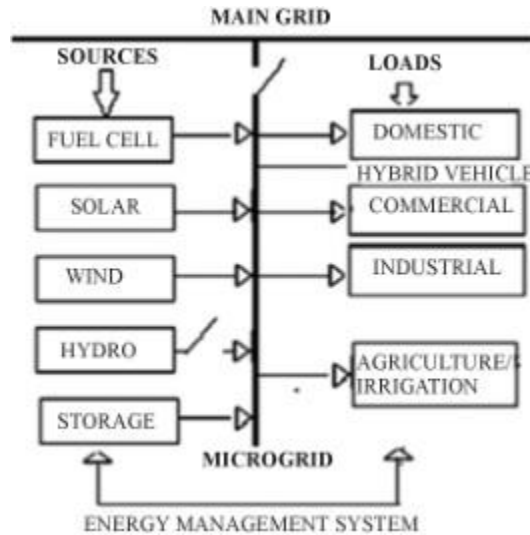


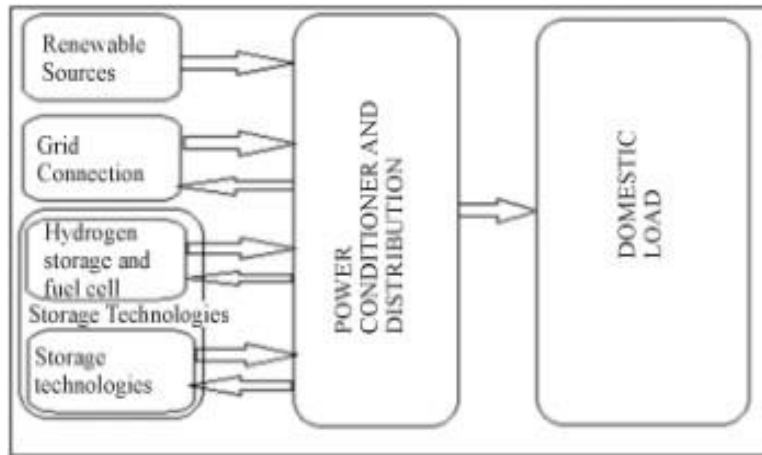
Figure 6 - Architecture of Microgrid

Selection of Renewable energy source is very important consideration due to location and environment condition of that land. Integration of this sources require proper energy storage and monitoring system. Electronics technology are being used for monitoring system of Microgrid operation. Energy storage and management system have several reason like smart Gris, distributes energy sources, bad impact on environment due to fossil fuel use, after use of storage energy, development of electric vehicle which is focused on implementation of renewable energy sources in microgrid. This system will provide smooth, uninterrupted energy to home appliances by using resynchronization algorithm and advanced islanding detection.

**Table 1:** System component of Microgrid

Main Sources	Macro Grid Generators
<b>Renewable Energy Resources</b>	<ul style="list-style-type: none"> <li>• Small hydro system</li> <li>• Wind energy</li> <li>• Bio fuel energy</li> <li>• PV solar cell</li> <li>• Ocean energy and geothermal energy</li> </ul>
<b>Energy Storage Systems</b>	<ul style="list-style-type: none"> <li>• Fuel cells (PEM, SOFC and alkaline)</li> <li>• Batteries (lithium)</li> <li>• Super capacitor</li> <li>• Pump storage</li> <li>• Fly wheel</li> </ul>
<b>Types of Loads</b>	<ul style="list-style-type: none"> <li>• Small (domestic)</li> <li>• Medium (commercial)</li> <li>• Large (agriculture/irrigation three phase) and industrial-three phase</li> </ul>
<b>Technical Parameters</b>	<ul style="list-style-type: none"> <li>• Preferably linear</li> <li>• Balanced line not unbalanced</li> <li>• System should be dynamic</li> </ul>

Decentralizing system is called as microgrid system by standalone operation which increase the system overall efficiency up to 85%- 95% by use of CHP system and reduce the loss of energy in transmission system.



*Figure 7 - Proposed Microgrid Distribution system*

To manage the flow of system active and reactive power balance, distributed generation can be used with banks of capacitor in power system. Control system takes care of whole system while all the resources is integrated in the main grid and reduce environmental impacts such as:

- Reduce the greenhouse gas emission
- Increase the energy security by use of distributed generation and all energy sources sharing

Microgrids carry out dynamic control over energy sources, enabling autonomous and automatic self-healing operations. During normal or high demand, or during the time of power grid failure, a microgrid can operate standalone of the power grid and disconnect generation nodes and power loads from disturbance without affecting the power grid connection. Microgrids interoperate with existing power systems, network infrastructure, and information systems and are capable of feeding power back to the larger grid during times of grid failure or power outages.

## 2.2 MICROGRID FEATURES

Microgrid components such as renewable or fossil-fueled generators, several circuit breakers and its control, loads, energy storage systems, must fulfill several requirements to produce reliable operation. Lawrence Berkeley National Laboratory has observed some important top-level microgrid features that should be considered in all standardization projects and research and development projects:

**Compatibility:** Microgrids are compatible with the current power grid. They may be considered as main units that support the development of the current system in an economically and environmentally friendly way.

**Stability:** Independent local control of generators, batteries, and loads of microgrids are based on frequency and voltage rating at the point of each component. Microgrid can perform stable operation during nominal operating conditions and during transient condition, without dependency of larger power grid. To achieve a high level of stability, additional research is required.

**Efficiency:** The utilization of generators, manage charging and discharging energy storage units, and can manage centralized as well as distributed microgrid supervisory controller structures consumption optimize. In this way energy management goals can be optimized on environmental related condition.

**Economics:** According to market research studies, by evaluation of microgrids economics of heat recovery it can be identified current market of energy. In addition, use of renewable energy resources will help to reduce greenhouse gas emission and cost of fuel.

### 2.3 DIFFERENT TYPES OF MICROGRID

Depending on size, location and market condition, microgrids can be divided into different types. Some microgrids are described below.

#### **Institutional Microgrids/campus environment microgrid**

Major concern about onsite generation with several load which are connected in industrial park. In microgrid segments, single owner of both generation and large loads can manage very easily and avoid several problems. Generation power range from 4 MW to 40MW or more.

#### **True Microgrid or Customer Microgrid**

It is connected at single point of common coupling(PCC) and self-operated. Usually it fit nearly to the current technology and control structure. Deployment of this type would be preferable from Customer point of view.

### **Remote off grid Microgrids**

Operation of this microgrid is in island mode without connect to the main grid. remote village power system in Village and generation of wind power are the best example of this type of microgrid which are interconnected and supply power to the local distribution. By implementing distributed wind and run of the river hydropower and solar photovoltaics, reducing fossil fuel goal has been achieved. Village power sytem have the lowest average capacity of power generation and distribution.

### **Military base microgrids**

This type of Microgrids are implemented with the focus on both cyber and physical security for military purpose to provide uninterrupted power without relying on the power grid. for forward operating bases , it includes mobile military microgrids i.e. Afghanistan. This approach is actively working by U.S department of Defense(DOD).

### **Utility/Community Microgrids**

There is no islanding operation in this type of Microgrid. European Countries lead this segment. By use of one or more distribution substations, community microgrid is correlated with local grid network and supported by local renewable energy sources and several distributed energy sources(DES).It provides Cost effective energy, secure and more sustainable energy. It use load flattering and efficient load design to reduce transmission cost and costly peaks. More efficient grid operation and power quality operation has achieved by use of community microgrid.

### **Industrial and commercial Microgrids**

This type of microgrids have good reliability and good power supply security, Usually big manufacturing industries is implementing this type microgrid due to its constant power supply capacity. For balancing and storing the energy , utility can be provided additionresources which is satisfied industrial energy needs. For Conventional energy production,PV technology is becoming an alternative energy source due to environmental concerns during the grid connected operation. Batteries are most impratant to match power generation and consumption demand.



Figure 8 - Utility/Community Microgrid

## 2.4 MAIN MICROGRIDS COMPONENTS

Microgrids consist of Several components like energy management system, communication system, controllers and power conversion elements, distributed energy resources and main key component is customer.

- It is main functions in power prediction from renewable energy sources, power planning and load forecasting. For power system reliability evaluation, data collecting and estimation has been done by energy management system.
- By Proper monitoring and control information sharing, communication system become medium in microgrid system. It is interconnect with different component and ensures control and management task in the system.
- Electrical Parameter of system like voltage, frequency and power quality which is controlled by use of proper controller. It is very important for the microgrid operation to change the parameter of system according to the requirement.
- Power conversion equipment like current and voltage transformer, are used to detect current and voltage limit for power system. Power electric converter interface is necessary to change the AC and DC voltage and current from the Distributed energy sources.
- DER produces the sufficient amount of energy to fulfill the demand of energy in Microgrid system and supply energy to meet require energy demand.
- Microgrid can be implemented according to the customer energy demand and customer participation is the important consideration for smart grid.



### 2.5 IMPACT OF MICROGRIDS ON THE DISTRIBUTION SYSTEM

There are several important parameters of microgrid operation should be consider as key feature during the production and transmission of electricity throughout the whole microgrid which is describe below:

#### **Fault level Increase**

Most MG use both synchronous and induction generator for energy generation so that it will increase the fault level of the distribution system and contribute to the system fault levels. Introducing impedance by reactor or transformer between the system and generator, system fault can be reduced. Development of distributed Generation can be a serious problem in urban areas where the existing fault level increase the rating of switch gear.[35]

#### **Power Quality**

Usually two aspects are considered to be important in power quality like:

- Variation in transient voltage
- Harmonic distortion of network voltage

Load as well as source fluctuation can cause voltage variation. It is very important to control the voltage variation due to relatively very large current changes during the disconnection and connection of the generator. Standalone operation of MG system observe more voltagechanges due to load disturbance which cause current change to the DG inverter. Ac output volage from the inverter will fluctuate by significant change in in voltage drop due to high output impedance of inverter.

Injection of harmonic current into sytem by incorrectly design MG with power electronics interface which cause voltage distortion of the network. These harmonics depends on mode of operation, power converter technology, the interface configuration. Fortunately, most new inverters are based on Insulated Gate Bipolar Transistor (IGBT), which uses Pulse Width Modulation (PWM) to generate quasi-sine wave. Higher frequency of carrier wave has quite pure wave form without distortion by use of recent advances semiconductor technology.

#### **Stability**

Objective of the Distributed generation scheme to generate the power from the RES and control the generator transient stability. During the fault condition in the distribution network, network voltage changes occurs and generator trips so that is the losses of

generation for short period of time. MGs will trip the internal protection scheme and control system takes a command to restart automatically. DG is observed as power system support then transient stability becomes more considerable importance.

### **Protection**

Different protection steps can be identified:

- Loss Of mains protection or anti-islanding
- Impacts of Existing protection of distribution system of MG
- Generation Component protection
- MGs faulted distribution network protection

## **3. Microgrid projects in Europe**

### **3.1. CURRENT PROJECT OF MICROGRID**

There are several major research efforts which has been supported by The European Union to devote exclusively to Microgrids. This Projects focused on Demonstration activity of Microgrid operation through laboratory experiment, appropriate control techniques investigation, and individual operation of single Microgrid. Maximum number of DER connected to create a Microgrid with laboratory facility was implemented in National Technical University of Athens (NTUA)Kythnos Island, Greece. Main objectives to control the microgrid operation and test small scale equipment. The system has two poles each connected with local Wind and PV generation and battery storage system, also connected each other by low voltage line as well as to the main power grid. By its own connection to the grid, each pole may operate as a Microgrid or by two bus microgrid connection, both pole may be connected via the low voltage line.

In Netherland, another Microgrids Project is located at Bronsbergen Holiday Park near Zutphen. It covers 210 cottages and 108 of them are connected to grid-connected PV systems. Three phase 400v network is connected to 10-KV medium-voltage network via distribution transformer.

Consortium for Electric Reliability Technology Solutions(CERTS) microgrid is located in Columbus, Ohio in USA. It has thyristor based static switch and three 60-kw converter based sources and internal combustion engine use natural gas which achieve maximum efficiencies over a wide range of loads. To insure a constant AC frequency at microgrid, output has been rectified and inverted.

In Japan, there are three projects are implemented at three different location like Kyoto Eco-

Energy project (Kyotango Project), Expo 2005 Aichi, and Regional Power Grid with Renewable Energy Resources in Hachinohe City (Hachinohe Project). Capable of matching energy demand and supply for microgrid operation has been established in these three projects. In Expo 2005 Aichi project, PV and a battery storage system and fuel cell has been used in power supply system. In September 2007, it declared a second grid-independent operation mode. In Hachinohe Project, Microgrid has private distribution line more than 5km to supply electricity primarily generated by the gas engine system. It has several small wind turbines and PV systems.

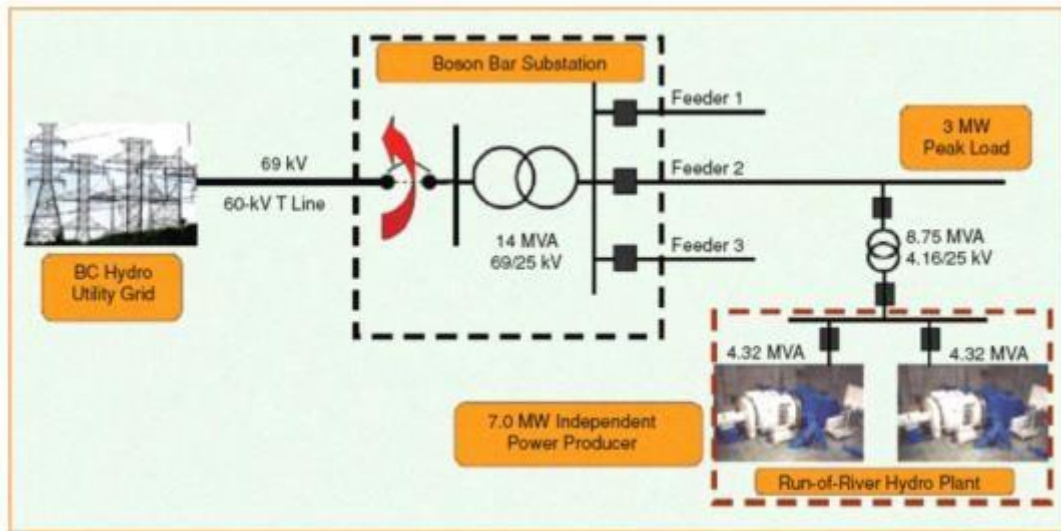


Figure 9: System configuration for the Boston bar IPP and BC Hydro planned islanding site

In Canada, several power outages in Boston Bar town had been experienced two or three times per year. One option to operate in an island mode and supply load on more or one feeder of substation and utilize the local independent power producer (IPP). It has two 3.45 MW hydro power generator It is connected to one of three feeders with the peak load of 3 MW.

### 3.2 ADVANTAGE AND CHALLENGE OF MICROGRID

Power quality and Reliability of current power system has been improved by systematic application Microgrid technologies at the local distribution level. There are mainly three major benefits includes: ensure local supply control (30%), fulfil local demand (approx.49%), and enhance grid reliability (36%). Reducing energy cost and good electricity supply reliability and grid security depends on lower frequency response of microgrid technologies. Integration of Distributed energy sources (DER) and battery storage option

becomes a foundational building block in the ultimate smart grid. During the brownout and blakouts, ability of microgrid is to island itself from the distribution system which enables Microgrid enablinf technologies both islanded and online like: Advanced Energy storage

- Smart transfer Switch
- Smart Meters
- Distribution Automation (DA)

Several research noted that most important technologies for Microgrid deployment were:

- Communication sensors and technologies,
- Distribution management system,
- Energy management system.

Microgrid can operate as a single collective load within the power system which is the primary advantage of a microgrid from the electric grid's perspective. Small scale renewable energy sources and small-scale combined heat and power (CHP) generate distributed power which can increase energy efficiency and environmental advantages over central generation. Microgrid technologies leads to way of thinking about building and designing smart power grids. By energy generation and distribution like heat, Microgrids economically and efficiently integrate buildings and customers' needs and enhance power reliability.

Power disturbances and blackouts are either substantially minimized or eliminated due to local power generation, ability to island ,redundant distribution, smart switches operation of microgrid technologies. By selling the power back to the utility/grid when not islandes, Microgrids can generate revenue for businesses and constituent consumers. Microgrids can set the stage for added consumer revenues from carbon credits and plug-in electric vehicles.

CHP operation of Microgrid makes more flexible and efficient power network. It is more convenient to transposer electricity than transporting heat. In electrical service, several methods are used for measuring power reliability and power quality. While deterioration in power quality has mixed and low effects like voltage swells, imbalances and harmonics etc., unscheduled outages are becomes more threatening nand disruptive to property and people. Universal level of PQR to every load should be provided in the network.

Microgrid Concept observe the number of challenges in dispatch, control and protection point of view. Several new technical challenges are describes below.

- Two modes of operation: Standalone/islanded and Grid connected mode.
- By connection/disconnection of loads, storage system and generators, gradually changes in LV network.
- In islanding operation, Low level of Short-Circuit current due to Power electronics Interfaced distributed generation(DG).
- Bidirectional power flow in both low voltage and medium voltage generation system.
- High rotating machine penetration which lead to increase fault current and rating of equipment.
- During the fault in LV and MV system, slower tripping time of system.
- Difficult protection tripping due to fault on feeders.

Usually Many microsources are connected to the microgrids by use of power electronics inverter which has incompatible output with the grid voltage. There are several problems have to be considered due to small fault current contribution of inverter output which is considered below:

- Difficulties in Inverter operation for Short circuit studies hence control strategy dependent operation.
- During the change of operation from Grid connected to islanded mode, fault current level is reduced significantly.
- For Different characteristics, The whole microgrids may have different inverter throughout the whole system.

Inverter design and application depends on inverter characteristics in cas of individual inverter.

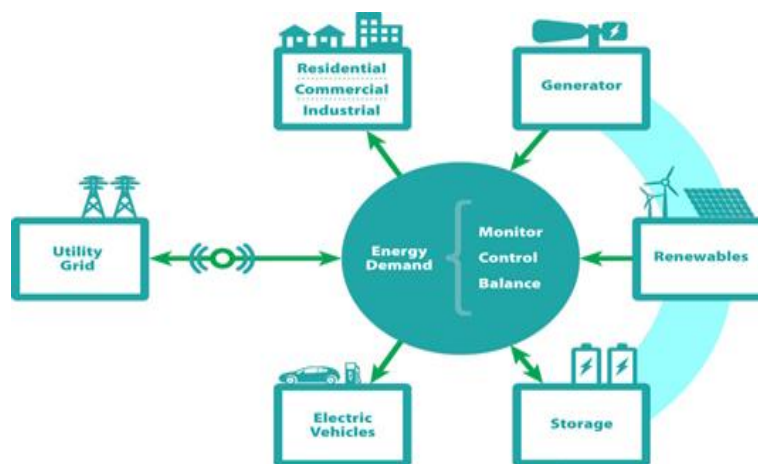


Figure 10 – Components of the microgrid

### 3.3 MICROGRID ARCHITECTURES AND CHARACTERISTICS

The technologies described above can be configured a number of ways to address a variety of different microgrid applications. As discussed above microgrids may consist of medium and low voltage distribution systems delivering power and/or thermal energy to loads in proximity served by DERs located on site. Microgrids can be interconnected to the macro-grid (interconnected microgrids) or designed to operate entirely as an island.

Microgrids interconnected to the extant electric system at the point of common coupling can move between grid- connected and isolated grid modes, depending on circumstances. While grid-connected, the microgrid’s control system may maintain a “grid dependent” or a grid-independent mode of operation, again depending on the circumstances. This flexibility allows interconnected microgrids to take advantage of grid resources yet maintain independence if needed.

Driesen and Katiraei identify three types of microgrid architectures that reflect different categories of applications, including utility microgrids, non-utility or industrial microgrids and remote or isolated microgrids. Table 2.3 below is a general classification of different microgrid architectures and their characteristics based on different applications, ownership structures and load types.

#### Microgrid Architectures

	<b>Utility Microgrids</b>	<b>Non-Utility Commercial or Remote/Isolated Industrial Microgrids</b>	<b>Commercial or Industrial Microgrids</b>
<b>Urban Networks</b>			
<b>Rural Networks</b>			
<b>Multi-facility Feeders</b>			
<b>Application</b>	Clusters of commercial and remote communities Downtown areas islanding university campuses	Planned industrial islands	residential buildings; and geographical
<b>Main drivers</b>	Outage management/improved reliability and control and renewables or CHP integration	Power quality enhancement, reliability and energy efficiency	Electrification of remote area and reduction of fuel use
<b>Benefits</b>	Greenhouse gas reduction; supply/fuel diversity; congestion management; distribution/transmission upgrade deferral; and ancillary	Premium power quality; service differentiation (i.e., reliability levels); CHP integration; and demand response management	Supply availability; renewables integration; greenhouse gas reductions; demand
<b>Operating modes</b>	Grid dependent (GD); grid independent (GI); and isolated	GD, GI, IG	IG grid (IG)

TECHNICAL ANALYSE OF MICROGRIDE

Faults on adjacent feeders or at  
power quality issues

Macrogrid power failure; substation

**Transition**

**Accidental to**

**GI and**

**IG Modes Schedule** System  
maintenance

Energy prices (peak); utility  
maintenance

**Source:** Dreese and Katrine, 2008

Each of these architectures has a different set of drivers. The utility microgrid may be particularly valuable in a downtown urban network or along a rural feeder line where service capacity is resource-constrained and reliability and power quality may be compromised or in danger of being compromised. Efforts to increase the amount of renewable energy or use CHP may also be drivers of utility microgrids. Non-utility commercial or industrial microgrids may be driven by a desire to reduce costs through self-generation as well as provide greater control over site power quality and reliability. These loads, or a portion thereof, may not tolerate even momentary outages and a microgrids can be adapted to serve the different load requirements of multiple commercial or industrial facilities.

Microgrids can also be designed to serve multi-facility residential customers or mixed use areas. Research conducted at Columbia University found, that due to their high demand for thermal energy relative electric, large multi-family buildings could serve as excellent hosts for CHP-based microgrid systems. Although less applicable to New York State, remote or isolated microgrids serve to electrify areas either currently without power services or with limited access to fuel supplies (e.g., remote communities, state parks or resource extraction sites).

The range of benefits produced by a given microgrid will likely reflect the intended application, architecture, and resources deployed. A utility microgrid may be focused more on integration of renewable energy supplies and as a result, provide greater emissions benefits than a non-utility microgrid intended primarily to provide cost savings or highly reliable power services. These characteristics will in large part be driven by the microgrid ownership and service characteristics. Microgrid ownership and service models are examined further in Section 2.8 below

### 3.4 MICROGRID OWNERSHIP AND SERVICE MODELS

Previous efforts to clarify and resolve some of the regulatory barriers to microgrid implementation have found that the environment for microgrids in the US is complex and uncertain. Across the country, regulators' views of what a microgrid is and how one might operate differently. As a result, it is likely that the viability of a given microgrid within today's legal and regulatory structure will depend on how the project is framed, particularly with respect to who owns the microgrid infrastructure, which types of customers receive service from the microgrid, and how profits from those services are earned. Below we provide a typology of microgrid ownership and service models to help identify the range of options for deployment and begin to shed light on the types of applications that may face the biggest hurdles. While we raise some general legal and regulatory issues here, a more complete discussion of these issues as they pertain to



New York State and other parts of the country is provided in the next section.

In our research, we identified only two other efforts to define and categorize ownership and service models for microgrids. In its examination of the potential future market opportunity for microgrids for California, NCI identified four ownership models with “strong” business cases including utility, municipal (government), landlord (a single, non-utility and non-governmental owner) and renewable energy cooperatives (multiple non-utility owners). NCI also identified four scales of service these owners might provide including single facility (< 2 MW), multi- facility (< 5 MW), feeder (5-20 MW) and sub-station (20+ MW).

King, in his research on the regulatory environment for interconnected microgrids across different US states, found that the way a microgrid is presented will have a significant effect on how regulators view it. “When framed as a small independent power producer,” King explains, “a microgrid may yield a different reaction than when it is framed as a large distributed generator, or placed in the context of energy services or demand management.” In order to reduce confusion and facilitate policy discussion and development, King proposed the following five models by microgrid ownership and business practice.

1. *Utility model* – the distribution utility owns and manages the microgrid to reduce customer costs and provide special services (e.g. high power quality and reliability) to customers on the system.
2. *Landlord model* – a single landlord installs a microgrid on-site and provides power and/or heat to tenants under a contractual lease agreement.
3. *Co-op model* – multiple individuals or firms cooperatively own and manage a microgrid to serve their own electric and/or heating needs. Customers voluntarily join the microgrid and are served under contract.
4. *Customer-generator model* – a single individual or firm owns and manages the system, serving the electric and/or heating needs of itself and its neighbors. Neighbors voluntarily join the microgrid and are served under contract.
5. *District Heating model* – an independent firm owns and manages the microgrid and sells power and heat to multiple customers. Customers voluntarily join the microgrid and are served under contract.

As King observed, depending on the state in which a microgrid is located, regulators may interpret these models very differently. For example, he found that the Utility and Landlord models tend to be viewed most approvingly by regulators while the District Heating model is viewed least approvingly. These views are shaped by state electric industry regulation and law, which is generally designed to protect incumbent distribution utilities and their customers from the potential risks of competition. Even after industry restructuring, which focused on encouraging competition in generation, distribution

utilities continue to be granted monopoly power to provide service to customers within a specified service territory. Service territories and franchises granted by municipal jurisdictions, effectively uphold what is considered to be a natural monopoly designed to avoid the duplication of service wires, reduce utilities' financial risks, and assure customers they will receive electric service. By implying a merchant distribution function, where an independent microgrid firm can serve multiple independent customers that join voluntarily, the District Heating model may be viewed as conflicting with these existing protections for distribution utilities.

The ability of a non-utility firm or cooperative to build and operate a microgrid revolves primarily around the following issues: how will the microgrid be interpreted under existing law, how heavily will it be regulated and will the incumbent attempt to block it from proceeding? If a proposed microgrid is defined by the regulator as a utility distribution company, it will likely face significant and probably insurmountable barriers to implementation, especially if it is located within the service territory or franchise area of an existing utility. Not only is it likely that regulatory authorities will be inclined to protect the incumbent distribution utility, but also the utility itself is likely to defend its franchise rights in court, if necessary. In many cases, the mere threat of tying up a potentially small enterprise such as a microgrid, in litigation over franchise rights could stop a project.

For example, in 1998, Pittsburg Electrical Insulation (PEI) Corporation proposed the construction of a cogeneration power park that would serve approximately 25 MW of load to a variety of customers on a campus it owned. The local utility opposed the project and petitioned the Pennsylvania Public Utility Commission (PUC) that the facility should be treated as a public utility under state law. Ultimately, the PUC issued a declaratory order exempting PEI's proposed project, partly on the basis that it owned the property on which it intended to serve. With this confirmation, PEI broke ground on the project and secured customer commitments to participate. Still, continued legal threats by the local utility in civil court and PEI's fear of ruining the business relationship it had with the utility, led the company to abandon its plans. Ultimately, the PEI project went forward under an agreement with the local utility as an "exempt wholesale generator." PEI produces power and steam, but sells its electricity on the wholesale market. The PEI project is also not able to island from the utility system, reducing the potential reliability value of the system to its tenants.

In addition to influencing its legal status, the economics of a given microgrid project – the incentives and practical considerations for building a microgrid – are also likely to differ depending on the ownership and service model. The extent to which the benefits derived from developing a microgrid can be captured by the developer will have a significant impact on the likelihood of it being built. For example, if utility or social

benefits are large – and incremental to the estimated customer benefits – for a particular proposed micro-grid project, then that project under a non-utility model may not work, because the customers would not be able to realize the complete (i.e., social) value of their investment. This may be the case for a number of environmental and energy system benefits, such as reduced emissions, avoided line losses, and avoided generation and distribution system capacity investments.

In order to provide more granularity to New York State’s consideration of microgrid opportunities and barriers, we developed a framework, following King, for thinking about *physical* and *virtual* microgrid ownership and service models. The framework includes nine models within two major categories of ownership: utility and non-utility. The reason for proposing these categories is not to judge how a given microgrid would be interpreted under the law. Instead, we observe that there are two general types of entities that might want to pursue microgrids, existing utilities, and non-utilities (e.g., cooperatives, independent firms, and independent campuses). Within the utility and non-utility categories there are a number of variations that relate to the service orientation of the microgrid as well as additional characteristics that might affect a given model’s permissibility. We highlight these differences in the discussion of the nine ownership and service models below.

### 3.5 UTILITY OWNED PHYSICAL MICROGRIDS

Existing electric distribution utilities may want to develop microgrids for various reasons, including to improve local reliability, differentiate their service offerings to customers or possibly to compete with non-utility microgrid service companies. In this context, we envision the potential for utilities to both fully owned (i.e., vertically integrated) and partially owned microgrids (i.e., unbundled). Although we do not address this issue in detail, utility-owned/operated microgrids could cover a range of scales including sections of distribution feeders, entire feeders or entire substation areas.

There are several important reasons for this distinction. First, under electric industry restructuring, most distribution utilities have been required or encouraged to sell their generation assets to third parties to facilitate competition. As a result, utilities in states that have deregulated – such as New York – are generally not investing in new generation assets, but are leaving that to Independent Power Producers (IPPs) that build new generating units in response to wholesale market conditions. Meanwhile, states are encouraging customer investment in photovoltaics, fuel cells, and other forms of advanced clean distributed generation. Therefore, it is very likely that a microgrid that includes utility ownership of the distribution assets might also include customer or third party owned generating facilities.

Implementing this type of microgrid will require regulatory and policy guidance and potentially the development of new markets for local energy and ancillary services. Alternatively, utilities may want to own the generation assets embedded within the microgrid (if they are allowed) so that they can exercise a greater degree of control over the system. Utilities already own backup generation, which is used for reliability purposes, and increasingly they are asking regulators for permission to own renewable assets, especially photovoltaics. Ultimately, this microgrid model may require policymakers to reconsider restrictions on utility ownership of generation assets.

### **A.Vertically Integrated Utility Model**

An existing electric utility owns the microgrid distribution infrastructure and generation and storage technologies operating on the system, providing electric and/or thermal energy services to participating customers. It also operates the microgrid control system, determining which generating units run and directing customer demand response or the shedding of non- critical loads in the event of a macro-grid interruption or for economic reasons. The microgrid allows the utility to differentiate its product and services to customers in the form of varying reliability and/or power quality services at varying costs. The research team did not identify an example of a vertically integrated utility microgrid; however, aspects of this model are represented by a reliability project undertaken by Central Hudson Gas and Electric in New York and the City of Naperville's smart grid initiative in Illinois.

### **B.Unbundled Utility Model**

An existing electric utility owns and maintains the electric distribution facilities serving the microgrid, which provides electric and, possibly thermal energy, while generation or storage assets are owned by participating customers or third parties. The utility will likely operate or direct the microgrid control system, and possibly use a control scheme that can accommodate the interests of multiple DER asset owners (i.e., one that enables and can integrate multiple agents, or customers, acting on their own behalf).

In this model, the utility would be an active partner with customers and generators to facilitate and manage the aggregation of loads and the deployment of generation on the microgrid. An example of an unbundled or hybrid utility microgrid is the project San Diego Gas and Electric developing in Borrego Springs, California. While SDG&E will own generation and storage assets located at its substation, it is also encouraging customer-sited generation and developing a price-driven demand response program for residential customers. At least one circuit served by the substation area will be capable of islanding to improve local reliability (see SDG&E case study in the Appendix).

### 3.6. NON-UTILITY OWNED PHYSICAL MICROGRIDS



Figure 11 – HV distribution system

The development of non-utility owned microgrids providing lower cost, more reliable and cleaner energy services could become a significant new area of investment for distributed energy services. We distinguish non-utility microgrid ownership models based on whether the primary purpose is for self-service or for merchant service.

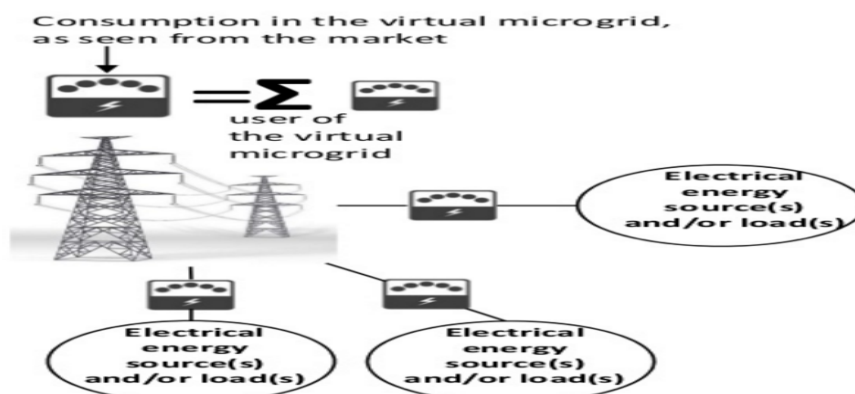


Figure 12 – Consumption in the virtual microgrid

### 3.7. VIRTUAL MICROGRIDS

A virtual microgrid, also referred to as “virtual private wires” or “virtual power plants,” is a distributed energy resource-pooling model that uses existing electric or steam distribution systems to link multiple energy production resources and loads. Under a virtual microgrid scheme, locally sited energy resources supply multiple end users, but there is no separate physical connection between participating supply and load. Instead, power and/or thermal energy is produced and sold among different users using the existing utility distribution infrastructures. In addition to integrating customer-owned

DER, virtual microgrids may aggregate demand response to provide virtual load balancing, or generate additional revenues through participation in organized energy markets or demand response programs. The microgrid owner/operator, which could potentially be a third party aggregator or a co-op, manages the “dispatch” of energy to meet the load requirements of participating customers. Virtual microgrid customers pay the utility distribution fees for power distributed to participating loads, but for the most part avoid, or can greatly reduce, transmission and grid commodity costs.

**Tab. 2 Physical of Microgride**

<b>Physical Microgrid</b>							
<b>Utility</b>		<b>Non-Utility</b>					
<b>Owns Wires</b>		<b>Own Use</b>			<b>Own Use w/ Some Merchant Sales</b>		<b>Merchant Only</b>
<b>Owns Generation</b>	<b>Non-utility generation</b>	<b>One Owner</b>	<b>Multiple Owners</b>				
<b>Manages Controls</b>	<b>May/may not manage controls</b>						
VERTICALLY INTEGRATED	UN-BUNDLED	CAMPUS 1	CAMPUS 2	JOINT OWNER-SHIP / CO-OP	CAMPUS 3	JOINT OWNER-SHIP / CO-OP	INDEPENDENT PROVIDER

<b>Virtual Microgrid</b>	
UTILITY AGGREGATOR	NON-UTILITY AGGREGATOR

### 4. Case study – LV Microgrid

Microgrid for calculation be composed of consumes Z1 – Z9, photovoltaic power plants FV1 – FV5 and small hydro power plant HC1. It is typical part of the residential distribution network. The microgrid on the scheme is calculated in two operating states.

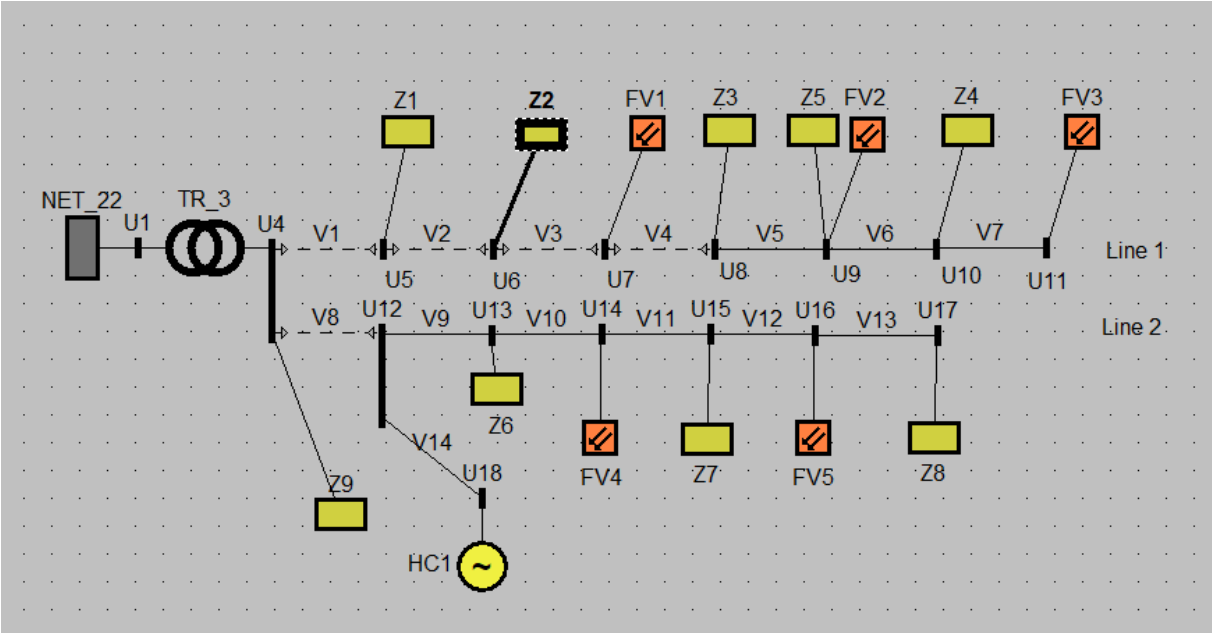


Figure 13 - Scheme A – FVE are in day operation state

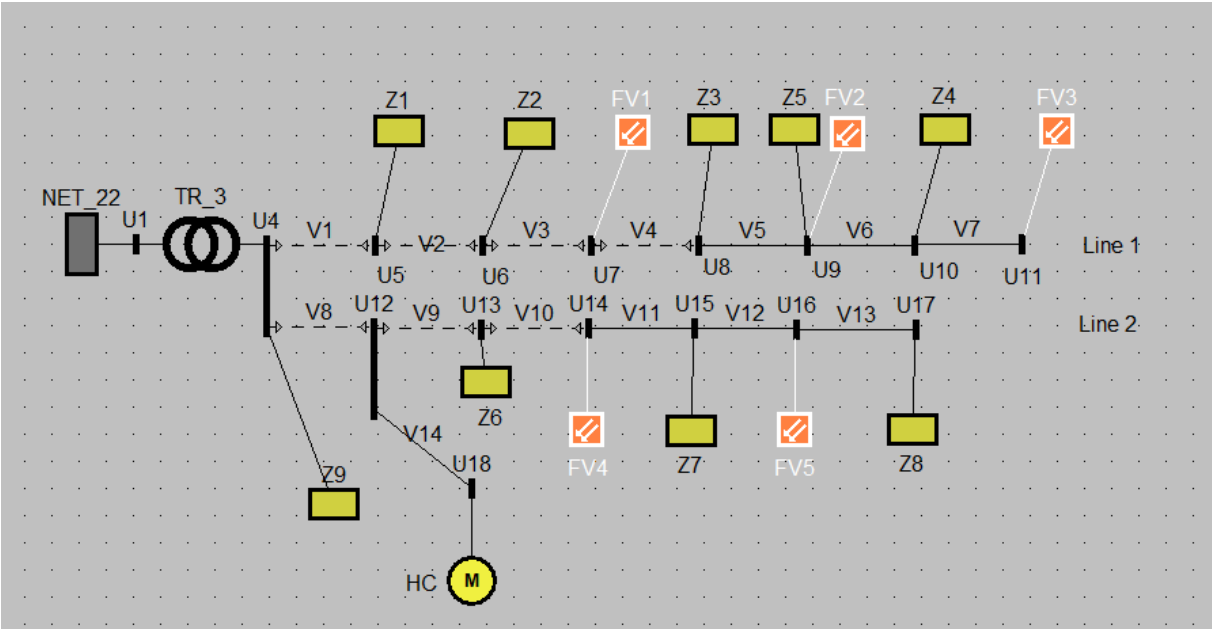


Figure 14 - Scheme B – FVE are in evening operation state

## Input network data for calculation

### Network 22 kV

Name	U <sub>n</sub> [kV]	U <sub>oper</sub> [kV]	I <sub>zkr</sub> [kA]	S <sub>zkr</sub> [MVA]
NET_22	22	23	1.57	60

### Transformer 22/0.4 kV

Name	U <sub>n1</sub> [kV]	U <sub>n2</sub> [kV]	S <sub>t</sub> [MVA]	P <sub>k</sub> [kW]	u <sub>k</sub> [%]	Primary connection	Secondary connection	I <sub>n1</sub> [A]	I <sub>n2</sub> [A]
TR_3	22	0.4	0.4	4.6	4	D	YN	10,5	578

### Parameters of the Line sections

Name	Type	Cros- section [mm <sup>2</sup> ]	U <sub>n</sub> [kV]	R [Ω/km]	X [Ω/km]	B [μS/km]	Length [km]	I <sub>max</sub> [A]
V1	70AYKY50	70	0.4	0.442	0.073	1	0.08	183
V2	70AYKY50	70	0.4	0.442	0.073	1	0.08	183
V3	70AYKY50	70	0.4	0.442	0.073	1	0.08	183
V4	70AYKY50	70	0.4	0.442	0.073	1	0.1	183
V5	50AES50	50	0.4	0.641	0.086	1	0.08	140
V6	50AES50	50	0.4	0.641	0.086	1	0.08	140
V7	50AES50	50	0.4	0.641	0.086	1	0.08	140
V8	70AYKY50	70	0.4	0,442	0.073	1	0,1	183
V9	50AES50	50	0.4	0.641	0.086	1	0,08	140
V10	50AES50	50	0.4	0.641	0.086	1	0,08	140
V11	50AES50	50	0.4	0.641	0.086	1	0,08	140
V12	50AES50	50	0.4	0.641	0.086	1	0,08	140
V13	50AES50	50	0.4	0.641	0.086	1	0,08	140
V14	70AYKY50	70	0.4	0.442	0,073	1	0,15	183

### Loads

Name	U <sub>n</sub> [kV]	I [A]	cos φ [-]	P [kW]	Q [kVAr]	S [kVA]
Z1	0.4	15.8	0.92	10	4.3	10,9
Z2	0.4	23.6	0.92	15	6.4	16.3
Z3	0.4	22.9	0.95	15	4.9	15.8
Z4	0.4	16.7	0.95	10	3.3	10.5
Z6	0.4	16.7	0.95	10	3.3	10.5
Z7	0.4	18.3	0.95	12	3.9	12.6
Z8	0.4	16.7	0.95	10	3.3	10.5
Z9	0.4	183	0.95	120	39	126

### Photovoltaic power plants

Name	U <sub>n</sub> [kV]	I [A]	cos φ [-]	P [kW]	Q [kVAr]	S [kVA]
FV1	0.4	11.6	1	8	0	8
FV2	0.4	11.6	1	8	0	8
FV3	0.4	36.1	1	15	0	15
FV4	0.4	11.6	1	8	0	8
FV5	0.4	7.2	1	5	0	5



### Small hydro power plant

Name	U <sub>n</sub> [kV]	I [A]	cos φ [-]	P [kW]	Q [kVAr]	S [kVA]
HC1	0.4	30.3	0,95	20	6.5	21

### Calculation results

Network calculations were made in two operating modes.

In the first operational state he thought the daily time operation of a distribution network with the power generation by photovoltaic power plants FV1 - FV5 and power generation by hydro power plant HC1.

The second operational state he thing about the operation of a distribution network in the evening time was thinking without the generation of power by photovoltaic power plants but with the generation of electricity by hydro power plant HC1

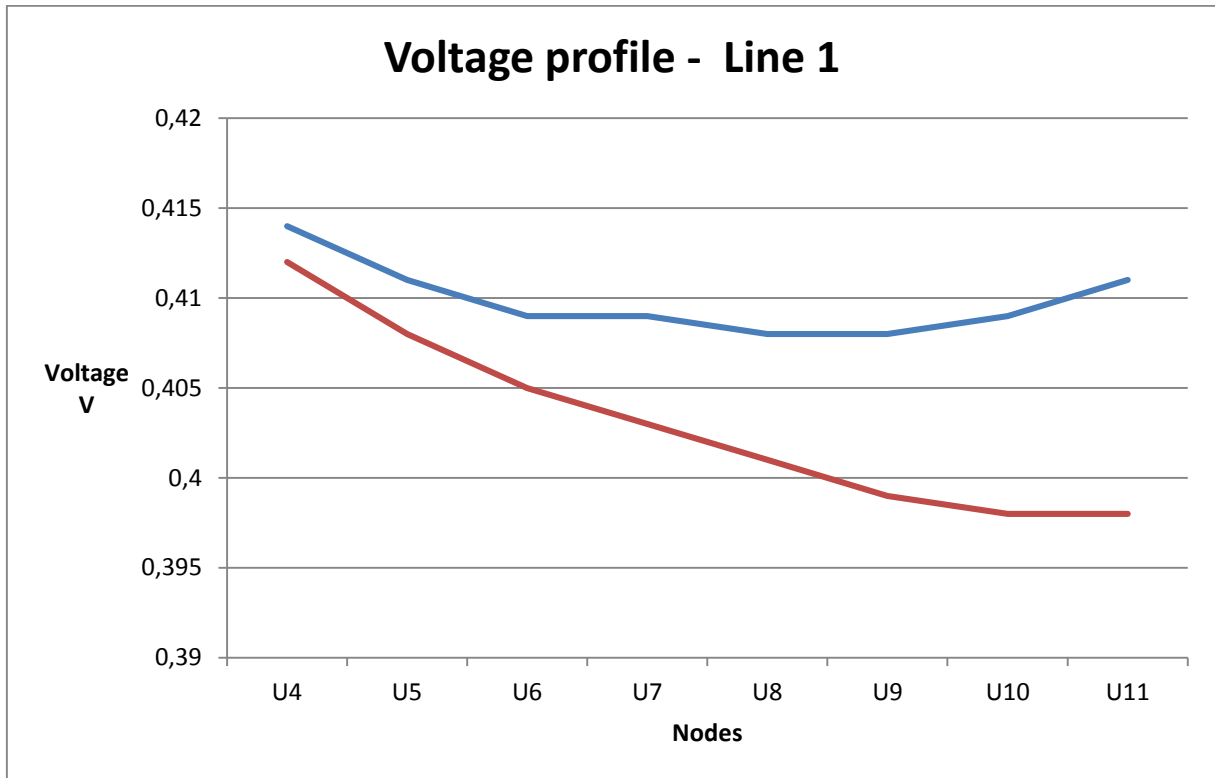
The results of both calculations are listed in the following table and graphically displayed on the following charts

### Calculation results for two operating state

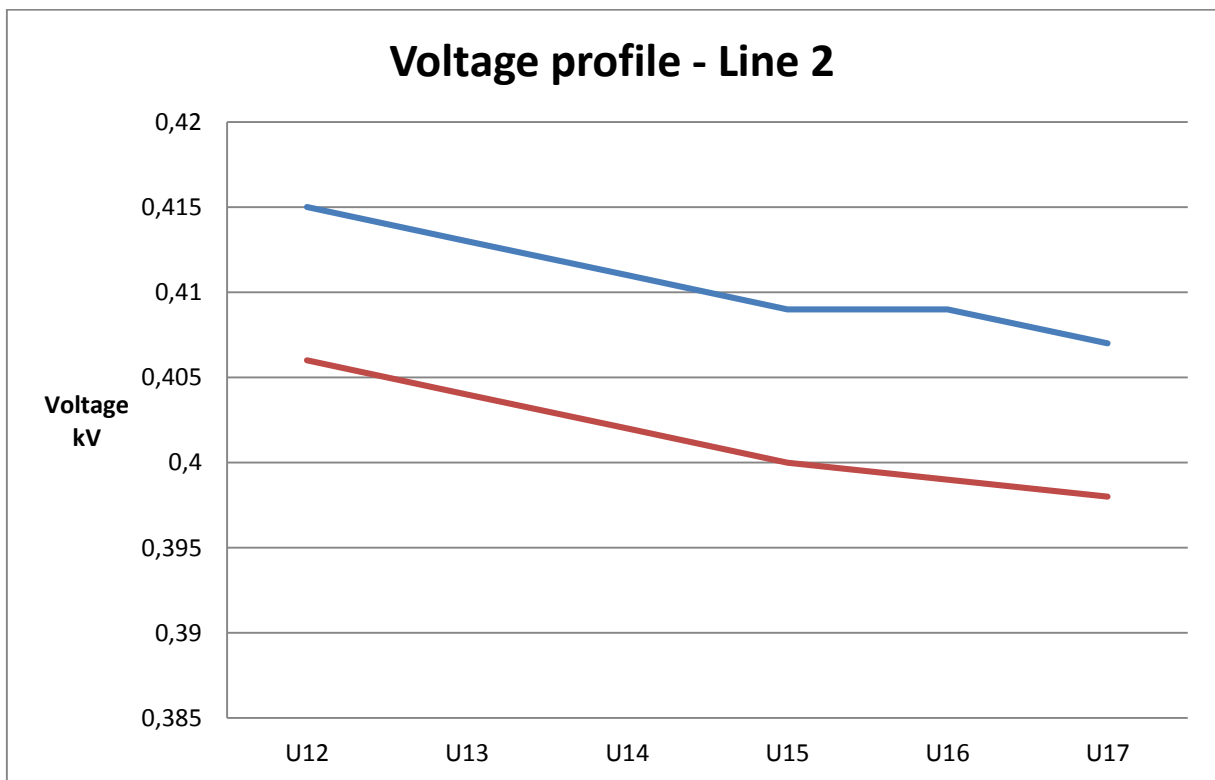
Node name	Voltage [kV] Operation with PVPP	Voltage [kV] Operation without PVPP
U4	0.414	0.412
U5	0.411	0.408
U6	0.409	0.405
U7	0.409	0.403
U8	0.408	0.401
U9	0.408	0.399
U10	0.409	0.398
U11	0.411	0.398
U12	0.415	0.406
U13	0.413	0.404
U14	0.411	0.402
U15	0.409	0.400
U16	0.409	0.399
U17	0.407	0.398
U18	0.422	0.398

### Transformer T3 power flow

	Node	P [kW]	Q [kVAr]	S [kVA]
Daily state	U1	130.8	68.7	147.7
	U4	-130.2	-66.8	146.3
Evening state	U1	225.2	77.7	238.2
	U4	-223.7	72.7	235.2



*Figure 15 – Voltage profile on line 1*



*Figure 16 – Voltage profile on line 2*

## Network operation – Connection HC1 to LV network

### Calculation results dU before connection of the HC1 and dU after connection to LV network

Name	dU before [%]	dU after[%]	Voltage difference [%]
U4	-3.363	-3.450	-0.087
U12	-2.844	-3.720	-0.877
U18	-2.844	-5.430	-2.587

### Network active losses

	P[kW]
Daily state	1.9
Evening state	4.8

## Calculation results

Calculations of network operation in two operational mode (day and evening) showed that the voltage changes in the distribution network are in the band of the Distribution network code for low-voltage networks.

At calculating the connectivity of small hydro power plant HC1 voltage change occurred about 2.6%.

Active losses in the network are lower in the time of day during the operation of photovoltaic power plants. In the night time are more than twice as much.

The largest share of active losses are in the transformer TR 3, and in the first line section V1.

## 5. Conclusion

The presented thesis had 4 chapters:

1. Generation and distribution infrastructure
2. Microgrid structure
3. Microgrids projects in Europe
4. A case study for small microgrid

The master thesis is focused on technical analysis mikrogrids. In the text are listed the basic elements of microgrids, ways to control microgrids, architecture of microgrids. Ways of operating are listed in detail the microgrids parallel to the distribution network, and Island operation. The following are the parameters of the quality of the electricity that have great importance when in operation. The author lists a number of pilot project of microgrids in Europe. In the final part of the work is presented a case study of small microgrid and the necessary calculations are made, in particular in the voltage profiles, connection of hydro power plant to distribution network, voltage changes, losses in microgrid. Result of calculating were discussed and compared with Czech standards.

## 6. References

More microgrids – flysheet I

More microgrids – flysheet II

Distribution network code

CSN EN 50 160

eVlivity application manual

Schlabbach, J, D Blume a T Stephanblome: Voltage quality in electrical power systems

Microgrids: An Assesment of the Value, Opportunities and Barriers, Final Report, 2010