Microgrid for the Department of Electrical Drives and Power Electronics

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Abstract
This paper provides a brief overview of current smartgrid and microgrid technologies and issues associated with their implementation. An architecture of the microgrid for the Department of Electrical Drives and Power Electronics is proposed. Main attention is paid to the control system. The paper sets out the functions and requirements to the main controller for a microgrid control system. The results of performance analysis show that 1756 ControlLogix can be used as a central controller for microgrid management. The knowledge acquired can be used for the design and construction of the microgrid for the department.

Keywords
Smartgrid, microgrid, distributed generation, controller

Introduction
Economic, technology and environmental incentives are changing the face of electricity generation and transmission. Centralized generating facilities are giving way to smaller, more distributed generation (DG) [1] partially due to the loss of traditional economies of scale. A better way to realize the emerging potential of distributed generation is to take a system approach which views generation and associated loads as a system or a smartgrid [2] and as a subsystem or a microgrid [3].

The most positive features of microgrids are the relatively short distances between generation and loads and low generation and distribution voltage level. Due to these factors supply electricity security and reliability are increased, power losses in the networks are reduced, costs on transmission and distribution decreased substantially.

Despite many advantages of microgeneration there remain many technical challenges and difficulties in this new power industry area. One of them is the design, acceptance, and availability of low-cost technologies for installing and using microgrids [4]. Microgeneration suffers from lack of experience, regulations and norms. Because of specific characteristics of microgrids, such as high implication of control components, large number of microsources with power electronic interfaces remains many difficulties in controlling of microgrids. Realization of complicated controlling processes in microgrids requires specific communication infrastructure and protocols. During the process of microgrid organization many questions concerning the protection and safety aspects emerge. Also, it is required to organize free access to the network and efficient allocation of network costs.

This paper reviews the overall architecture of the microgrid concept. The main aims of the paper are to explain the principles of microgrid’s functioning, to clarify the main ideas and positive features of microgrids, and to find out their advantages. Furthermore, the objective of this paper is to develop an architecture and management structure of the microgrid for the Department of Electrical Drives and Power Electronics of Tallinn University of Technology. In addition, the aim of the paper is to analyze the main component of the microgrid – the central controller, which controls all the processes and energy flows inside a microgrid and communicates with the main grid.

1 Grid technologies
1.1 Smartgrid
A smartgrid [2] is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.

The information technology base of the smart energy network is communications and control systems that create two fundamentally new capabilities [5]:

- the ability to precisely manage electrical power demand down to the residential level;
- the ability to network vast numbers of small-scale distributed energy generation and storage devices.

The benefits of the smartgrid are [2]:

- the connection and operation of generators of all sizes and technologies are facilitated better;
- consumers are allowed to play a part in optimizing the operation of the system;
• consumers are provided with greater information and choice of supply;
• the environmental impact of the whole electricity supply system significantly are reduced;
• enhanced levels of reliability and security of supply are delivered.

The new grid is expected to provide key functions given in [6], [7]: self-heal; incorporation of the consumer; resilience of attacks; provision of high power quality; accommodation of a wide variety of generation options, fully enabling maturing electricity markets, and optimization of all grid sets. Life cycle management, cost containment, and end-to-end power delivery is improved in the smartgrid design. Several technologies need to be implemented in the smartgrid to assist it in achieving these functions. Among them are advanced control methods, advanced components, communications, and improved decision support systems.

1.2 Microgrid

Microgrid is a relatively new concept in the electric power distribution. It is an enabling component of a smartgrid [7]. The microgrid concept assumes a cluster of loads and microsources operating as a single controllable system that provides both power and heat to its local area [3], [8], [9].

A microgrid is described as a small (several MW or less in scale) power system with three primary components: distributed generators with optional storage capacity, autonomous load centers, and system capability to operate interconnected with or islanded from the larger utility electrical grid [10], [11] - [13]. In another words, a microgrid consists of a combination of generation sources, loads and energy storage, interfaced through fast acting power electronics [14], [15].

The microgrid concept is driven by two fundamental principles [16], [17]:
1) A systems perspective is necessary for customers, utilities, and society to capture the full benefits of integrating distributed energy resources into an energy system;
2) The business case for accelerating adoption of these advanced concepts will be driven, primarily, by lowering the first cost and enhancing the value of microgrids.

The primary goal of microgrid architectures is to significantly improve energy production and delivery to load customers, while facilitating a more stable electrical infrastructure with a measurable reduction in environmental emissions [10]. The customer-driven microgrid is a promising concept in several fronts because it [18] provides means to modernize today’s power grids by making it more reliable, secure, efficient, and de-centralized; provides systematic approaches to utilize diverse and distributed energy sources for DG; addresses how to utilize DG more efficiently and more effectively and provides more reliable and greener power to customers; provides uninterruptible power supply functions; cost reductions for consumer and utilities.

A review of the literature on microgrids reveals the following functions of a microgrid [3], [10], [15], [19] - [20]:
• regulation of power flow on feeders;
• regulation of voltage at the interface of each microsource;
• maintaining the power quality inclusive of voltage profile, voltage fluctuations, and harmonic distortion;
• improving the dynamic response, maintaining stability margin, and voltage / frequency restoration of the system during and after transients;
• providing logic and control for islanding and reconnecting the microgrid during events;
• centralized or decentralized control necessitating levels of communication infrastructure;
• ensuring stable and adaptable control system behavior for seamless “plug-and-play” implementation and sensible load control;
• minimizing emissions and system losses.

The main function of a microgrid is to ensure stable operation during faults and various network disturbances.

1.3 Interaction of smartgrid and microgrid

In order to ensure proper operation of the smartgrid, it is important that its constituent parts operate satisfactorily. An integral part of the smartgrid is a microgrid. Therefore, it is necessary that a control strategy for the microgrid in both grid-connected and islanded modes be devised [7]. The microgrid must be connected to the smartgrid without compromising grid reliability or protection schemes or causing other problems, consistent with the minimal standards for all connected devices. Microgrids can benefit the grid by reducing congestion and other threats to system adequacy if they are deployed as interruptible or controlled loads that can be partially shed as necessary in response to changing grid conditions. In addition, microgrids could provide local premium power and ancillary services, such as local voltage support, although the low voltage limits its ability to feed into the grid. If the microgrid had such features it could be considered a model citizen of the smartgrid [21].

2 Microgrid architecture and components

In [22] four classes of microgrids are identified: Single facility microgrids include installations such as industrial and commercial buildings, residential buildings, and hospitals, with loads typically under 2 MW. These systems typically have low inertia and require backup generation for off-grid operation.
Multiple facility microgrids span multiple buildings or structures, with loads typically ranging between 2 MW and 5 MW. Examples include campuses (medical, academic, municipal, etc.), military bases, industrial and commercial complexes, and building residential developments.

Feeder microgrids will manage the generation and/or load of all entities within a distribution feeder – which can encompass 5-10 MW. These microgrids may incorporate smaller microgrids – single or multiple facility – within them.

Substation microgrids will manage the generation and/or load of all entities connected to a distribution substation – which can encompass 5-10 MW. It will likely include some generation directly at the substation, as well as distributed generation and microgrids included at the feeder and facility level.

Microgrids include several basic components for operation such as [3], [4]:

1. Distributed generation [1] units are small sources of energy located at or near the point of use. There are two basic classes of microsources; one is a DC source (fuel cells, photovoltaic cells, etc.), the other is a high frequency AC source (microturbines, reciprocating engine generators, wind generators), which needs to be rectified. An AC microgrid can be a single-phase or a three-phase system. It can be connected to low voltage or medium voltage power distribution networks.

2. Distributed storage technologies are used in microgrid applications where the generation and loads of the microgrid cannot be exactly matched. Distributed storage provides a bridge in meeting the power and energy requirements of the microgrid. Distributed storage enhances microgrid systems overall performance in three ways. First, it stabilizes and permits DG units to run at a constant and stable output, despite load fluctuations. Second, it provides the ride through capability when there are dynamic variations of primary energy (such as those of sun, wind, and hydropower sources). Third, it permits DG to seamlessly operate as a dispatchable unit. Moreover, energy storage can benefit power systems by damping peak surges in electricity demand, countering momentary power disturbances, providing outage ride-through while backup generators respond, and reserving energy for future demand. There are several forms of energy storage, such as the batteries, supercapacitors, and flywheels.

3. The interconnection switch is the point of connection between the microgrid and the rest of the distribution system. New technologies in this area consolidate the various power and switching functions (power switching, protective relaying, metering, and communications) traditionally provided by relays, hardware, and other components at the utility interface into a single system with a digital signal processor. The interconnection switches are designed to meet grid interconnection standards.

4. The control system of a microgrid is designed to safely operate the system in grid-parallel and stand-alone modes. This system may be based on a central controller or imbedded as autonomous parts of each distributed generator. When the utility is disconnected, the control system must control the local voltage and frequency, provide (or absorb) the instantaneous real power difference between generation and loads, provide the difference between generated reactive power and the actual reactive power consumed by the load, and protect the internal microgrid.

3 Microgrid management

3.1 Architecture of the control system of the microgrid

The architecture of the control system of the microgrid consists of three critical components [3]:

1) Local microsource controllers respond in milliseconds and uses locally measured voltages and currents to control the microsource during all system or grid events. Fast communication among microsources is not necessary for microgrid operation; each inverter is able to respond to load changes in a predetermined manner without data from other sources or locations. This arrangement enables microsources to “plug and play” – that is, microsources can be added to the microgrid without changes to the control and protection of units that are already part of the system. The basic inputs to the microsource controller are steady-state set points for power, and local bus voltage.

2) System optimizer. System optimization is provided by the energy manager. The energy manager uses information on local electrical and heat needs, power quality requirements, electricity and gas costs, wholesale/retail service needs, special grid needs, demand-side management requests, congestion levels, etc. to determine the amount of power that the microgrid should draw from the distribution system. The energy manager provides for system operation of the microgrid through dispatch of power and voltage set points to each microsource controller. This function could be as simple as having a technician enter these set points by hand at each controller to a state-of-the-art communication system with artificial intelligence.

3) Distributed protection. The protection coordinator must respond to both system and microgrid faults. For a fault on the grid, the desired response may be to isolate the critical load portion of the microgrid from the grid as rapidly as is necessary to protect these loads. This provides the same function as an uninterruptible power supply at a potentially lower incremental cost. The speed at which the microgrid isolates from the grid will depend on the specific customer loads on the microgrid. If a fault occurs within the island able to portion the microgrid, the desired protection is to isolate the smallest possible section of the radial feeder to eliminate the fault.
3.2 Control methods

The control structure of the microgrid has different levels. On the one hand, each generator has its own local controller. On the other hand, there is a higher centralized controller which is responsible for the management of the microgrid. This centralized controller deals with the microgrid management functions (connection and disconnection of the microgrid, the synchronization process, the detachment of loads) and with the power references of the generators. A communication infrastructure is needed between the centralized controller and the generators/loads local controllers. The microgrid functionalities as well as its control methods depend on the mode of operation [23]:

1. In the islanded mode, due to the unavailability of the utility grid, two requirements must be fulfilled: the power balance between the generation and the consumption and the control of the main parameters of the installation (voltage amplitude and frequency). Depending on the synchronization between the local voltage reference and the grid voltage (if it is available), two operation modes can be defined: asynchronous islanded mode or synchronous islanded mode. In the asynchronous islanded mode, the voltage reference is arbitrarily established. In the synchronous islanded mode, this reference is the same as the grid voltage. This mode is also called the synchronization mode and it is the mode that necessarily precedes a reconnection with the grid.

2. In the grid-connected mode, the balance between the generation and the consumption as well as the control of the parameters of the system is guaranteed by the utility grid. Thus, generators are regulated with the criterion of optimized economic exploitation of the installation. Concerning the programmable generator, the objective of the control is to optimize the microgrid performance in order to contribute to the grid operation and this way receiving as much bonus payments as possible and avoiding possible penalties.

3. Transition from Grid-Connected to Islanded Mode. Disconnection of the microgrid from the grid can be provoked by many causes, like unsatisfactory grid voltage (in terms of amplitude or waveform) or even economic aspects related to power price. In order to monitor grid voltage characteristics a voltage monitoring module is required. This module measures continuously the grid voltage comparing it with a pre-established threshold value. When any of the phase voltages goes down the threshold value, the detection signal is activated. If 20 ms after the first detection this signal is still activated, the microgrid must be disconnected from the utility grid and it must pass to the islanded operation mode, otherwise the microgrid will remain connected to the utility grid. As soon as the microgrid is disconnected from the grid, the programmable generator controller passes from a power control mode to a voltage control mode.

4. Transition from Islanded to Grid-Connected Mode. If the grid-disconnection cause disappears and the grid voltage fulfills the desired requirements, the transition from the islanded to the grid-connected mode can be started. The grid voltage conditions will be again monitored by the voltage monitoring module. This way if the grid voltage exceeds the threshold value, the detection signal is deactivated. If 20 ms after the first detection the detection signal is still deactivated, it means that the utility grid has returned back to normal operating conditions and the microgrid can reconnect to the grid. However, before the reconnection, the microgrid has to be synchronized with the grid voltage in order to avoid hard transients in the reconnection. To do so, the microgrid operates in a synchronous islanded mode during 100 ms with the aim of decoupling the reference variation and the physical grid reconnection transients. In this operating mode the voltage in the microgrid is set to the characteristics of the grid voltage, frequency and phase.

4 System description

4.1 Description of the resources of the Department of Electrical Drives and Power Electronics

The microgrid system intended for the Department of Electrical Drives and Power Electronics, Faculty of Power Engineering, at the Tallinn University of Technology. The department comprises two lecture rooms, six laboratories and office rooms, including: Laboratory of Power Electronics (101); Laboratory of Electrical Drives (102); Laboratory of Electrical Lighting (417), Laboratory of Industry Automation (423); Laboratory of Electrical Apparatus and Sensors (429); CAD and e-Study Laboratory (431); a lecture room of electrical apparatus (430); a general-purpose lecture room (422). Teaching, research and technical staff occupy 15 office rooms and a seminar room [24]. The power of departmental rooms and laboratories is shown in Table 1. Departmental computer network is linked to the faculty and university network. It operates at speeds up to 1 Gbit/s. Switches which are used in departmental laboratory computer network operate at speeds up to 100 Mbit/s. 250 unique internet IP-addresses are in the departmental computer networks.

Table 1. The power supplied to departmental laboratories

<table>
<thead>
<tr>
<th>Electrical parameters, functions, data</th>
<th>Number laboratories</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power (voltage 240 V), kW</td>
<td>101 102 417 422 423 429 430 431</td>
<td>31</td>
</tr>
<tr>
<td>Power (voltage 240 V / 400 V), kW</td>
<td>5 5 3 5 5 2 2 4</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>40 50 2 2 3 2 2 10</td>
<td>111</td>
</tr>
</tbody>
</table>
4.2 The microgrid structure

Based on the departmental resources and on the basis of the information described in [3], [4], the structural scheme of the microgrid for the Department of Electrical Drives and Power Electronics was proposed. It is shown in Fig. 1.

![Diagram of the microgrid structure](image)

**Fig. 1. Structural scheme of the microgrid for the Department of Electrical Drives and Power Electronics**

The components of the microgrid are located in three buildings: Faculty of Power Engineering, TUT Library, School of Economics and Business Administration. According to the classification given in [22], this microgrid can be defined as a single facility Microgrid.

The system comprises a diesel generator with a nominal power of 176 kW / 220 kVA, voltage of 240 V / 400 V and maximum current of 318 A. The generator is used as a distributed energy resource in this microgrid. This generator is interfaced to the electrical network using automatic relay logic (ARL2). Also, the system comprises the battery banks (E1 and E2) to insure continuous supply of the local load. They are used as a distributed energy storage in the microgrid. They are interfaced to the electrical network through two uninterruptible powers: UPS1 (160 kVA), and UPS2 (240 kVA). Consequently, we can conclude that the microgrid has two main possible operation modes: grid-connected and islanded mode.

Main clients for the microgrid are the computers and servers located in the laboratories and office rooms in the Department of Electrical Drives and Power Electronics; computers and servers located in the School of Economics and Business Administration Building. The clients of the Library Building (computers) are interfaced to the electrical network using an automatic relay logic (ARL1). In addition, four experimental loads (Experim. loads 1..4) are used that can be connected to the distributed shield located in the Laboratory of Electrical Drives (102). The eight gauges (P1..P8) – Powermonitor 3000 [25] assign these loads. Their task is to measure electrical power and energy parameters of the network, such as voltage, current, power, energy, power factor and transmit this information to the controller.

The microgrid is connected with the general city electricity grid using two two-section transformer substations (6000 kV / 400 kV) located in the Faculty of Power Engineering and the School of Economics and Business Administration Buildings.
4.3 Description of the control system

Taking into account the features of the power network of the Department of Electrical Drives and Power Electronics, the control system structure was proposed for the microgrid is shown in Fig. 2.

![Diagram of the microgrid control system](image)

**Fig. 2. Core modules of the microgrid of management**

To satisfy the basic properties, a microgrid advanced control comprises three control levels:

1) group of local controllers;
2) central controller;
3) operator console and application server.

The electrical network includes electrical switches, devices, communication infrastructure, etc. The local controllers are used to control the diesel generator the automatic relay logic ARL1, ARL2 (Fig. 1), and the UPS1, UPS2 systems. The central controller operates in real time. Its aims are: to collect information from the measuring devices (P1..P8); to transfer data from the operator console and the application server; to manage the power supply switches; and to transmit the control commands to the local controllers.

Operator console is a computerized workstation with special software (such as RSEnergyMetrix [26]). Its main goals are: to collect data from the measuring devices; to visualize information received; to display the basic modes of the microgrid; to transfer control commands to the central controller. In addition, operator console is designed to develop and debug software for the microgrid control system.

Application server is designed for archiving data received from the measuring devices. The redundant LAN based on the Ethernet industrial network protocol is used for data transfer for all those control units. This control system structure provides an opportunity for immediate control center access via remote consoles and web based laptops for necessary actions to be taken.

4.4 Analysis of the central controller

Based on the functions of the microgrid [3], [10], [15], the requirements to a central controller may be formulated as follows:

- presence of a real time system;
- sufficient number of inputs / outputs (digital and analog);

- non-volatile memory for program code and data storage;
- presence of the channels for communication (EtherNet/IP, DH-485);
- reprogrammability;
- convenient programming language;
- friendly programming interface;
- high data rate;
- high working frequency;
- ability to self-diagnosis;
- temperature range -40 °C … +85 °C;
- immunity against shock and electrical noise;
- optimal price.

To analyze compliance with the stated requirements the programmed logic controller of 1756 ControlLogix Allen-Bradley [27] was used. It has already been used for teaching purposes in the laboratories of the Department of Electrical Drives and Power Electronic. Considering the requirements listed above, the key characteristics of this microcontroller were reviewed. Table 2 shows some of the characteristics.

**Table 2. Some characteristics of 1756 ControlLogix controller [27]**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>User memory</td>
<td>750 KB / 2 MB / 4 MB / 8 MB / 16 MB</td>
</tr>
<tr>
<td>I/O memory</td>
<td>478 KB</td>
</tr>
<tr>
<td>Optional flash memory</td>
<td>64 MB, 128 MB</td>
</tr>
<tr>
<td>Digital I/O</td>
<td>max 128,000</td>
</tr>
<tr>
<td>Analog I/O</td>
<td>max 4000</td>
</tr>
<tr>
<td>Total I/O</td>
<td>max 128,000</td>
</tr>
<tr>
<td>Controller connections</td>
<td>250</td>
</tr>
<tr>
<td>Temperature, operating</td>
<td>0 … +60 °C</td>
</tr>
<tr>
<td>Temperature, storage</td>
<td>-40 … +85 °C</td>
</tr>
<tr>
<td>Current draw 5V DC</td>
<td>1200 mA</td>
</tr>
<tr>
<td>Current draw 24V DC</td>
<td>14 mA</td>
</tr>
<tr>
<td>Power dissipation</td>
<td>3.5 W</td>
</tr>
</tbody>
</table>
The ControlLogix system provides discrete, drives, motion, process, and safety control together with communication and state-of-the-art I/O in a small, cost-competitive package. The system is modular, so it is possible to design, build, and modify it efficiently – with significant savings in training and engineering. The 1756 ControlLogix controller provides a scalable controller solution that is capable of addressing a large amount of input/output (I/O) points. This controller operates with a multitasking, multiprocess operating system. The multitasking operating system supports 32 configurable tasks that can be prioritized. One task can be continuous. The others must be periodic or event tasks. Each task can have as many as 100 programs, each with its own local data and logic, allowing virtual machines to operate independently within the same controller. 1756 ControlLogix controller supports the same set of instructions in multiple programming languages. RSLogix 5000 Enterprise series software supports a comprehensive set of embedded motion instructions that can be programmed using the relay ladder, structured text, or sequential function chart editors. CompactFlash cards offer nonvolatile memory (flash) to permanently store a user program and tag data on a ControlLogix controller. The 1756 ControlLogix controller provides a scalable controller solution that is capable of addressing a large amount of I/O points. This controller can communicate with computers or other processors across RS-232-C, DeviceNet, DH+, ControlNet, and EtherNet/IP networks [27].

**Advantages:**
- the 1756 ControlLogix is an example of a real time system controller;
- high reliability of the controller: the controller is designed for extended temperature ranges, resistance to vibration and impact and, most importantly, immunity to electrical noise;
- the 1756 ControlLogix has the facility for extensive I/O arrangements, they can be used to manage power switches of the microgrid;
- I/O modules have built-in surge suppression current, diminishing of the effects of high voltage transients;
- the 1756 controller does not require a battery: the controller uses internal flash memory to store its program during shutdown;
- the ControlLogix supports Ethernet protocol, this property can be used to communicate over the EtherNet/IP network between the components of the microgrid in real time.

**Disadvantages:**
- the 1756 ControlLogix has lower degree of flexibility in comparison with embedded microcontrollers;
- high cost of the controller. However, cost of a packaged ControlLogix is low compared to the cost of a specific custom-built controller design for a microgrid application.

The results of the performance analysis show that 1756 ControlLogix can be used as a central controller for microgrid management for the Department of Electrical Drives and Power Electronics.

**Conclusions**

In this paper a review of current smartgrid and microgrid technologies has been provided. Basic principles of microgrids functioning, protection and control were explained.

The architecture of the microgrid for the Department of Electrical Drives and Power Electronics and a control system structure for the departmental microgrid were proposed. The functions and requirements to the central controller for the microgrid control system have been set. As a result of the analysis, the major advantages and disadvantages of the controller 1756 ControlLogix for microgrid management have been identified.

It is intended that the results obtained in this paper may be used as the groundwork for further development of the microgrid for the Department of Electrical Drives and Power Electronic.

**Acknowledgement**

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