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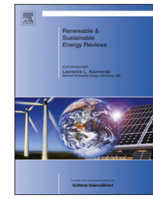

Hierarchical control structure in microgrids with distributed generation: Island and grid-connected mode

Omid Palizban*, Kimmo Kauhaniemi

Department of Electrical and Energy Engineering, University of Vaasa, Vaasa FI-65101, Finland

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The hierarchical control structure of a microgrid can be described as having four levels responsible for processing, sensing and adjusting, monitoring and supervising, and maintenance and optimization. The responsibility of the hierarchical control level is to provide control over the production of power from renewable sources. This paper comprehensively investigates the principles of hierarchical control in micrgrids from a technical point of view. In the first step, this article covers the control of the power generation using two popular renewable energy sources, namely wind turbines and photovoltaics. The synchronization and power flow between the microgrid and the main network is then investigated. Finally, some research questions are presented to improve the performance of the hierarchical control, especially in the secondary decentralized control and energy storage systems.

Contents

1. Introduction . . . 797
2. Inner control loop . . . 799
   2.1. Wind power . . . 799
      2.1.1. DFIG . . . 799
   2.2. Photovoltaic system . . . 799
   2.3. Voltage and current-control loop discussion . . . 801
3. Primary control . . . 801
   3.1. Primary control based on grid-forming . . . 802
      3.1.1. Control methods with communication . . . 802
      3.1.2. Control methods without communication . . . 803
   3.2. Primary control based on grid-following . . . 804
      3.2.1. Natural framework . . . 804
      3.2.2. Synchronous framework . . . 805
      3.2.3. Stationary framework . . . 806
   3.3. Primary control discussion . . . 806
4. Secondary control . . . 806
   4.1. Centralized control . . . 808
   4.2. Decentralized control . . . 808
   4.3. Secondary control discussion . . . 810
5. Tertiary control . . . 810
6. Conclusion . . . 811
Acknowledgment . . . 811
References . . . 811

* Corresponding author. Tel.: +358 29 449 8309, +358 465297780.
E-mail address: omid.palizban@Uva.fi (O. Palizban).

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Nomenclature

DER	Distribution Energy Resource
DFIG	Double Fed Induction Generator
DG	Distributed Generation
DMS	Distribution Management System
f	frequency
$f^{\min}$	minimum value of frequency
f^{ref}	reference of frequency
f^{ref}_{mg}	reference of frequency for microgrid
f_{mg}	frequency in microgrid
f_{DG_i}	frequency in individual DG
$\overline{f}_{DG_k}$	average frequency for all DG units
FLL	Frequency locked loop
Δf	error of frequency
Δf_{DG_k}	control signal providing by DG_k
G_i	integral gain
G_p	proportional gain
G_{if}	control parameters for frequency of secondary level compensator
G_{iv}	control parameters for voltage of secondary level compensator
G_{ip}	control parameters for active power of tertiary level compensator
G_{iQ}	control parameters for reactive power of tertiary level compensator
G_{pf}	control parameters for frequency of secondary level compensator
G_{pv}	control parameters for voltage of secondary level compensator
G_{pp}	control parameters for active power of tertiary level compensator
G_{PQ}	control parameters for reactive power of tertiary level compensator
HC	Harmonic compensator
HV	High voltage
LV	Low voltage
MG	Microgrid
MGCC	Microgrid Central Controller
MPPT	Maximum Power Point Tracking
MS	Microsource
MV	Medium voltage
P	active power
P^{ref}	reference of active power
$P^{\max}$	maximum value of active power
PV	Photovoltaic
PCC	Point of Common Coupling
PI	Proportional integral
PLL	Phase locked loop
PR	Proportional resonant
ΔP	error of active power
Q	reactive power
Q^{ref}	reference of reactive power
$Q^{\max}$	maximum value of reactive power
Q^{ref}_{grid}	reference of reactive power for main grid
$\overline{Q}_{DG_K}$	average reactive power for all DG units
Q_{DG_i}	reactive power in individual DG
Q_{grid}	reactive power of main grid
ΔQ	error of reactive power
ΔQ_{DG_K}	control signal providing by DG_k
R	Resistor
RES	Renewable energy source
$T_{P_{(S)}}$	transfer function of active power
T^{abc}_{PI}	transfer function of PI controller in *abc* frame
T^{abc}_{PR}	transfer function of PR controller in *abc* frame
T^{dq}_{PI}	transfer function of PI controller in *dq* frame
$T^{\alpha\beta}_{PR}$	transfer function of PR controller in stationary frame
$T_{Q_{(S)}}$	transfer function of Reactive power
V^{ref}	reference of voltage
$V^{\min}$	minimum value of voltage
V^{ref}_{mg}	reference of voltage for microgrid
V_{mg}	voltage in microgrid
V_{DG_K}	voltage in individual DG
$\overline{V}_{DG_K}$	average voltage for all DG units
VSC	Voltage source converter
ΔV	error of voltage
ΔV_{DG_K}	control signal providing by DG_k
X	inductance

1. Introduction

Photovoltaic cells (PV) and wind power generation are the most popular of the energy sources that can be integrated into the main network in the form of Distributed Generators (DG) or Microgrids (MG). Indeed, MGs consist of a methodical organization of such DG systems [1–6]—an organization that leads to increase in system capacity and achieves high power quality [7].

From the control point of view, in a traditional system, distribution of electricity is managed with a multilayer process and connected to the main network [8]. However, in MG and DG systems (the modern approach), the management of electricity distribution is handled in different sectors for participation in active network management based on market terms [9–11].

As presented by Vandoorn et al. [12], in the modern approach, the control of generation units and systems—especially in island mode—have some significant conflicts with the conventional system, such as the lack of rotating inertia, the changes in the effect of line impedance on active and reactive power control, and the variations in power generation from RESs.

Since future distribution networks will require completely novel smart-grid concepts [13], it is necessary to conceive of flexible MGs that are capable of intelligently operating in both grid-connected and island modes. In this regard, the authors present a control algorithm for MGs participating in the active network management in [14,15]. Moreover, along with the control algorithm, these papers present a general standardization of MGs for hierarchical control. This research is, however, theoretical and investigates standardization from a standards point view, so the objective of the present paper is to investigate the control algorithm, both technically and from the point of view of micro-grid control, from power generation using RESs (*zero level*) to synchronizing the MG with the main network (*third level*).

Based on the previous research, controlling the DGs and MGs is critical, and it is necessary to implement a hierarchical control system for them [16]. As shown in Fig. 1, the hierarchical control structure of MGs can be classified into four control levels. In the first step, the paper focuses on the principle of how the power is generated with the two most popular RESs, namely photovoltaic and wind turbine generation. The output voltage and current from the grid-side power converter of these sources are input data for the inner control loop (*level zero*). Then, to achieve high impact management, accurate references are required, which is the responsibility of the *primary control*. The strategy of the control level is an independent local control for increasing the reliability of the power system. On the next level, the approach of *Secondary*