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A survey on control of electric power distributed generation systems for microgrid applications

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A B S T R A C T

The introduction of microgrids in distribution networks based on power electronics facilitates the use of renewable energy resources, distributed generation (DG) and storage systems while improving the quality of electric power and reducing losses thus increasing the performance and reliability of the electrical system. The hierarchical control structure, which consists of primary, secondary, and tertiary levels for microgrids that mimic the behavior of the mains grid, is reviewed. The main objective of this article is to give a description of state of the art for distributed power generation systems (DPGS) based on renewable energy and explore the power converters connected in parallel to the grid which are distinguished by their contribution to the formation of the grid voltage and frequency and are accordingly classified in three classes. This analysis is extended focusing mainly on the three classes of configurations: grid-forming, grid-feeding, and grid-supporting. The article ends up with an overview and a discussion of the control structures and strategies to control distribution power generation system (DPGS) units connected to the network.

Contents

Abbreviations: AC, Alternating current; CHP, Combined heat and power; DB, Deadbeat; DC, Direct current; DER, Distributed energy resources; DG, Distributed generation; DPC, Direct power control; DPGS, Distributed power generation systems; *dq*, Park transformation; EES, Electrical energy storage; FACTS, Flexible AC transmission system; FIR, Finite impulse response; HC, Harmonic compensator; HES, Hybrid Energy System; ILC, Iterative learning control; IMP, Internal model principle; IRSMC, Integral resonant sliding mode controller; LQ, Linear quadratic; LQG, Linear Quadratic Gaussian; LQR, Linear Quadratic Regulator; MG, Microgrid; NPC, Neutral-point-clamped; NN, Neural network; NNIPI, Neural network interfacing-parameters identifier; NNGVE, Neural network grid-voltage estimator; PI, Proportional integral; PID, Proportional integral derivative; PR, Proportional resonant; PWM, Pulse width modulation; PCC, Point of common coupling; PED, Power electronics device; RC, Repetitive feedback control; SISO, Single-input single-output; SMC, Sliding mode controller; THD, Total harmonic distortion; UPS, Uninterruptible power supply; VPP, Virtual power plants; VSC, Voltage-source converters

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1. Introduction

Today, there is an increasing use of small-scale renewable power sources into modern electric grids, because the current growing demand for electrical energy [1,2]. Photovoltaics, wind power and hydroelectric power are three of the renewable energies that are mostly used; they are clean for the environment and inexhaustible. This renewable energy has experienced rapid technological development, which makes them at affordable prices. This advantage allows the energy security of countries to reduce imports of fossil fuels, which allows maintaining a lower cost than usual prices and improves the standard of living without harming the environment, especially in a time when the economic crisis is timely. Another advantage, they can easily support the electrical network in remote sites and rural areas [2]. As shown in Fig. 1, the rate of investment of wind energy was more important in 2010, but it started dropping in 2011, 2012 and 2013 in contrast to the solar energy that has experienced the same problem a year later compared to wind power. Despite the economic problems many countries support programs connecting renewable energy with global and local power grid. In order to integrate different kinds of renewable energy sources, the concept of microgrid (MG) was proposed several years ago [3]. A microgrid can be defined as a part of the grid consisting of prime energy movers, power electronics converters, distributed energy storage systems, and local loads [4].

This makes the electrical network more flexible and intelligent [5]. Microgrids and virtual power plants (VPPs) are two low voltage distribution network concepts that can participate in active network management of a smart grid [6,7]. They are becoming an important concept to integrate distributed generation (DG) and energy storage systems [5,8]. The interest of DG grows and is taking importance [9] when it is composed of different energy resources: Photovoltaics, wind power and hydroelectric power with electrical energy storage (EES) (e.g., batteries or super capacitors) [6] forming a Hybrid Energy System (HES) [2], because they can easily support the electrical network in island mode and rural areas or grid- connection mode. Other non-renewable based power systems (diesel or gas), whose generation profile can be easily controlled are also likely to be integrated into microgrids [10]. This gives the user the possibility to produce and store part of the electrical power of the whole system [9]. The use of DPGS makes no sense without using distributed storage systems to cope with the energy balances [5]. Microgrids should be able to locally solve energy problems and hence increase flexibility [11]. The advance carried in recent years in power electronics makes this latter very attractive when integrating renewable energy resources, distributed energy storage systems and active loads [4,12]. The Power Electronic Converters are typically used as interfaces between these devices and the MG, acting as a voltage source (voltage source inverter VSI, in the case of AC network micro) [3,8,12]. MGs need to be able to operate intelligently in both grid and island mode [13]. At the same time, AC and DC sources sometimes coexist in a practical microgrid. The interfacing converters are usually connected in parallel [3]. The control of the parallel VSIs forming a MG has been investigated in the last years [12]. Thus, the greatest challenge is to ensure stability and voltage regulation for offering a better power quality for the customer [9]. In order to avoid circulating currents among the converters without using any critical communication between them, the droop-control method is often applied [5,11]. This is a kind of collaborative control used for sharing active and reactive power between VSIs in a cooperative way [12]. These control loops, also called $P-\omega$ and $Q-E$ droops, have been applied to connect inverters in parallel in uninterruptible power supply (UPS) systems to avoid mutual control wires while obtaining good power sharing [5,11,14,15]. However, although this technique achieves high reliability and flexibility, the price to pay is that the sharing is obtained through voltage and frequency deviations in the system (load dependent frequency and amplitude deviations) [12,16,17], which limit its application [5,11]. In order to solve these problems, an external control loop named secondary control is implemented in the microgrid control central to restore the nominal frequency and amplitude values in the microgrid [4,5,11,12]. An additional tertiary control can be used for bidirectional control the power flow. In case of AC microgrids, the objective is to regulate the power flows between the grid and the microgrid at the point of common coupling (PCC) [5,11,18,19]. In countries with hydro power potential, small hydro turbines are used at the distribution level, in order to sustain the utility network in dispersed or remote locations [20]. At present time, most of renewable based DG units directly produce DC or variable frequency/voltage AC output power and hence power electronics devices (PEDs) have become the key elements in order to realize the MGs [21]. But an increased amount of DPGS based on wind turbine and photovoltaic are connected to the utility network and can create instability in the power systems because of the variation of the wind and sun. In order to maintain a stable power system in countries with a large penetration of distributed power, transmission system operators issue more stringent demands regarding the interconnection of the DPGS to the utility grid [22]. Besides their low efficiency, the controllability of the DPGS based on both wind and sun are their main drawback [23]. As a consequence, their connection to the utility network can lead to grid instability or even failure, if these systems are not properly controlled. Moreover, the standards for interconnecting these systems to the utility network are