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Aggregate load-frequency control of a wind-hydro autonomous microgrid

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ABSTRACT

This paper presents an aggregate load-frequency controller for an autonomous microgrid (MG) with wind and hydro renewable energy sources. A micro-hydro power plant with a synchronous generator (SG) and a wind power plant with an induction generator (IG) supply the MG. Both generators directly feed power into the grid without the use of additional power electronics interfaces, thus the solution becoming robust, reliable and cost-effective. An original electronic load controller (ELC) regulates the MG frequency by a centralized load-frequency control method, which is based on a combination of smart load (SL) and battery energy storage system (BESS). SL and BESS provides the active power balance for various events that such systems encounter in real situations, both in cases of energy excess production and energy shortage. Moreover, the proposed ELC includes an ancillary function to compensate the power unbalance produced by the uneven distribution of the single-phase loads on the MG phases, without the use of extra hardware components. A laboratory-scale prototype is used for experimentally assessment of the proposed solutions. The experimental results emphasize the effectiveness of the ELC while also showing its limitations.

1. Introduction

Due to the continuously increasing demand in global energy coupled with a depletion of fossil fuels resources and increase in pollution, the integration of renewable energy sources (RES) in power systems of small, medium and large scale is constantly expanding. The European Union countries make important efforts to reach the targets of producing energy from RES [1], the main issue being the integration of RES-based distributed generators in the classical networks and the organization of a proper legal framework and technical regulations for their development [2,3].

In this context, a new power system structure called microgrid (MG) has evolved, which is able to sustain the local energy demand with electrical and at times thermal energy. Developed initially for supplying remote consumers, the MG is becoming the base structure of the future smart grid, which is expected to be developed from clusters of MGs designed with plug-and-play features and interconnected through special data-exchange and power-exchange highways [4]. The MG can operate autonomously, feeding the local consumers, or interconnected, in which case the energy is traded at the market price [5].

Generally, a MG consists of one or several microsources, storage devices, power quality conditioners and consumers, as well as all the equipments and the required infrastructure to operate a small-scale power system [6].

Although there are no specific international standards about isolated electrical systems, the power quality should be similar to that of the interconnected systems, because the consumers of both isolated and interconnected systems are the same, and therefore their equipments require usually the same power quality to operate.

This paper tackles the problem of frequency control in RES-based MGs according to the existing power quality standards. The active power balance directly affects the MG frequency, and the literature presents three main solutions to cope this issue in autonomous systems: dissipating the power excess on dumping resistances [7–9], using energy storage systems (e.g. batteries, fuel cells/electrolyzers, flywheels) [10–12], or combined solutions [13,14]. On this line, the paper proposes an original aggregate electronic load controller (ELC) based on a hybrid topology of a smart load (SL), developed by the authors, and a battery energy storage system (BESS), which successfully manage the active power balance within MG. Moreover, using the same hardware the ELC provides active power unbalance, produced by the uneven distribution of the single-phase loads, by adding only a control component to the SL.

The rest of this paper is organized as follows. Section 2 describes the studied MG structure. Section 3 introduces the proposed ELC

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configuration while the control strategy is presented in Section 4. The experimental results discussed in Section 5 emphasize the effectiveness of the proposed solution while Section 6 concludes the paper.

2. System configuration

The studied three-phase four-wire MG consists of a micro-hydro power plant (MHPP) in parallel with a wind power plant (WPP), as shown in Fig. 1. The MHPP includes a micro-hydro turbine (MHT) that directly drives a synchronous generator (SG). The SG accomplishes the MG voltage control through an automatic voltage controller (AVR) placed on the field winding side [15]. The SG is star-connected with the neutral available, which forms the forth wire of the MG. Thus, the system supplies both single- and three-phase loads.

The MHPP civil work may include a small-capacity dam to store the water during the energy excess periods, which in this case arise when the wind power production is high, and thus reducing the MHPP loading. In this way, the power reserve and the MG security of supply increase, whereas the use of a WPP as secondary energy generator is better justified. This paper focuses only on the case when the MHT is ungoverned and the water flow in consequence remains quasi-constant. The aforementioned solution of storing the wind energy as hydro, so the MG includes a slow response power reserve, in combination with fast-acting BESS represents a future research.

The WPP is equipped with a conventional three-blade wind turbine (WT) connected through a gearbox to a squirrel-cage induction generator (IG), which is directly connected to the MG, as such WT operates in quasi-fixed speed operation mode.

Even if doubly fed IG provides better performance in terms of wind energy yield due to the possibility of controlling the rotor speed around the rated value, squirrel-cage IG was preferred in this application because it does not require power electronics interfaces, and therefore the system reliability increases. Moreover, for small output powers, kW-range, doubly fed IG and the required power electronics converters become an expensive solution.

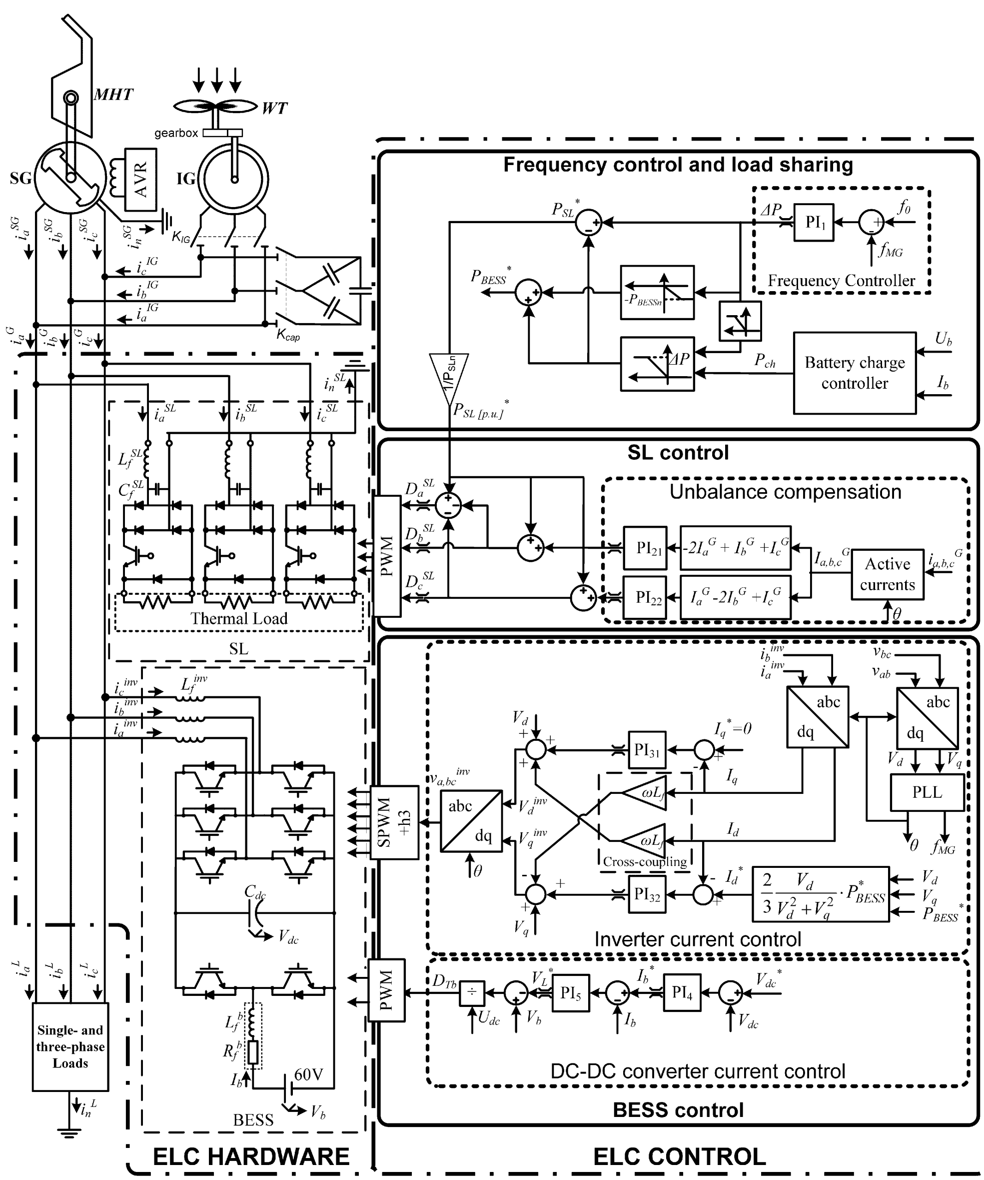

Fig. 1. The proposed MG configuration (hardware and control).