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A robust control algorithm for a multifunctional grid tied inverter to enhance the power quality of a microgrid under unbalanced conditions

Ahmed Safa[a,b,*], E.L. Madjid Berkouk[a], Youcef Messlem[b], Abdelmadjid Gouichiche[b]

[a] LCP, Department of the Electrical Engineering, ENP, Algiers, Algeria
[b] Laboratoire de génie électrique et des Plasmas LGEP, Université Ibn Khaldoun Tiaret, Algeria

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ABSTRACT

This paper proposes a robust control algorithm for a Multifunctional grid-tied inverters (MFGTI) under unbalanced load and main voltage conditions. The proposed algorithm uses the instantaneous power theory to design the MFGTI controller. A Positive Fundamental Components Estimator (PFCE) is used to estimate the undesired components of the load current such as harmonics, reactive current, and negative sequence component. The PFCE is a lightweight open loop algorithm. Hence, a good robustness is achieved with a lower computation burden. Furthermore, a new sliding mode controller (SMC) is used as a DC bus voltage regulator to enhance the dynamic performance and robustness against parameter variation. The MFGTI is connected at the Point of Common Coupling (PCC), interfacing the microgrid to the main grid. Alongside the active power injection, the proposed control algorithm allows the MFGTI to compensate reactive power, mitigate harmonics, and balance the load. Thus, the microgrid will meet the different power quality standards. An experimental prototype is designed to verify both the performance and robustness of the control algorithm. The attained results confirm the validity of the proposed algorithm.

1. Introduction

Over the last few years, the architecture of the power grid has metamorphosed from the central generation based mainly on fossil fuel to the Distributed Generation (DG) using Renewable Energy Sources (RES) [1]. The new smart grid concepts lie in the grouping of these DG units and loads in a microgrid. A microgrid is an aggregation of DG units and local loads; together they appear to the main grid as a bidirectional active load [2]. When connecting to the grid, a microgrid can absorb or deliver active power to the grid. In the case of a grid fault, a microgrid should be able to work in island mode, thus the self-healing concept. The microgrid is connected to the grid via a single point, the Point of Common Coupling (PCC). To be connected to the main grid, a microgrid has to meet the power quality requirement imposed by the Power System Operator (PSO) among them the IEEE 519-2014 [3] and IEEE 1547 [4].

Most DG units use power electronics converters as an interface to the grid [5]. The development of these converters and their control algorithm makes it possible to use them for multiple purposes. In the year 2000 [6], authors studied the potential use of the DG to provide ancillary services. Researchers used this potential to enhance the power quality of a microgrid by connecting a MultiFunctional Grid Tied Inverter (MFGTI) at the PCC [7]. Alongside to the active power injection from a DG source, the MFGTI will provide the microgrid with ancillary services such as harmonic mitigation, power factor correction, and load balancing. The connection of the MFGTI at the PCC will allow the microgrid to meet the different power quality requirement.

The three-phase MFGTI is well documented in the literature [8–24]. Synchronous Reference Frame Phase Locked Loop (SRF-PLL) is commonly used to synchronize the MFGTI to the grid and estimate harmonics [8–13,25]. The use of PLL suffers from the problem of grid frequency drift, estimation error under non-ideal main voltage and complex computations as discussed in [26,27]. PLL-less control algorithm is proposed in [14,17,28,29]. Even though grid frequency drifts and delays problems are omitted in these works, the complex computation problem persists. Moreover, Poor filtering performance characterized by a relatively high Total Harmonic Distortions (THD) is noticed.

Alongside harmonics, unbalance is an important issue in power quality. It affects negatively the power system and electrical equipment. Beside instability and power losses in power system, unbalance causes overheating in electrical machines, overloading in transformers and oscillation in the output of power electronics converters [30]. As ancillary services, the MFGTI is used in load balancing. The problem of

* Corresponding author at: Laboratoire de génie électrique et des Plasmas LGEP, Université Ibn Khaldoun Tiaret, Algeria.
E-mail address: safa.ahmed@univ-tiaret.dz (A. Safa).

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unbalance is addressed in [10,12–17,31–34]. A combination of series and shunt converters is used in [14,15] which complicate the system structure. A three-phase four leg inverter is used in [10,12,13] to compensate the unbalance. The additional leg represents an extra cost compared to the simpler three-phase three-wire configuration. A three-phase three-wire configuration is used in [17,31]. Although authors used a simple configuration, the control algorithm is complex.

The above-mentioned solutions in controlling the MFGTI and providing ancillary services are characterized by either a complex algorithm, complex inverter structure, or low performance. This paper uses a three-phase three-wire inverter with a simple and robust control algorithm that guarantees good performances with a low computation time.

This paper addresses the problem of controlling an MFGTI under highly disturbed environment. The main contribution of this paper is the use of a new Positive Fundamental Component Estimator PFCE alongside a new DC bus controller based on sliding mode theory. Using a Sliding Mode Controller (SMC) combines the benefits of having a good dynamic performance and robustness against the variation of the system parameters. The PFCE is based on a simplified version of the three-phase Adaptive Quadrature Signal Generator (3ph-AQSG) introduced in [27]. This novel form of implementation guarantees the injection of active power, compensation of harmonics, reactive power, and balancing the load under undesirable main voltage condition.

The MFGTI is controlled in three stages. The first stage estimates the reference current to enhance the power quality. Then, the DC bus is regulated to inject the active power in case of presence of an RES or absorb the active power from the grid in case of the RES absence. Finally, in the third stage, the output current of the MFGTI is controlled.

This paper is organized as follows: The general system structure is presented in Section 2. The *pq* theory, the PFCE algorithm, the reference power calculation, the DC bus controller, and the overall control algorithm are dealt with in Section 3. Thereafter, the laboratory prototype, the conducted tests, and experimental results are laid out in Section 4. Finally, conclusions are drawn in Section 5.

2. System configuration

Fig. 1 illustrates a typical configuration of a microgrid connected to the main grid [35]. The MFGTI is connected at the PCC as a microgrid interface to the grid. Being connected at the PCC, the MFGTI will be able to inject active power, compensate harmonics and reactive power, and balance the microgrid loads. Thus, for the main grid, the microgrid will be a linear balanced active load. Another benefit of the MFGTI is the ability to balance the microgrid currents even under unbalance main voltage.

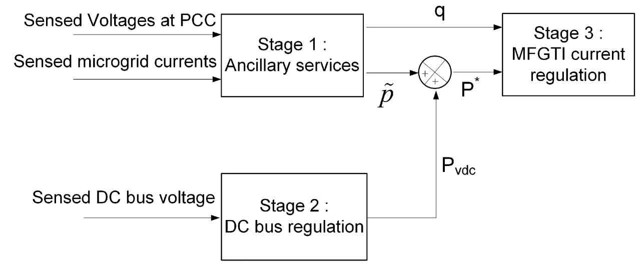

Fig. 2. The Proposed MFGTI Control Algorithm.

The MFGTI performances depend primarily on the control algorithm. The rapid changes in the microgrid, the main grid perturbations, and the intermittent nature of the RES require a robust and fast control algorithm. Thus, the aim of this paper is to avoid methods based on synchronous reference frame or depends on the system parameters (PI-based regulators).

3. Control algorithm

This paper proposes a new control strategy for an MFGTI. The control is performed in three stages (Fig. 2). First, ancillary services are provided (harmonic mitigation, reactive power compensation, load balancing, etc.). Then, the DC bus is regulated by injecting the active power provided by the RES. Finally, the output current of the MFGTI is controlled. The MFGTI overall performances depend on each stage performances. Hence, in this paper, three algorithms that combine simplicity, robustness, and low computation demands are used. In first stage, the PFCE is used to provide the ancillary services. In the second one, the SMC controller is used to regulate the DC bus voltage and inject the active power. In the third one, hysteresis current controller is used with regard to its simplicity and robustness.

3.1. Background of the instantaneous power theory

In 1983 Akagi et al. proposed the instantaneous power theory also known as *pq* theory [36]. This theory calculates the instantaneous power that flows through a three-phase system. It uses the Clarke transformation of currents and voltages given by:

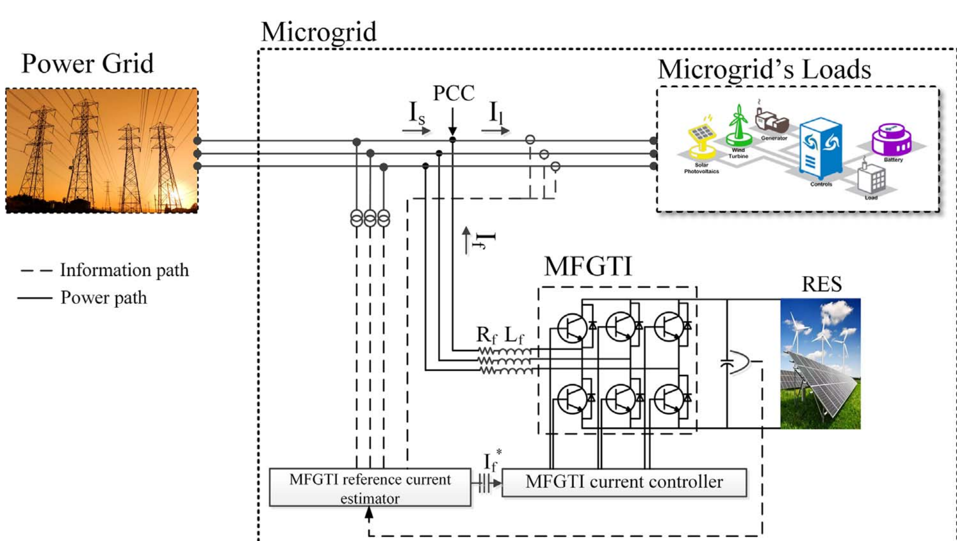

Fig. 1. System configuration.