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Review and Classification of Control Systems in Grid-tied Inverters

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ABSTRACT

High performance grid-tied inverters have stringent control requirements both under steady-state and under transient conditions. Many different control systems have been applied to grid-tied inverters. However, there are few publications reviewing the literature on these control systems and their classification, particularly with regard to recent developments in this area. In this paper, a review of solutions for the control of grid-tied inverters is carried out. These control systems are compared and classified as implementation platform, reference frame, output filter of inverter, control strategy, modulation method, and controller. The major advantages and disadvantages of these parameters are highlighted and compared. Then, the most important characteristics of these parameters have been presented in a table to show which parameters can be used in various control systems for grid-tied inverters.

1. Introduction

Nowadays, an increase in demand for energy brings about some problems such as grid instability, outage, etc. for power distribution [1]. Using distributed power generation system (DPGS) is a reasonable solution for these problems, because it causes more flexibility, balance, and stability for the grids. Also, it can improve the management of distribution networks and reduce the released Carbon [2]. Photovoltaic systems, wind turbine systems, and energy storage systems like battery bank, fuel cell, and active filter are examples of DPGS.

The output voltage of this system is usually DC, but it should be converted to AC before being discharged into the grid or used by various loads. Therefore, in the grid-connected DPGS, inverters play a key role in enabling the DPGS to convert the DC voltage and current to AC and deliver them to the grid. The delivered energy enjoys special properties and standards, so it should be controlled before delivering. Thus, it is necessary to use a suitable controller for inverters modifying the type of energy and power. In fact, the inverter and its controller are an interface between DPGS and the grid to transfer the high quality power. Since the grid wave shapes are AC and sinusoidal, the DPGS output should be sinusoidal as much as possible.

Connecting DPGS to the grid is very important since it results in numerous problems including the grid instability and disturbance if no suitable controller is designed for it. That is why these systems should be able to overcome the grid distortions. Thus, a high-speed controller along with a compatibility algorithm is needed in this regard.

Also, the design of the controller is fundamental and considerable. Instability and failure taking place on the grid are the result of an inappropriate design for the controller. Only an applicable controller can contrast to grid distortion [1].

Fig. 1 illustrates a general structure for distributed systems. Depending on the connection of the generation system to the utility network or to local loads, the power produced can be delivered to one of them [1].

A power conversion unit includes a single-phase inverter with an L-filter which is an interface unit between the power generating system and the grid or local loads as shown in Fig. 2.

Controlling the distributed system is an important issue that can be divided into two major parts.

1) Input-side controller: The main property of this controller is the extraction of the maximum power that comes from the input source. Also, input-side converter must be protected by this controller.
2) Grid-side controller: This controller can perform the following tasks:

- control of the active power delivered to the grid;
- control of the reactive power transfer between the grid and the DPGS;
- control of the DC-link voltage;
- assuring high quality of the injected power; and
- grid synchronization.

Grid-side converter should have the basic features listed above. Furthermore, the grid operator may request ancillary services like

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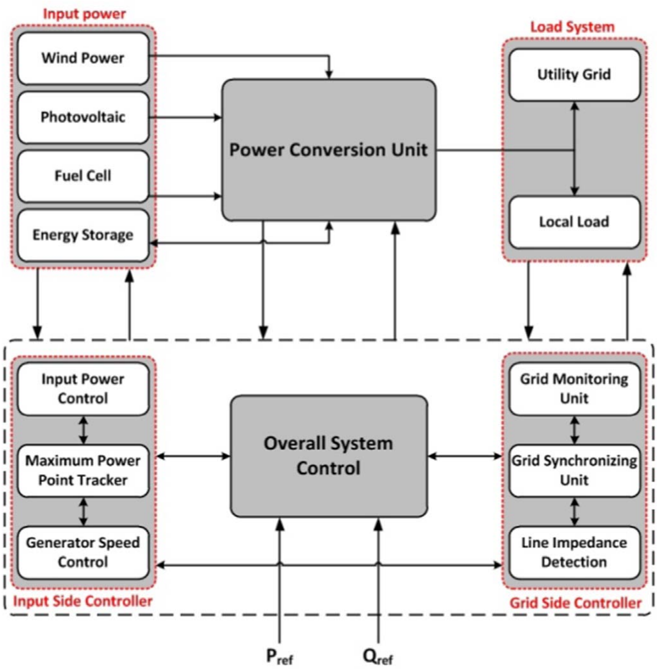

Fig. 1. General structure of DPGS with different power sources [1].

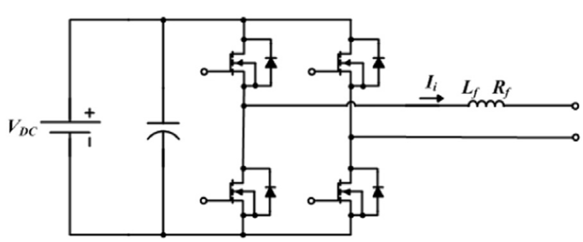

Fig. 2. An example of power conversion unit in DPGS.

voltage harmonic compensation, active filtering or local frequency, and voltage regulation [1].

In this paper, different control systems performed on grid-connected inverters are analyzed and a review of solutions is done for the control of grid-tied inverters. These control systems are classified and compared as reference frame, implementation platform, output filter of inverter, control strategy, modulation method, and controller. The major advantages and disadvantages of these parameters are highlighted and compared. Then, the most important characteristics of these parameters are presented in a table to show which parameters can be used in various control systems in grid-tied inverters.

The purpose of presenting this review is the comparison of various distributed generation systems to determine differences, advantages, and disadvantages of each system to choose the optimal control system. Thus, in Sections 2 and 3, the comparison and classification of the methods and parameters used in various control systems will be presented. Then, a general comparative table will be presented in section 4 to study the types of control systems presented in credible scientific articles. Finally, conclusions are presented in section 5.

2. Comparison of different control systems

There are many different parameters to examine and compare different control systems based on which control system is compared.

Implementation, controller, output filter of inverter, modulation method, control strategy, and the reference frame are some parameters used for this comparison explained as follows. It is important to note that the controllers will be classified and fully explained in the next section.

2.1. Implementation platform

All of the control systems can be implemented at analog or digital platform each including some advantages and disadvantages as follows:

2.1.1. Analog

It's clear that Analog signals are the input and output of these control systems which are analyzed and designed by Laplace transformation or time-continuous analyses. Robust against break down or crash, high dynamic range, continuous processing, diagnostic instrumentation availability, and so on are the advantages of this platform. Also, its defects are slow development, interference, hard to build in comparative logic and intelligent control systems and hard to do MIMO.

2.1.2. Digital

The input and output of the implemented control system of the digital platform are digital signals that are usually analyzed and designed by Z-transformation or time-discrete analyses. The advantages of the digital platform are flexibility, quick development, easy to build in comparative logic, and intelligent control systems as well as easy to do MIMO, high accuracy, and robustness against interference. Also, the disadvantages of this platform involve low processing speed, low dynamic range, while software interfaces are not user-friendly.

The digital implementation technologies used in control systems can be classified into three categories as follows:

1. Digital Signal Processor (DSP) Based [3–5]
2. Field Programmable Gate Array (FPGA) Based [6–8]
3. Microcontroller Based [9–11]

DSP based implementation has the most usage in credible scientific articles. These article often process data using fixed-point arithmetic, though some more powerful versions use the floating point. For some fast controllers, FPGAs might be used. The advantages of FPGAs include the ability to re-program in a field to fix bugs and parallel structures. For slow applications, a traditional slower processor such as a microcontroller may be adequate.

2.2. Reference frame

Control systems can be implemented into one-phase or three-phase ones in the grid-connected systems that are compatible with the power system. In order to create a special capability for control systems and to facilitate the design, transformation of one-phase and three-phase systems into other systems is used as follows [1,12]:

2.2.1. abc reference frame

This frame is applied in three-phase systems the same as three-phase systems without any transformation. An individual controller has to be used for each phase current in an abc frame, but star or delta connection of three-phase systems has to be considered in the design of control systems. The non-linear controllers are used in this system, because they deliver a quick dynamic response.

2.2.2. dq reference frame

This frame is used in three-phase systems and Park transformation is used to transform an abc frame to an dq frame. This transformation causes the grid current and voltage waveforms to be transformed into a reference frame that rotates simultaneously with the grid voltage. In this manner, control variables are changed into DC variables that are easily filtered and controlled. Fig. 3 shows the general structure of the rotating reference frame.

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