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Design and real time implementation of fuzzy switched controller for single phase active power filter

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ABSTRACT

This paper proposes a novel fuzzy switched controller (FSC) integrated in direct current control (DCC) algorithm for single phase active power filter (SPAPF). The controller under study consists of conventional PI controller, fractional order PI controller (FO-PI) and fuzzy decision maker (FDM) that switches between them using reduced fuzzy logic control. The proposed controller offers short response time with low damping and deals efficiently with the external disturbances while preserving the robustness properties. To fulfill the requirements of power quality, unity power factor and harmonics limitations in active power filtering an experimental test bench has been built using dSPACE 1104 to demonstrate the feasibility and effectiveness of the proposed controller. The obtained results present high performance in steady and transient states.

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1. Introduction

Recently, current harmonics become a serious problem in power distribution systems caused by connecting nonlinear loads to the electrical grid; especially power electronics converters in industry fields as well as by domestic consumers [1–5]. These harmonics fed from nonlinear loads pollute the grid by affecting the current and voltage waveforms and leading to a reduction of the power factor [6]. Thus, several standards were proposed to avoid deterioration of power quality such as IEEE harmonic standard 519 that strictly imposes a value less than 5% of the global THD [7]. Traditional solutions based on RLC circuits were designed to face these problems regarding to their advantages presented in simplicity and low cost [1]. Moreover, these kinds of passive filters eradicate particularly low order frequencies (3th, 5th, 7th, 11th...) but they are susceptible to originate series and parallel resonances between the power supply and load [8–10]. Thus, active power filters are often used to compensate reactive power by reducing distortions of current due to nonlinear loads [11,12].

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In the literature, active power filters are presented with several topologies. Among them, single phase active power filter (SPAPF) is widely used in medium and low power installations due to its low cost and high efficiency [13]. Indeed, SPAPFs are allowing an easier installation without the need to interrupt the power supply or loads [13]. A number of new control techniques have been proposed to control SPAPFs with regard to the integration of control and sensorless methods [11]. The majority of techniques based on complicated calculus of instantaneous active and reactive power lead to slow computing time and need powerful calculation units (such as DSPs) [8]. For this reason, this paper improves the regulation side of the direct current control (DCC) which is a simple algorithm consisting of two control loops [13]. An outer voltage loop used for DC-bus voltage regulation while an inner current loop is used to generate switching command signals.

In industrial fields, the PI controller with fixed parameters is known as good solution in regulation loops and continued to be the most widely used process control technique for many decades because the simple structure is easier for engineering design [14]. This controller is good in steady state but has some weakness in dynamic state [15]. Indeed, the conventional PI controller is sensitive to parameters variation and external disturbances [16]. Unfortunately, this kind of controllers cannot satisfy the requirements in DC-bus regulation loops and leads to degradation in control performance. Nowadays, using fractional order PI

controller (FO-PI) in control systems received more and more attention of scientists to increase the control accuracy [16,17]. First, the fractional order $PI^\lambda D^\mu$ controller was proposed by Poblubny in [18], where a better control performance was demonstrated in comparison with the conventional PID controller because of the extra real parameters λ and μ [16]. The FO-PI controller solves the drawbacks of the conventional one in dynamic state by giving extra degree of freedom to the controller, offering faster response [19,20] and being robust to the parameters variation due to its flat phase around the crossover frequency as demonstrated in the Ref. [20]. However, FO-PI controllers have bad effects on the power quality in active filtering in steady state. Especially, the need of the approximation method when building these controllers as demonstrated in [21].

Recently, using soft computing techniques such as fuzzy logic [22–24], neural networks [25] and genetic algorithm [26,27] have successfully been used in many control applications [23] and in regulation loops especially such as variable order fractional PID controller based on fuzzy logic to deal with parameters variation of the system has been proposed in [28], the robustness of a fractional PID controller using neural network has been enhanced in [29], a novel fractional order (FO) fuzzy Proportional-Integral-Derivative (PID) controller has been proposed in [27], which used a genetic algorithm to optimize their parameters, an IP controller to reduce the first overshoot of DPC technique has been integrated in voltage regulation loop in [10,19], a higher order sliding mode controller based on super twisting algorithm has been used in [30]. But the complexity of these controllers is far beyond the fixed parameters PI controller that leads to high online calculation ability and increases the cost of hardware as well as software of the system [14]. Nevertheless, all mentioned controllers have improved the control performance from some aspects and ignore the other aspects.

The main contribution of this paper is to propose a new robust controller named fuzzy switched controller (FSC) in the outer voltage regulation loop of the DCC technique regarding to the steady and dynamic performance. The proposed FSC consists of conventional PI controller, FO-PI controller and fuzzy decision maker (FDM) that switches between the conventional and the fractional order controllers based on a reduced fuzzy logic (FL) rules to guarantee low cost. FL has become common application to deal with complex nonlinear processes and to enhance the closed loop performance [31]. The implementation of FL control is rather difficult and leads to high cost. Thus, a reduced FL rules is used to decrease the calculation [14]. PI and FO-PI controllers are selected from one to another depending on their performance under certain operating conditions. When the error between the actual value and its reference is considered small; the FDM switches to the conventional PI controller. Elsewhere, the FDM switches to the FO-PI controller to deal with the abnormal condition. The FO-PI

controller is designed to bring the DC-bus voltage closer to the reference as faster as possible. Thus, the FSC guarantees high performance and low cost with less calculation and complexity. All obtained results prove that the FSC outperforms the use of conventional or fractional order controller.

This paper presents a procedure to design a robust fuzzy switched controller to enhance the DC-bus regulation of SPAPF. The validity of the proposed DCC approach (FSC-DCC) has been investigated through real time bench implementation. The steady state and dynamic behavior of FSC-DCC algorithm have been presented with the robustness tests in practice.

2. Power system and control algorithm

2.1. Power system configuration

The single phase compensation system shown in Fig. 1 is composed of an electrical grid supplying a nonlinear load represented by a single phase bridge rectifier feeding RC load and a SPAPF which is a voltage source inverter (VSI) with 4 IGBTs including a capacitor C_{dc} in the DC part and an inductance L_f in the other part. The configuration of the SPAPF is able to compensate current harmonics, to ensure a power factor (PF) correction and to eliminate voltage distortions.

2.2. DCC technique

Fig. 2 shows the proposed direct current control algorithm for SPAPF. It is composed of two control loops, the first one is the outer voltage loop, which is responsible to keep the measured capacitor voltage (V_{dc}) oscillating around a desired reference (V_{dc}^*) and generate the maximum source current amplitude (I_{smax}). The second is the inner current loop that compares the calculated reference current (I_s^*) with the measured reference current. Finally, the error Δi_s passed through a hysteresis band (± 0.1 A) to obtain the switching command signals.

3. The proposed controller design

This paper presents a new systematic design of switched controllers by proposing a fuzzy switched controller (FSC) as shown in Fig. 3. The FSC composed of conventional PI controller, fractional order PI controller (FO-PI) and switches between them using fuzzy decision maker (FDM). The FDM selects the best controller according to the value of $\varepsilon(t)$ (the error between the actual capacitor voltage V_{dc} and its reference V_{dc}^*) when persistent external disturbances are detected.

The closed loop of DC-link voltage of the SPAPF is shown in Fig. 4. Where, Fig. 4a is the equivalent closed loop in the steady state when the conventional PI controller has been selected. On the other hand, Fig. 4b is the equivalent closed loop regulation when the FO-PI

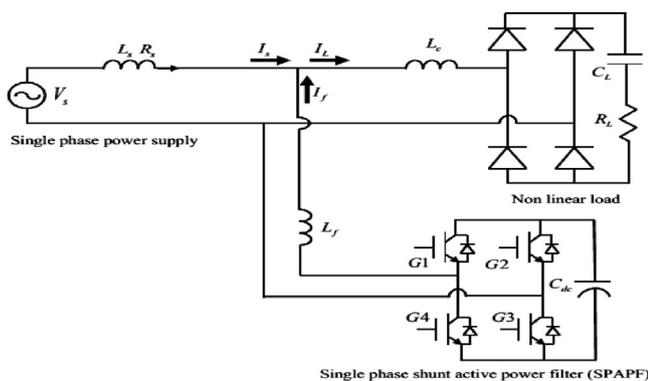


Fig. 1. Scheme of the power system under study.

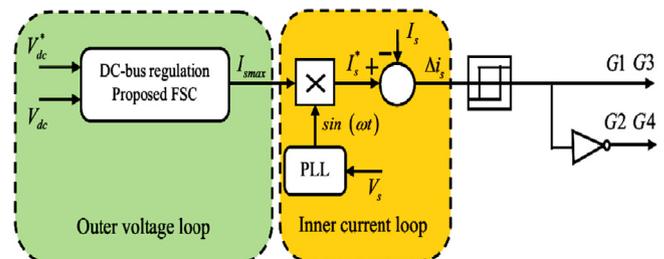


Fig. 2. Proposed control scheme (FSC-DCC technique) for SPAPF.

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