

Adaptive Control for Shunt Active Power Filter under Stochastic Solar Photovoltaics Behavior

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Abstract—The paper discusses the challenges in controlling a two-stage photovoltaic (PV)-based shunt active power filter (SAPF) under distorted grid conditions and stochastic PV system behavior. To address this, the paper proposes an adaptive proportional integral (API) regulator to regulate the DC-link voltage, which adapts its parameters based on the DC-link error voltage to provide low bandwidth for disturbance rejection and high bandwidth for dynamic performance enhancement. The paper also proposes an estimation method for the reference current using the sliding discrete Fourier transform and the instantaneous symmetrical component theory, which is suitable for non-ideal grid or load conditions. The accuracy of the proposed reference current estimation method is analyzed using time- and frequency-domain analysis. The performance of the PV-SAPF system with the proposed control algorithms is illustrated through simulation and real-time hardware validation under various grid conditions. Despite distorted grid conditions, the total harmonic distortion of the grid current is substantially within IEEE Std 519-2014. The proposed API regulator and reference current estimation method show promising results in improving the performance of the PV-SAPF system in the presence of internal and external disturbances.

Index Terms—Distributed generation, instantaneous symmetrical component theory, phase-locked loop, power system harmonics, reactive power supply, shunt active power filter, sliding discrete Fourier transform.

I. INTRODUCTION

Renewable energy sources such as solar photovoltaic (PV), wind energy, and fuel cells are now being considered as potential alternatives to traditional fossil fuel-based energy sources. Compared to other renewable energy sources, solar

PV is widely used [1]. PV panels generate direct current (DC) electricity, which requires the use of power electronics converters to connect to the conventional grid at the point of common coupling (PCC) [2]. Furthermore, charging stations for electric vehicles (EV) and variable speed drives are major applications for power electronics converters [3]. The utility grid is interconnected with these higher penetrations of power electronics devices and nonlinear loads. Since nonlinear devices draw non-sinusoidal currents from the utility, it creates serious power quality issues. This results in the AC grid being injected with undesirable harmonics. When the injected harmonics exceed a certain level, transformers, generators, motors, capacitors, and cables connected to the same utility may overheat. Hence, the injection of harmonics into the grid must be less than 5%, according to the IEEE 519-2014 [4] requirements.

This paper addresses the challenges of integrating PV-based power into the grid, which negatively affects network stability and supply quality due to the intermittent nature of solar power generation. To improve grid stability and power quality at the point of common coupling, photovoltaic systems based on the shunt active power filter (PV-SAPF) have been studied. The two-stage configurations of PV-SAPF systems offer more advantages in terms of modularity, operation, and control than single-stage architectures [1]. In a two-stage PV-SAPF system, the DC-DC converter stage increases the PV voltage, extending its working range and module flexibility. The maximum power point tracking (MPPT) scheme regulates the energy flow between the PV string and the DC-link of the inverter [5]. The perturbation and observation (P&O) based MPPT algorithm is widely used, but has limitations, which are addressed by adaptive P&O MPPT algorithms [6]. The PV-SAPF system requires an outer and inner loop controller. The outer loop controls the DC-link voltage and generates the reference current for the inner loop, which is responsible for injecting a sinusoidal current with a power factor close to unity to meet the load demand [7]–[10]. Conventional SAPF systems rely on proportional-integral (PI) controllers to regulate both fixed DC-link (FDC) and adaptive DC-link (ADC) voltages. However, the inherent characteristics of PI controllers pose limitations on disturbance rejection and dynamic response speed [11], [12]. Furthermore, ADC control may suffer from performance degradation during grid voltage sag and swell conditions. The nonlinear PI (NPI) is utilized in DC-link controllers to mitigate voltage fluctuations occur due to unbalanced non-linear load [5]. However, tuning parameters of

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