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Proportional Integral Control Realized in Stationary and Synchronous Reference Frames for a Single-Phase UPS Inverter System: A Comparative Study

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ABSTRACT

Voltage regulation of the single-phase UPS inverter has design challenges in terms of dynamic performances and control complexity. Widely used conventional integral controllers, such as proportional integral and proportional resonant in stationary frame (SF) of reference have limitations of either steady state error or implementation difficulties. Although a mature technique in three-phase applications, the synchronous reference frame (SRF) control scheme has not been exhaustively investigated for single-phase UPS inverters due to complex multiple transformations. This paper suggests a voltage control scheme which can be alternatively used in both stationary and synchronous reference frames. Three integral controllers namely, SF-proportional integral (SF-PI), SF-proportional resonant (SF-PR) and SRF-proportional integral (SRF-PI) are comparatively evaluated for steady state and transient performances. A systematic procedure for the design of control parameters with stability analysis in the frequency domain for the closed loop control system is also presented. Respective controllers are simulated in discrete time frame using MATLAB/Simulink and experimentally implemented using the TMS320F2812 Digital Signal Processor based laboratory prototype.

KEYWORDS

Active damping; Multi-loop; Proportional resonant (PR); Synchronous reference frame (SRF); Uninterruptible power supply (UPS); Voltage source inverter (VSI)

1. INTRODUCTION

The proliferation of clean, emissions-free energy sources due to greater environmental awareness is a trend around the globe. Rooftop solar panels have already become a household essentiality; small-scale wind generators and miniature fuel cell systems are also gaining popularity for individual homes, farms, and small businesses as cost-efficient alternatives. These systems inevitably utilize power electronic converters to supply stand-alone load or grid [1–5]. Voltage source inverters (VSIs) in the stand-alone mode have stringent voltage regulation specifications under different loading conditions. The major requirements include low total harmonic distortion (THD), small steady state error on load and fast transient response on step load transition [6].

To meet the above requirements, various single/multi-loop systems using different states and command feedback/feed-forward variants have been proposed in [7,8]. Apart from this, a controller largely specifies the steady state and dynamic performance of the system. Many compensators based on deadbeat [9,10], model predictive [11], learning such as repetitive or iterative [12,13], and nonlinear controllers like sliding mode or neural network [14–17] have been proposed. Among all the above, the PI controller is the simplest to realize and; hence, still most widely used. However, it suffers from a drawback of steady state amplitude and phase error, if implemented in a stationary frame (SF). Using the synchronous reference frame approach, first ac quantities are converted to dc and then the PI regulator is used to eliminate the steady-state error as dc compensators. Nevertheless, it is not so straightforward to apply it for the single-phase case as in the case of three-phase systems. A fictitious orthogonal phase has to be generated from the real signal to transform stationary signals to SRF [18,19]. The proportional resonant (PR) compensator is an attractive alternative, which shows an excellent steady state performance due to infinite gain at the ac frequency, in the SF of implementation. However, the full usability of the theoretical concept is not possible in a digital implementation, especially in the case of fixed point digital signal processors (DSPs). Moreover, sensitivity to frequency variation and exponentially decaying transient responses are also major drawbacks of such a controller [20]. Lossless LC filter is ideal to suppress pulse width harmonic, due to efficiency concern in spite of the fact that it poses some serious stability threats at the resonant frequency. Multi-loop structures with the inner current