Input-Output Linearization of a Single-Phase Active Multilevel Rectifier in D-Q Synchronous Reference Frame

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Abstract — A control scheme constituted by a nonlinear state feedback current controller and a PI voltage controller for a single-phase active multilevel rectifier is designed. The control is based on the system modeled in the d-q synchronous reference frame. Through input-output linearization theory a current controller that decouples the d-q components is obtained. Stability of zero dynamics is verified. Due to that the internal dynamics contains variables of interest; an external control loop by means of a PI controller connected in cascade with the current loop in the d-axis is designed to regulate its behavior. This control scheme achieves fast regulation of the DC bus voltage without steady state errors, high power factor, low harmonic content and robustness in face of parametric variations. The presented control scheme is verified by simulations on a switched model.

Keywords—AC-DC power conversion, D-Q Synchronous Reference Frame, Input-Output Linearization.

I. INTRODUCTION

The use of noncontrolled rectifiers causes well known problems as low power factor, AC mains current distortion and lack of DC bus voltage regulation before perturbations as voltage sags. In [1] a Single-Phase Active Multilevel Rectifier (SPAMR) is presented, this topology improves the power factor (PF) and decreases current total harmonic distortion (THD), using an output power estimator the power factor (PF) and indirect regulation of the DC bus voltage. If voltage sags ride-through capability in the SPAMR is considered, voltage sags are not contemplated. Besides, in [4] voltage sags ride-through capability in the SPAMR is considered, helped by a selector, the gains of a PI voltage controller can be switched when a sag is detected, however this solution implies the design of different values of gains for each different value of sag. In [5] a partial input-output feedback linearization of the SPAMR is proposed using a continuous form of the discontinuous model introduced in [1], as a result a current controller indirectly commands the DC bus voltage, however the reference current is determined by means of an asymptotic estimator, the proposed solution obviates the output power estimator. In [6] several flatness-based current controllers for a three-phase PWM boost rectifier are compared, exploiting flatness of the model, five stabilization concepts are obtained and the reference current is estimated by a reduced order load observer considering parameter uncertainty. In [7] a linear PI current control is obtained performing the d-q single phase transform to AC mains current equation achieving zero steady state errors and locally decoupling the d-q components. In this paper a mathematical model of the rectifier in the d-q coordinates is presented and used to derive the control scheme. Based in input-output linearization theory, a state feedback current control that decouples the d-q components is obtained. Performing a transformation, internal stability of the system is shown to be stable, however reference current may be precalculated using the nominal parameters of the system and load resistance, yet this type of indirect DC bus voltage control is very sensitive to model uncertainties. To overcome this problem, implementation of a cascaded PI controller connected on the d-axis of the current loop is proposed, which happens to be an external control loop, completing the control scheme structure. In contrast with [1], [4] y [5] this control strategy does not need the knowledge of load current, therefore no estimator or measurement of load current is needed. The single phase d-q transformation allows independent control of magnitude and phase of AC mains current; this characteristic is exploited to achieve high PF and indirect regulation of the DC bus voltage.

II. CIRCUIT DESCRIPTION

The SPAMR is shown in Fig. 1, the circuit consists on a noncontrolled rectifier bridge and two bidirectional switches. A boost inductor is placed between AC mains and the rectifier bridge to minimize the current ripple. It also has two equal capacitors connected in series to obtain a neutral point. The functions of this rectifier are: to decrease current THD in AC mains and to correct PF. This is achieved by switching the switches properly, resulting in a three-level PWM voltage between ab terminals if the switches operate at the same time. On the other hand, when the switches operate independently, a five-level PWM pattern is generated.

![Fig. 1 Single-Phase Active Multilevel (SPAMR)](image-url)
VII. CONCLUSIONS

A model of the SPAMR is presented using the single-phase $d$-$q$ transformation; through this model a study on its input-output linearization is done and a nonlinear current controller that indirectly regulate the DC bus voltage is obtained. To provide robustness to the control scheme a linearization of the DC bus voltage equation is performed, thus a PI compensator connected in cascade to the $d$-axis provides the reference signal for the current controller. The control scheme is implemented in MATLAB/Simulink and tested in a switched model in software PSIM proving robustness, high PF, low THD and fast dynamic response. The use of the system modeled in the $d$-$q$ reference frame to design the control scheme is proved to be a good approximation of the real system which provides some attractive properties as independent control of $d$-$q$ axis and zero steady state errors. It is left open some important points such as a formal prove of stability in closed loop of the scheme showed in Fig. 3, the use of a five-level PWM technique to maintain balanced the output voltages and the experimental validation.

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REFERENCES