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Advantages of the passivity based control in dynamic voltage restorers for power quality improvement

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ABSTRACT

A better and feasible control strategy for dynamic voltage restorers (DVR) is presented in this paper: the passivity based control (PBC) allows a better compensation performance under transient and steady state operating conditions, and provides tracking with zero error of any reference for linear and nonlinear loads. The closed-loop source-DVR-PBC-load system is asymptotically stable at all operating points, with practically very slight constraints; its transient response is faster than with classical controllers, and does not present overshoots. These characteristics do not depend on source voltage disturbances, the kind of load, or parameter variations. The PBC uses less digital operations than the PI, and does not require *dq* transformations.

1. Introduction

Linear control has always been considered the standard solution to use in static power converters. The PI control and other classical linear controllers have been extensively used in the power quality field to perform online compensation of voltage or current disturbances, aiming to protect critical equipment. The PI control is normally used either in current or voltage loop schemes, but normally a zero steady state error is not fully achieved and the stability is restricted around a region of one operating point. In some power converter applications the system in fact moves the operating point constantly, and then a more suitable controller is needed.

One topology for power quality improvement which has received special attention is the dynamic voltage restorer (DVR) (Fig. 1), since it can protect voltage-sensitive equipment from sags and swells [1,2]. The DVR is basically a series compensator equipped usually with energy storage which is inserted between the source and the critical load. With the series scheme, several reported research works have focused only on the compensation of sags with active power (VR), and others are focused only on the active filter function (AF). Since the same series-scheme is used for both the AF and the VR functions, and the functions do not oppose each other, it is theoretically possible to apply both simultaneously; using the fundamental voltage component of the compensator for load voltage regulation, and its harmonic components to cancel the harmonic distortion. To compensate swells, the compensator usually must have regeneration means, a mechanism of dissipation, or the capacity of power absorption. One approach to avoid this is by regulating the load voltage making the compensator use only

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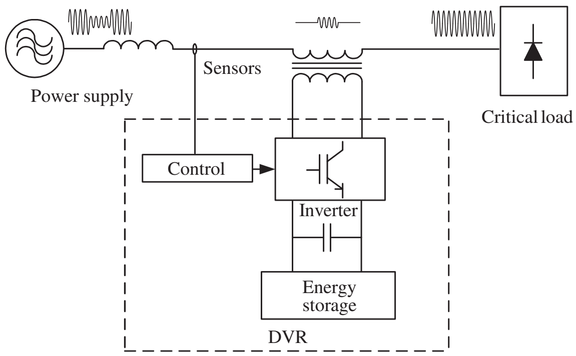

Fig. 1. Dynamic voltage restorer (DVR) topology.

reactive power during the process. By using reactive power, no energy is needed to be provided from or absorbed by the energy storage. Then, the equipment can also compensate swells without regeneration, power dissipation, or the overrating of the storage; and can compensate sags in loads with low power factor without using energy [3,4].

Many of the active power compensators used as active power filters or as dynamic voltage restorers which have been reported in the literature have frequently used the PI control due to its simplicity, but the resulting scheme actually requires additional algorithms to carry out the conversion of the signals involved in the control into *dc* quantities, to achieve a proper controller operation. The synchronous reference frame concept (*dq*) or the instantaneous reactive power theory (*pq*) are tools usually used for this purpose, or in some cases, additional modifications of the control scheme are used to improve performance, so that the PI can operate with ac signals [5–9], but adding complexity. In fact, even with such modifications, the tracking of the compensation references is not fully accomplished. Generally, they achieve zero steady state error for the fundamental component, but not so for harmonics. Both conditions are necessary if, for instance, a DVR is pretended to be used simultaneously with the active filter function.

An important and crucial stage of a DVR is its control scheme. The use of PI-based control laws in DVR systems actually imposes a very limited range of stability, due to its well-known characteristics which are valid around one operating point. The DVR evidently requires a control which provides better performance, since the possibility of significant changes in the operating point is always present due to load changes (in the active and reactive power ratings, and in linearity), by parameter variations, by changes in the voltage harmonic distortion of the power source, and especially by the compensation of deep sags or swells (which can be either with the classical in phase compensation or with another phase). The sag is defined as a decrement from 0.1 p.u. up to 0.9 p.u. of the nominal rms value of the source voltage which can have a duration from half a cycle up to 1 min. The swell is defined in a similar way but represented by the raise from 1.1 p.u. to 1.8 p.u. with respect to the nominal value [10,11].

A number of advantageous automatic control schemes can be currently found in the literature which could be explored to fulfill the control requirements of the DVR, such as H-∞, fuzzy logic [12], back-stepping [13], sliding mode [14], and passivity based control [15,16], among others. In the present paper, the passivity based controller (PBC) is proposed to be applied as one solution to overcome the aforementioned control problems of the DVR. This strategy has been applied in power converter applications [17–21]. It has also been applied in a matrix converter voltage compensator [22], but without formal analytical justifications about its model, behavior, and under general circumstances. The main contribution of this paper is the presentation of a complete formal justification of the PBC for DVR compensators. The importance of this analysis lies in the feature that it is carried out including real parameters, such as the LC filter losses and the line impedance, as well as considering a generalized model which includes both linear and nonlinear loads. Regarding the operation, load changes and the existence of severe disturbances are considered. As a result, simple and general stability conditions are stated and error convergence to zero is guaranteed. In addition, the important topic of practical implementation issues has also been approached. In summary, a rather general analysis is presented which is valid for any of the operating points of the system.

As will be proven, with the PBC as a controller of the DVR, zero steady state error in the tracking of any reference signal can be achieved. It provides a faster transient response than PI controllers and does not generate overshoots. Furthermore, the closed loop source-DVR-PBC-load set is asymptotically stable at all possible operating points, which allows severe changes in it, and the load can be linear or nonlinear at any power rating. The conditions to fulfill stability are very simple, in contrast to the resultant constraints with classical controllers. Besides, the computational load associated with its digital operations is low, the tuning is simple and does not require transformations to the synchronous reference frame.

The benefits of the PBC applied to the dynamic voltage restorer are verified with analyses and simulations, observing the steady state error, the settling time, the output to input response, the number of sensors required, the computation processing load, the tuning, and the stability. Since the PI control has been extensively and classically used in the operation of DVRs, a comparison of the performance of the PBC with respect to the PI is also presented to validate the obtained advantages and improvements.