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A FUZZY BASED SLIDING MODE CONTROLLER DESIGN FOR A VOLTAGE REGULATED BOOST CONVERTER

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ABSTRACT

This paper proposes the implementation of a fuzzy based robust sliding model control design to obtain voltage regulation in a boost converter with high dc gain. The proposed controller has an inner loop based on sliding- mode control whose sliding surface is defined for the input inductor current. The current reference value of the sliding surface is modified by a fuzzy logic controller in an outer loop that operates over the output voltage error.Robustness is analyzed in depth taking into account the parameter variation related with the operation of the converter in different equilibrium points. Simulations and experimental results are presented to validate the approach for a 20–100-W boost converter stepping-up a low dc voltage (15–25-V dc) to a 400-V dc level.

Keywords: Fuzzy, SMC, VGBC

I INTRODUCTION

The need of developing an ad-hoc electronic equipment for power distributed systems, electric vehicles, and energy backup architectures, which are supplied by batteries, fuel cells, photovoltaic modules, or other dc sources is prompting engineers to use a 400-V dc bus as a core of the distribution. Examples of this are residential micro grids, hybrid vehicles, telecom installations, and data centers among others. Nonstandard dc–dc converters with the capability to step-up a low-dc voltage to a high-voltage level are required since the canonical boost converter has severe constraints to obtain gains higher than ten. Although both transformer-based and transformer-less topologies can be proposed, the requirements in power density, weight, size, and cost of the new devices make the transformer-less topologies a more interesting choice. Among these topologies, single-switch converters derived from the conventional boost converter, such as quadratic boost and the cubic boost converters can be attractive solutions since they can operate within a safe duty cycle range avoiding modulator saturation.

Besides, the quadratic boost converter shows a better tradeoff between efftciency and duty cycle operating range than the cubic boost converters because of the higher com- plexity and number of components of the cubic structure. Moreover, robust control of the boost converter has be- come an attractive research fteld in past years due to the non minimum phase nature of its control to output transfer function, which results from the linearization of the converter averaged equations around the steady state and whose parameters have a high degree of uncertainty. To solve this problem, different methods have been pro- posed such as robust gain scheduled control, robust linear quadratic regulator (LQR) control , robust nonlinear adap- tive control , and internal mode control, among others. Although the quadratic boost converter is a boost-derived converter topology, its structure has a higher complexity and so far few solutions have been reported, all existing proposals being based on pulse width modulation. The ftrst approaches were based on cascade control with an inner current loop, which is obtained using average cur- rent control or current programmed control , and an outer voltage loop that regulates the output voltage using a fuzzy logic controller whose design does not consider the uncertainty in the converter parameters. A more recent proposal uses the same scheme to regulate the output voltage of the quadratic boost converter, but tackles the control problem using reduced redundant power process- ing.

The aim of this paper is to tackle the problem of regulat- ing the output voltage in the quadratic boost converter operating in continuous conduction mode with high duty cycle values. This latter constraint imposes the use of a hysteretic comparator to perform the required modulation in the control loop without risk of saturation.

Hysteresis-based controllers are increasingly used to im- plement voltage regulation modules since they exhibit, at the expense of a variable switching frequency, a fast dynamic response in a wide regulation range with high duty cycle values. To design accurately this type of con- trollers in switching power converters, three techniques have been compared in : 1)describing function, 2) Tsyp- kin’s method, and 3) sliding-mode control theory. It has been proved that the sliding-mode approach is the best solution and that it also allows a comprehensive descrip- tion of the converter dynamics in the time domain. The sliding-mode control theory has been successfully applied in power switching converters, its applications ranging from voltage regulation in dc–dc power converters , syn- thesis of canonical elements for power processing, and tracking of time varying current references, to control of the inrush current in the converter startup .

The sliding-mode control is used in this approach to de- sign a hysteresis-based quadratic boost converter that provides a regulated output voltage of 400-V DC from an input voltage in the range of 15–25-V DC. In this paper, the deftnition of a simple sliding surface for the regulation of the input inductor current yields the indirect control of the output voltage by forcing the mentioned current to reach a desired reference value in the equilibrium state. Therefore, if the current reference in the sliding surface is modifted by the action of a fuzzy logic controller, it will be possible to regulate the output voltage to a desired level. Thus, the proposed controller consists of two loops, namely, an inner loop for input inductor current control and an outer loop establishing the reference for the in- ner loop to ensure the output voltage regulation. Hence, to cope with the parameter uncertainty, a robust loop shaping method is chosen to synthesize the fuzzy logic controller with robustness constraints.

II SLIDING MODE CONTROL THEORY

In control system, sliding mode control, or SMC, is a non- linear control method that alters the dynamics of a nonlin- ear system by application of a discontinuous control signal that forces the system to "slide" along a cross-section of the system's normal behavior. The state-feedback control law is not a continuous function of time. Instead, it can switch from one continuous structure to another based on the current position in the state space.

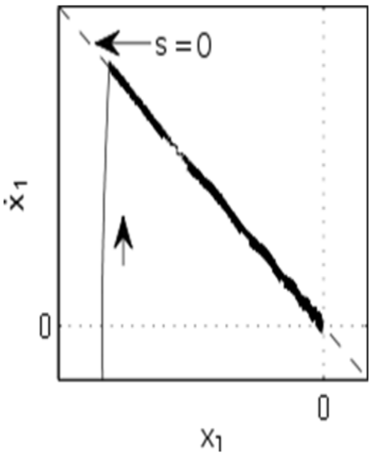

Figure 1. Phase plane trajectory of a System being stabilized by a sliding mode controller. After the initial reaching phase,the system states "slides" along the line.

The particular surface is chosen because it has desirable reduced-order dynamics when constrained to it. In this case, the surface corresponds to the ftrst-order LTI system, which has an exponentially stable origin. ing mode control is a variable structure control method. The multiple control structures are designed so that tra- jectories always move toward an adjacent region with a different control structure, and so the ultimate trajectory will not exist entirely within one control structure. In- stead, it will slide along the boundaries of the control structures. The motion of the system as it slides along these boundaries is called a sliding mode and the geo- metrical locus consisting of the boundaries is called the sliding (hyper) surface.

Theory, any variable structure system, like a system un- der SMC, may be viewed as a special case of a hybrid dynamical system as the system both flows through a continuous state space but also moves through different discrete control modes.

The sliding mode along the surface commences after the finite time when system trajectories have reached the surface. In the theoretical description of sliding modes, the system stays confined to the sliding surface and need only be viewed as sliding along the surface. However, real implementations of sliding mode control approximate this theoretical behavior with a high-frequency and generally non-deterministic switching control signal that causes the system to "chatter" in a tight neighborhood of the sliding surface. In fact, although the system is nonlinear in general, the idealized (i.e., non-chattering) behavior of the system in when confined to the surface is an LTI system with an exponentially stable origin.

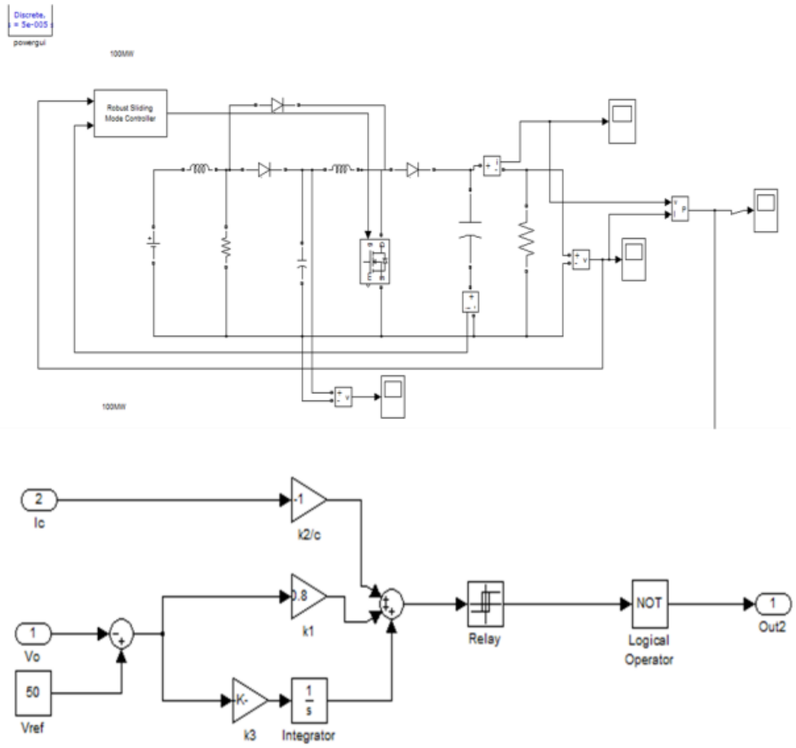

Figure 2. The Matlab / Simulink Model Of Pi Based Sliding Model Control Of Boost Converter

Intuitively, sliding mode control uses practically infinite gain to force the trajectories of a dynamic system to slide along the restricted sliding mode subspace. Trajectories from this reduced-order sliding mode have desirable properties (e.g., the system naturally slides along it until it comes to rest at a desired equilibrium). The main strength of sliding mode control is its robustness. Because the control can be as simple as a switching between two states (e.g., "on"/"off" or "forward"/"reverse"), it need not be precise and will not be sensitive to parameter variations that enter into the control channel. Additionally, because the control law is not a continuous function, the sliding mode can be reached infinite time (i.e., better than asymptotic behavior). Under certain common conditions, optimality requires the use of bang–bang control; hence, sliding mode control describes the optimal controller for a broad set of dynamic systems.

One application of sliding mode controller is the control of electric drives operated by switching power converters. Because of the discontinuous operating mode of those converters, a discontinuous sliding mode controller is a natural implementation choice over continuous controllers that may need to be applied by means of pulse-width modulation or a similar technique of applying a continuous signal to an output that can only take discrete states. Sliding mode control has many applications in robotics. In particular, this control algorithm has been used for tracking control of unmanned surface vessels in simulated rough seas with high degree of success. Sliding mode control must be applied with more care than other forms of nonlinear control that have more moderate control action. In particular, because actuators have delays and other imperfections, the hard sliding-mode- control action can lead to chatter, energy loss, plant damage, and excitation of un-modeled dynamics. Continuous control design methods are not as susceptible to these problems and can be made to mimic sliding-mode controller.

III MATLAB SIMULATION & RESULTS

In order to verify the effectiveness of the proposed inverter and justify its operation, a 150-W prototype is implemented in the laboratory. The implemented pro- to type is shown in Fig. 5. In this section, the design procedure and experimental results of this prototype are presented. The controllers of the dc–dc and dc–ac stages of the proposed inverter are implemented in an AVR micro controller.

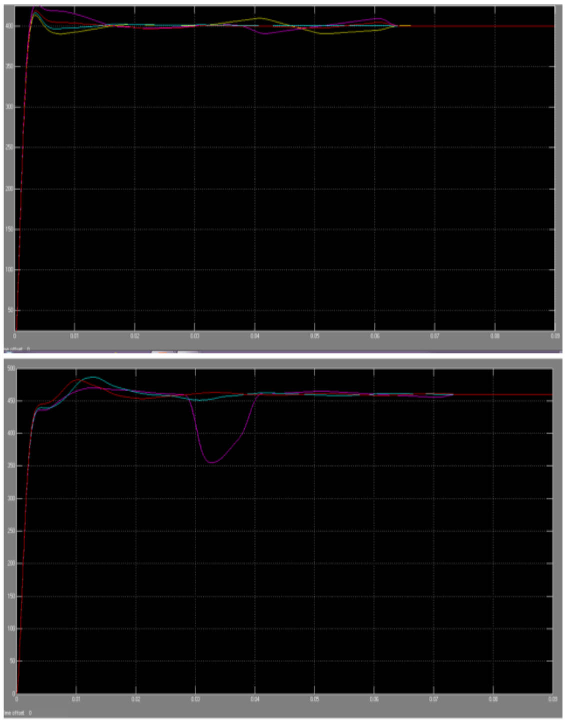

Figure 3. Output Waveforms of Pi Based Sliding Model Control of Boost Converter.

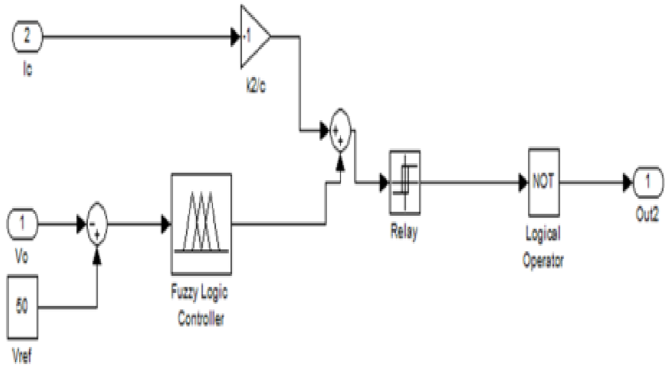

Figure 4. Proposed Fuzzy Based Sliding Mode Control Model

In commercial appliances like heating ventilation and air conditioning (HVAC) systems

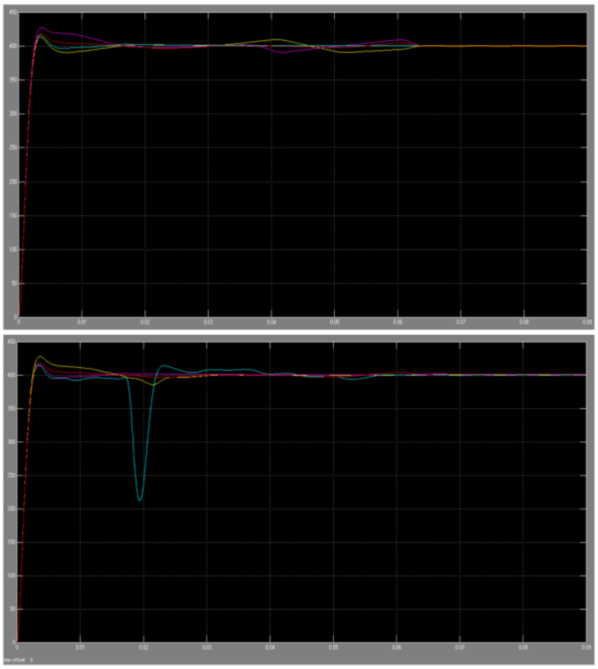

Figure 5. output waveforms of fuzzy based sliding mode control boost converter model

IV CONCLUSION

The settling response of the fuzzy controller is faster than the PI controller with lesser disturbances. The design of fuzzy controller depends on the expert knowledge of the boost converter and is tuned using trial and error method as a result faster response and reduced steady state error is obtained.

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