

Robust LMI control of a boost converter supplying constant power loads

Control LMI robusto de un convertidor Boost que alimenta cargas de potencia constante

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Abstract—This paper presents the synthesis of a robust LMI-based controller for a boost converter supplying a constant power load (CPL). The converter connects a DC bus to a CPL requiring regulated output voltage. In the absence of control, the system may exhibit unstable behavior due to the destabilizing characteristics of the CPL. The proposed robust linear controller stabilizes the system and provides output-voltage regulation while accounting for parametric uncertainties. Specifically, the controller synthesis imposes prescribed constraints on closed-loop pole location, control effort, and disturbance attenuation. The controller is evaluated using a switched boost-converter model implemented in PSIM under load-power and input-voltage disturbances. Simulation results show settling times of approximately 2 ms for the load disturbance and 1.5 ms for the input-voltage disturbance, together with improved damping compared with the conventional LQR controller. These simulation results demonstrate the effectiveness of the proposed LMI-based controller in maintaining output-voltage regulation under the evaluated operating conditions.

Index Terms— Boost Converter; Constant Power Load (CPL); Linear Matrix Inequalities (LMI); Robust Control; Stability Analysis.

Resumen—Este trabajo presenta la síntesis de un controlador robusto basado en LMI para un convertidor elevador que alimenta una carga de potencia constante (CPL). El convertidor conecta un bus de CC a una CPL que requiere una tensión de salida regulada. En ausencia de control, el sistema puede presentar un comportamiento inestable debido a las características desestabilizadoras de la CPL. El controlador lineal robusto propuesto estabiliza el sistema y proporciona regulación de la tensión de salida teniendo en cuenta incertidumbres paramétricas. Específicamente, la síntesis del controlador impone restricciones prescritas sobre la ubicación de los polos de lazo cerrado, el esfuerzo de control y la atenuación de perturbaciones. El controlador se evalúa mediante un modelo conmutado del convertidor boost implementado en PSIM ante perturbaciones de potencia de carga y tensión de entrada. Los resultados de simulación muestran tiempos de establecimiento de aproximadamente 2 ms ante la perturbación de carga y 1.5 ms ante la perturbación de tensión de entrada, junto con un mayor amortiguamiento en comparación con el controlador LQR

convencional. Estos resultados de simulación demuestran la efectividad del controlador basado en LMI para mantener la regulación de la tensión de salida bajo las condiciones de operación evaluadas.

Palabras claves—Análisis de Estabilidad; Carga de Potencia Constante (CPL); Control Robusto; Convertidor Boost; Desigualdades Matriciales Lineales (LMI).

I. INTRODUCTION

SWITCHED-MODE POWER SUPPLY power supplies (SMPS) constitute fundamental components in contemporary power conversion and conditioning systems. Specifically, DC-DC converters perform essential voltage and power-level adaptation in critical applications, including electric vehicles, telecommunications infrastructure, data centers, and DC microgrids. Within this class of topologies, the boost converter is widely used to elevate the input voltage, for example, from renewable energy sources or intermediate bus architectures, to meet the requirements of downstream loads and subsystems. In DC microgrid applications, characterized by distributed DC sources and loads, robust controller design is particularly relevant due to system disturbances, parametric uncertainties, and, critically, the destabilizing influence of constant power loads (CPLs). These loads exhibit a negative incremental impedance characteristic, which degrades voltage-regulation performance and can destabilize the DC-bus voltage [1].

Controlling boost converters using conventional methods (e.g., linearized PI compensation around an operating point) is challenging because of their non-minimum-phase nature, characterized by a right-half-plane zero (RHPZ). This imposes fundamental constraints on the closed-loop bandwidth and may degrade transient-response performance, particularly in applications requiring stringent voltage regulation. Furthermore, the inherent nonlinearity/bilinearity of the averaged model is compounded by dynamic interaction with

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constant power loads (CPLs). The negative incremental impedance of CPLs reduces the effective damping of the system, inducing pole migration toward unstable regions and potentially destabilizing the DC bus in the absence of appropriately designed compensation strategies [2]–[4]. In light of these difficulties, several advanced control strategies have been investigated, including passivity-based control/IDA-PBC with Hamiltonian foundations, higher-order sliding-mode control, optimal and robust control (LQR/ H_∞), and predictive or fuzzy approaches. In buck and buck–boost converters supplying CPLs, PBC approaches have demonstrated structural robustness and Lyapunov stability, with improved responses to sudden load changes compared with classical PI control [5].

Robust designs based on LQR and optimal formulations for PWM/bilinear converters have also been reported, improving disturbance attenuation and performance in the presence of parametric variations [6]–[8]. Among nonlinear strategies, [9] proposes a state-feedback-linearization control law applied to the averaged boost-converter model with a CPL. This approach transforms the inductor-current dynamics into a virtual linear loop (source–resistor–inductor) to regulate the output voltage despite the negative incremental impedance of the load. The scheme redesigns the internal current loop and reports transient improvements over linear regulators. Furthermore, specific reviews of CPLs emphasize their destabilizing effect and the need for control schemes with formal stability and performance guarantees [10].

In this context, control based on Linear Matrix Inequalities (LMIs) has gained relevance because stability, robustness, and performance requirements—such as pole-region constraints, control-effort bounds, and norm-based disturbance attenuation—can be formulated as convex optimization problems. This framework also enables polytopic uncertainties and multiple design objectives to be addressed systematically. LMI-based approaches for non-minimum-phase converters have shown how stability regions and physical constraints, such as actuator limits, can be incorporated directly into the controller synthesis, while robust LMI controllers with explicit control bounds have also been proposed for DC–DC converter structures [10], [11]. More recently, LMI-based voltage controllers have been developed for DC microgrids considering CPL uncertainty, reference variations, input disturbances, and integral action to ensure zero steady-state error [1].

A closely related contribution is the work of Fuentes et al. [12], which develops an LPV/LMI framework for classical buck, boost, and buck–boost converters under parameter variations and operating conditions involving constant-power loads. Their methodology considers robust and gain-scheduled state-feedback control, H_∞ disturbance attenuation, D-stability constraints for transient-performance requirements, control-signal limitations, and integral action for reference tracking. Therefore, LMI-based robust control, integral action, disturbance attenuation, pole-location constraints, and control-signal limitations for DC–DC converters with CPLs have already been addressed in the literature.

Accordingly, the present work does not claim novelty from the isolated use of these LMI-based design ingredients. Instead,

it focuses specifically on a boost converter supplying a CPL and adopts a polytopic uncertain representation associated with the considered CPL-power and input-voltage operating ranges. A single fixed state-feedback gain is obtained by enforcing the LMI conditions at the vertices of the resulting uncertainty polytope. Within the same synthesis problem, the formulation simultaneously considers quadratic stability, H_∞ disturbance attenuation, prescribed closed-loop pole-location constraints, integral action for zero steady-state tracking error, and a bound on the incremental control action associated with the duty-cycle variation. The resulting controller is evaluated using a switched converter model implemented in PSIM and is compared with a conventional full-state LQR controller under load and input-voltage perturbations. Thus, the contribution of this work is delimited to the particular fixed-gain polytopic formulation adopted for the considered boost-converter operating domain and its simulation-based assessment, rather than to the application of LMI-based robust control to DC–DC converters with CPLs itself.

The remainder of this paper is organized as follows. Section II presents the methodology, including the switched model of the boost converter supplying a CPL, its linearized representation, the treatment of parametric uncertainties, and the LMI-based control-design requirements. Section III describes the controller design and presents the PSIM simulation results used to assess the proposed strategy. Finally, Section IV summarizes the main conclusions, limitations, and directions for future work.

II. METHODOLOGY

To address the control problem of step-up DC–DC switched converters supplying constant power loads, this work proposes the use of a robust control strategy based on linear matrix inequalities (LMIs). The approach begins by modeling the uncertainties inherent to the converter, which may arise from variations in system matrix parameters or time-varying variables. These uncertainties are subsequently represented as a convex polytopic set. Once the uncertainty model is established, a robust multi-objective controller is designed by formulating LMI-based constraints, allowing for guaranteed disturbance rejection and pole placement within a specified region. The following sections present these aspects in detail.

A. Mathematical Formulation

Fig. 1 shows the schematic of a boost converter, which consists of a single MOSFET (Q), a DIODE (D), and the passive elements L and C . The circuit is powered by a direct current source (V_g), which can be a solar panel, a battery or simply the rectified grid. The constant power load is represented by a dependent source that relates the constant power over the output voltage. The state variables are the current inductor i_L and the voltage in the capacitor v_C ; therefore, the state vector corresponds to $x(t) = [i_L(t) \ v_C(t)]^T$.

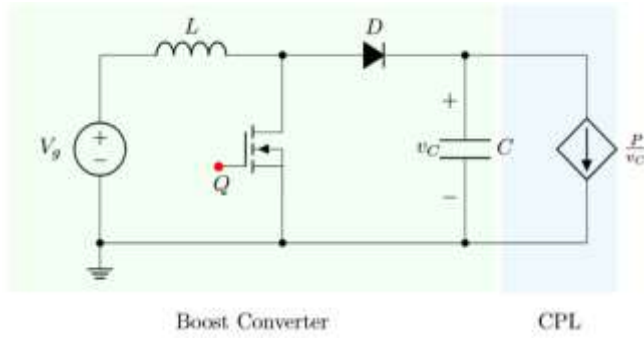


Fig. 1. Schematic circuit of a boost converter feeding a CPL load.

The MOSFET (Q), is periodically turned on and off by a control signal $u(t) = \{0, 1\}$, since PWM modulation is considered and the converter operates in continuous conduction mode (CCM). The dynamics during the T_{on} and T_{off} intervals can be written as shown in (1).

$$\dot{x}(t) = A_i x(t) + B_{u_i} u(t) \quad i = (1, 2) \quad (1)$$

Being,

$$\begin{aligned} A_1 &= \begin{bmatrix} 0 & 0 \\ 0 & -\frac{P}{C v_c^2} \end{bmatrix} & B_{u_1} &= \begin{bmatrix} \frac{V_g}{L} \\ 0 \end{bmatrix} \\ A_2 &= \begin{bmatrix} 0 & -\frac{1}{L} \\ \frac{1}{C} & -\frac{P}{C v_c^2} \end{bmatrix} & B_{u_2} &= \begin{bmatrix} \frac{V_g}{L} \\ 0 \end{bmatrix} \end{aligned} \quad (2)$$

where A_i and B_{u_i} ($i \in \{1, 2\}$) are the state matrices and the input vector for T_{on} and T_{off} , respectively. Note that the converter load is represented by the expression $\frac{P}{v_c}$, where P is the constant power that can be supplied to a load. It is well established that constant-power loads display positive instantaneous impedance yet negative incremental impedance. The standard approach models the CPL as a negative incremental resistance, but the approximation holds only for small-signal deviations around the operating point. (1) can be written compactly in terms of $u(t)$ as shown in (3).

$$\dot{x}(t) = A_2 x(t) + B_{u_2} \left[\begin{matrix} (A_1 - A_2)x(t) + \\ (B_{u_1} - B_{u_2}) \end{matrix} \right] u(t) \quad (3)$$

Combining (2) and (3), the converter dynamics read:

$$\begin{aligned} \frac{di_L}{dt} &= -(1-u) \frac{v_c}{L} + \frac{V_g}{L} \\ \frac{dv_c}{dt} &= -(1-u) \frac{i_L}{C} + \frac{P}{C v_c} \end{aligned} \quad (4)$$

Using state-space averaging [13], the switched model of (4) is approximated by substituting the binary signal $u(t)$ with its

duty cycle $d(t)$ and replacing the state vector by its values averaged over a switching period. The linear small-signal averaged model is obtained by moving the equilibrium to the origin and expressing state and duty-cycle variations around their equilibrium values, i.e.:

$$x(t) = x^* + \tilde{x}(t) \quad (5)$$

$$d(t) = D_d + \tilde{d}(t)$$

with x^* the equilibrium state and D_d the duty-cycle equilibrium value. Hence, according to (5), the boost converter's equilibrium state is presented in (6).

$$x^* = \begin{bmatrix} i_L^* \\ v_c^* \end{bmatrix} = \begin{bmatrix} \frac{P}{V_g} \\ \frac{V_g}{(1-D_d)} \end{bmatrix} \quad (6)$$

Using (4) and (5), the converter dynamics can be linearized as shown in (7).

$$\dot{\tilde{x}}(t) = A \tilde{x}(t) + B_u \tilde{d}(t) + B_\omega \tilde{\omega}(t) \quad (7)$$

$$\tilde{z}(t) = C_z \tilde{x}(t) + D_{zd} \tilde{d}(t) + D_{z\omega} \tilde{\omega}(t)$$

Where $\tilde{x}$, $\tilde{d}$, and $\tilde{\omega}$ denote the averaged incremental values of the state vector, duty cycle, and disturbance, i.e., $\tilde{x} = x - x^*$, $\tilde{d} = d - D_d$, y $\tilde{\omega} = [\Delta v_g \quad i_o]^T$ with the matrices shown in the (8).

$$A = \begin{bmatrix} 0 & -\frac{D'_d}{L} \\ \frac{D'_d}{C} & -\frac{P D_d'^2}{C V_g^2} \end{bmatrix} \quad B_u = \begin{bmatrix} \frac{V_g}{L D_d'} \\ \frac{P}{C V_g} \end{bmatrix} \quad (8)$$

$$\begin{aligned} B_\omega &= \begin{bmatrix} \frac{1}{L} & 0 \\ 0 & \frac{1}{C} \end{bmatrix} & C_z &= [0 \quad 1] & D_{zd} &= [0] \\ D_{z\omega} &= [0 \quad 0] \end{aligned}$$

It should be noted that Δv_g represents input voltage disturbance, and i_o represents load current disturbance. To guarantee zero steady-state error in $v_c(t)$, a new state $\tilde{x}_3(t)$ is introduced as the integral state, as presented in (9).

$$\tilde{x}_3(t) = \int_0^t (V_{ref} - v_c(t)) d\tau \quad (9)$$

Where V_{ref} represents the reference voltage. This new state ensures $\lim_{t \rightarrow \infty} v_c(t) = V_{ref}$.

B. Uncertain polytopic representation of the Boost Converter with CPL

Considering that certain converter parameters are uncertain, some terms in expression (7) are known only within an

operating range. To ensure that the control requirements are met for any admissible parameter value, the vector ρ is defined which groups the uncertain terms, such that $A(\rho)$ and $B_u(\rho)$ depend linearly on ρ [8]. Considering P and D_d as uncertain parameters, the model's dependence lies exclusively in A and B_u . Since this dependence is nonlinear, two auxiliary uncertain variables are introduced to enforce linearity [9]. Accordingly, the vector of uncertain parameters ρ is defined as shown in (10).

$$\rho = \left\{ D'_d \quad P \quad PD_d'^2 \quad \frac{1}{D'_d} \right\} \quad (10)$$

Hence, ρ is confined to a polytope with $L = 2^4$ vertices, whose coordinates are limited by (11).

$$\begin{aligned} \rho_1 &\in [\rho_{1min}, \rho_{1max}] = \{D'_{dmin}, D'_{dmax}\} \\ \rho_2 &\in [\rho_{2min}, \rho_{2max}] = \{P_{min}, P_{max}\} \\ \rho_3 &\in [\rho_{3min}, \rho_{3max}] = \{P_{min}D_{dmin}^2, P_{max}D_{dmax}^2\} \\ \rho_4 &\in [\rho_{4min}, \rho_{4max}] = \left\{ \frac{1}{D'_{dmax}}, \frac{1}{D'_{dmin}} \right\} \end{aligned} \quad (11)$$

Although only two uncertain parameters are chosen, $\rho \in \mathbb{R}^4$ is introduced so that $A(\rho)$ and $B_u(\rho)$ are linear in ρ , as shown in (12).

$$\begin{bmatrix} \dot{i}_L \\ \dot{\tilde{v}}_C \\ \dot{\tilde{x}}_3 \end{bmatrix} = \begin{bmatrix} 0 & -\frac{\rho_1}{L} & 0 \\ \frac{\rho_1}{C} & -\frac{\rho_3}{CV_g^2} & 0 \\ 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} \tilde{i}_L \\ \tilde{v}_C \\ x_3 \end{bmatrix} + \begin{bmatrix} \frac{V_g \rho_4}{L} \\ \frac{\rho_2}{CV_g} \\ 0 \end{bmatrix} \tilde{d}(t) \quad (12)$$

It is worth noting that the uncertain representation adopted here differs from the LPV formulation reported in [12]. For the CPL case, [12] parameterizes the boost-converter model using six bounded time-varying quantities, namely D_{on} , P , $\frac{1}{v_o}$, v_o , i_L , and V_{in} , resulting in polynomial parameter dependencies in the state-space matrices. In the present formulation, the uncertainty description is constructed specifically from the selected CPL-power and input-voltage-related operating ranges. Auxiliary uncertain variables are introduced so that the resulting system matrices can be represented affinely with respect to the uncertainty vector, and robust feasibility is subsequently imposed at the vertices of the resulting polytope. Therefore, the distinction lies in the uncertainty embedding adopted for the boost-CPL model and in the resulting vertex-based fixed-gain synthesis, rather than in the use of LMI-based robust control itself.

The following section details the control constraints for the above uncertain models.

C. LMI Design Constraints

This subsection presents several LMI constraints employed in the proposed robust control for a boost converter with a

constant-power load (CPL). To determine the state-feedback gain vector K with desirable dynamic performance, constraints are imposed on quadratic stability, control effort, closed-loop pole placement, and disturbance attenuation, taking into account the parametric uncertainties specified in (10). These specifications, drawn from [8], [14], [15] and [16], are formalized in the following theorems.

Theorem 1: System (7) is stabilizable via state feedback $u(t) = Kx(t)$ and satisfies the transfer function of disturbances $\omega(t)$ to outputs $z(t)$ $\frac{\|z\|_2}{\|\omega\|_2} < \gamma$, if and only if there exists a symmetric positive-definite matrix $W = W^T > 0 \in \mathbb{R}^{n \times n}$ and a matrix $Y \in \mathbb{R}^{m \times n}$ such that the matrix inequality in (13) is satisfied.

$$\begin{bmatrix} AW + WA^T + B_u Y + Y^T B_u^T & B_\omega & W^T C_y^T + Y^T D_{yu}^T \\ B_\omega^T & -\gamma I & 0 \\ C_y W + D_{yu} Y & 0 & -\gamma I \end{bmatrix} < 0 \quad (13)$$

where a controller for such state feedback is given by $K = YW^{-1}$. This result can be directly extended to polytopic uncertain systems [15]-[16].

An additional key constraint is pole placement. The closed-loop poles are required to lie within a prespecified region [8], [14]-[16], which guarantees a decay rate no less than α , a minimum damping ratio $\zeta = \sin(\theta)$, and an upper bound on the natural frequency $\omega_0 = r$; this, in turn, limits the maximum overshoot and the rise and settling times.

Theorem 2: The poles of the closed-loop system (7) with $u(t) = Kx(t)$ lie in the prescribed region $S(\alpha, r, \theta)$ if there exist a symmetric positive-definite matrix W and a matrix Y satisfying (14), (15) and (16).

$$AW + WA^T + B_u Y + Y^T B_u^T + 2\alpha W < 0 \quad (14)$$

$$\begin{bmatrix} \cos(\theta)(AW + WA^T + B_u Y + Y^T B_u^T) & \sin(\theta)(AW - WA^T + B_u Y - Y^T B_u^T) \\ \sin(\theta)(-AW + WA^T - B_u Y + Y^T B_u^T) & \cos(\theta)(AW + WA^T + B_u Y + Y^T B_u^T) \end{bmatrix} < 0 \quad (15)$$

$$\begin{bmatrix} -rW & WA^T + Y^T B_u^T \\ AW + B_u Y & -rW \end{bmatrix} < 0 \quad (16)$$

Although the above restrictions allow for control with good dynamic performance, too high a gain K will induce saturation of the duty cycle and consequently deteriorate performance. Since the control signal for dc-dc converters corresponds to the incremental duty cycle, the control signal is limited to the range $[-D, 1 - D]$. To satisfy this requirement, the control input is constrained as stated in the following theorem.

Theorem 3: For system (7), the control effort satisfies $\|d(t)\|_2 < \mu$ for all $t \geq 0$ along the closed-loop trajectory, for any initial condition $x(0)$ in the $\varepsilon(W) := \{x: x^T W^{-1} x \leq 1\}$, if the LMI (17) hold.

$$\begin{bmatrix} 1 & x(0)^T \\ x(0) & W \end{bmatrix} \geq 0 \quad \begin{bmatrix} W & Y^T \\ Y & \mu^2 I \end{bmatrix} < 0 \quad (17)$$

where again $K = YW^{-1}$.

The design of a robust control for a boost converter with CPL consists of solving inequalities (13)-(17) to find the matrix variables W and Y that minimize the H_∞ and γ that satisfy the pole placement constraints of the region $S(\alpha, r, \theta)$ and control signal limitation for all the extremes of the polytopic model (12).

Thus, the control synthesis reduces to the optimization problem shown in (18).

$$\begin{aligned} &\underset{W, Y}{\text{Minimize}} \quad \gamma && \text{under conditions} \\ &(13), (14), (15), (16) \text{ y } (17) && (18) \end{aligned}$$

For all $L = 2^4$ vertices.

Solving this convex optimization problem (18) produces a controller K that satisfies the specified constraints. The problem can be solved in MATLAB using the YALMIP toolbox, which connects to standard SDP solvers (e.g., SeDuMi, SDPT3, MOSEK).

III. CONTROL DESIGN AND SIMULATION RESULTS

This section presents the design and simulation-based validation of a robust LMI-based control strategy for regulating the output voltage of a boost converter supplying a constant power load (CPL), under the parametric uncertainty defined in (10). Table I lists the electrical parameters of the converter, whereas Table II compiles the synthesis settings used in the LMI constraints.

Using these specifications, the synthesis problem is solved numerically to obtain the state-feedback gain K .

The resulting controller is evaluated on a switched converter

TABLE I
BOOST CONVERTER PARAMETERS

Parameter	Value
V_g	12V
L	88μH
C	200μF
P_o	57.6W
V_{ref}	24V
$[D'_{amin}, D'_{amax}]$	[0.3, 1]
$[P_{min}, P_{max}]$	[10, 100]W
f_s	100kHz

TABLE II
PARAMETERS CONSTRAINTS CONTROLLER LMI

Parameter	Value
θ	25°
α	500
μ	15
r	$\frac{2\pi f_s}{10}$

model implemented in PSIM. For benchmarking, the closed-

loop response is compared to that of a conventional state-feedback controller designed on the nominal plant and operating points. Based on the parameters in Table I, the uncertain variables ρ_3 and ρ_4 defined in (10) lie in the intervals [0.9, 100] and [1, 3.33], respectively.

The robust guarantees established by the LMI synthesis apply exclusively to the uncertainty domain defined by $P \in [10 \ 100]W$ and $D'_d \in [0.3 \ 1]$. Consequently, operating conditions outside these intervals are not covered by the theoretical robust stability and performance guarantees derived from the polytopic model. Simulations performed outside this domain are therefore interpreted only as stress tests intended to evaluate the extrapolation capability of the controller and not as verification of the LMI-certified robustness. To assess the guaranteed operating region, additional simulation scenarios within the prescribed uncertainty set are considered separately.

Using the values in Table II, the design targets a settling time $4/\alpha = 8 \text{ ms}$, a minimum damping ratio of $\zeta = 0.42$ ($\theta = 25^\circ$), and to keep the control effort within acceptable limits, a value of $\mu = 15$ was selected empirically using a trial-and-error procedure.

The optimization problem (18) is convex and is efficiently solved using Yalmip [17] in MATLAB version 2018. Using this procedure yields a globally optimal solution when the problem is feasible and promptly certifies infeasibility otherwise. The resulting state-feedback controller for the boost converter is given by (19).

$$K = [-0.2830 \quad -0.4224 \quad 604.0806] \quad (19)$$

Under this controller, the H_∞ norm from the output-current disturbance to the output voltage satisfies $\frac{\|z\|_2}{\|w\|_2} < \gamma = 2.4486$ (7.8 dB).

The proposed boost-converter controller with a CPL is evaluated using a switched model implemented in PSIM. Fig. 2 shows the simulation schematic. The schematic comprises a power stage and a control stage. The power stage implements the basic boost topology supplying a CPL, modelled as a dependent current source that enforces the nonlinear relationship $i_{load} = P/v_C(t)$.

The control stage is implemented through a linear combination of the control law shown in (20).

$$d(t) = -0.283i_L(t) - 0.4224v_C(t) + 604.0806x_3(t) \quad (20)$$

However, this law can be easily implemented using an analog circuit, as shown in Fig. 3.

To evaluate robustness and performance, the proposed robust LMI controller is benchmarked against a conventional full-state LQR designed on the nominal (uncertainty-free) plant. The state-feedback gain vector F_{LQR} is computed with MATLAB's `lqr` function using the cost (weighting) matrices Q_w and R_w specified in (21).

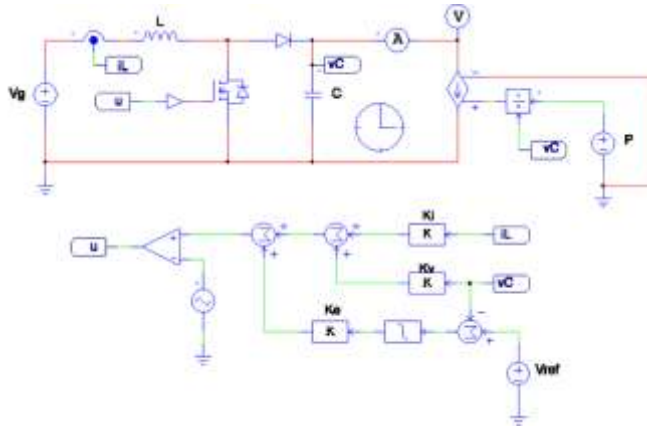


Fig. 2. PSIM schematic circuit of the boost converter feeding a CPL load.

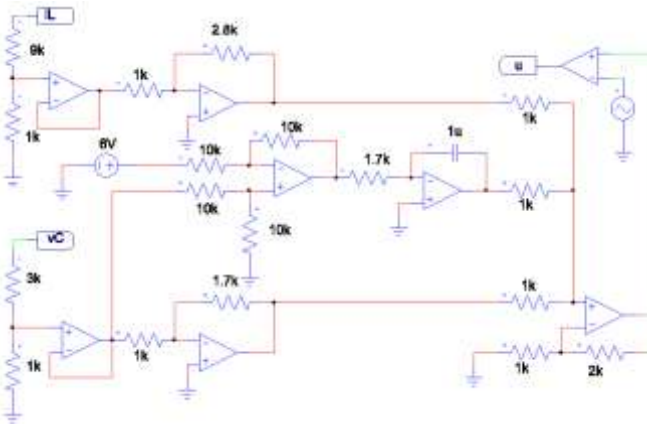


Fig. 3. Analog Circuit for Control Stage.

$$Q_w = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 10^8 \end{bmatrix} \times 10^{-6} \quad R_w = 1 \quad (21)$$

Hence, the LQR feedback gain F_{LQR} is given by expression (22).

$$F_{LQR} = [-0.0206 \quad -0.0222 \quad 100] \quad (22)$$

The closed-loop performance of the proposed controller is further assessed through stress-test scenarios extending beyond the uncertainty domain considered in the LMI synthesis. It should be emphasized that these scenarios extend beyond the uncertainty set used for controller synthesis. Therefore, the corresponding responses provide simulation-based evidence of controller performance under extrapolated operating conditions, but they do not constitute verification of the robust stability and performance guarantees associated with the prescribed uncertainty polytope.

Fig. 4 depicts the converter's output current i_o and capacitor voltage $v_c(t)$ when regulated by the conventional LQR (22) and by the proposed control law (19). The load current steps from 2.4 A to 7.4 A at 20 ms, corresponding to a power change from 57.6 W to 177.6 W, and returns to 2.4 A at 40 ms. Under the proposed controller, the $v_c(t)$ response settles in approximately 2 ms and exhibits greater damping than with the

classical LQR.

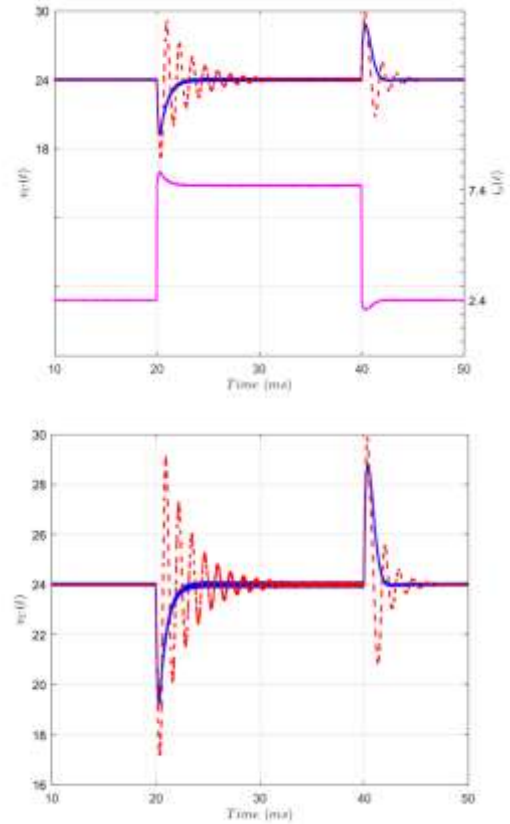


Fig. 4. Simulated output-voltage ($v_c(t)$) transient response of the boost converter with CPL under a (magenta line) load step transient of 5A with (solid blue line) the robust controller K and (red dashed line) the conventional LQR controller F_{LQR} .

For the load-power stress test, the robust LMI controller exhibits a maximum output-voltage deviation of approximately 4.8 V (20%), whereas the nominal LQR controller reaches approximately 6.8 V (28%) following the load increase. The LMI-controlled response returns to the $\pm 2\%$ settling band in approximately 2–3 ms, while the LQR response requires approximately 8–10 ms and exhibits considerably larger oscillations. When the load returns to its initial value, the LMI controller again exhibits a faster and more strongly damped response. These results indicate improved transient damping of the proposed controller for the particular stress-test scenario considered.

Fig. 5 presents the inductor-current ($i_L(t)$) waveform under the same load perturbation. The LMI-based robust controller exhibits superior performance both a shorter settling time and stronger damping than the conventional LQR.

Now, Fig. 6 shows the capacitor-voltage ($v_c(t)$) responses to an input-voltage variation, comparing the conventional LQR controller with the LMI-based robust controller. The input V_g drops abruptly from 12 V to 6 V at 20 ms and returns to 12 V at 40 ms. In both transitions, the proposed scheme exhibits superior dynamic performance to the classical LQR, with a shorter settling time and stronger damping.

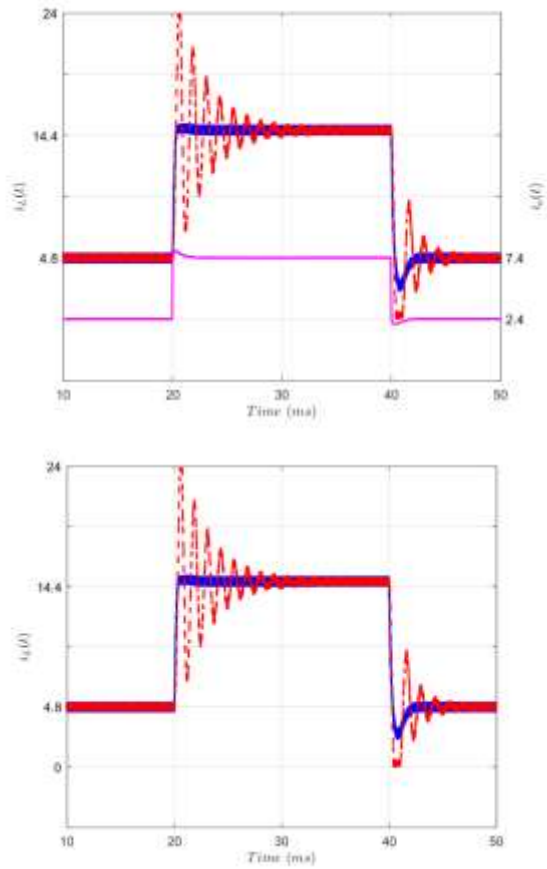


Fig. 5. Simulated inductor-current ($i_L(t)$) transient response of the boost converter with CPL under a (magenta line) load step transient of 5A with (solid blue line) the robust controller K and (red dashed line) the conventional LQR controller F_{LQR} .

It is evident that the conventional LQR fails to maintain output-voltage regulation under input-voltage variations, leading to system instability. For the input-voltage stress test, the LMI controller maintains a bounded output-voltage response despite the input-voltage variation from 12 V to 6 V. The minimum output voltage is approximately 21.2 V, corresponding to a maximum deviation of about 2.8 V (11.7%) from the 24 V reference, and the response returns to the $\pm 2\%$ settling band in approximately 1.5–2 ms. In contrast, the nominal LQR response becomes unstable for this particular operating condition. When the input voltage returns to 12 V, the LMI controller exhibits a maximum output voltage of approximately 26.5 V and subsequently recovers the 24 V reference.

Analogous to the load-disturbance case, Fig. 7 shows the inductor-current $i_L(t)$ waveform under an input-voltage variation. It is evident that, following the disturbance, the system becomes unstable under the conventional LQR controller.

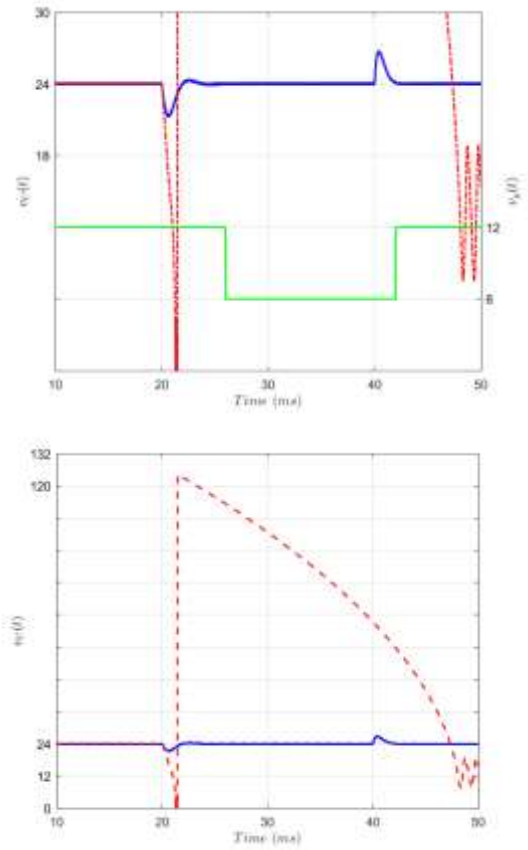


Fig. 6. Simulated output-voltage ($v_C(t)$) transient response of the boost converter with CPL under a (green line) input voltage disturbance of 6V with (solid blue line) the robust controller K and (red dashed line) the conventional LQR controller F_{LQR} .

To complement the qualitative comparison provided by Figs. 4–7, Table III summarizes representative transient-performance indices estimated from the simulated output-voltage responses. The settling time was determined using a $\pm 2\%$ band around the 24 V reference.

As shown in Table III, the robust LMI controller exhibits smaller output-voltage deviations and shorter settling times than the nominal LQR controller for the load-variation stress test. Following the load increase, the maximum voltage deviation is approximately 4.8 V (20%) for the LMI controller and 6.8 V (28.3%) for the LQR controller. Moreover, the LMI response returns to the $\pm 2\%$ settling band in approximately 2–3 ms, whereas the LQR response requires approximately 8–10 ms and exhibits more pronounced oscillations. For the input-voltage stress test, the LMI controller maintains a bounded response, with a maximum voltage deviation of approximately 2.8 V (11.7%) following the 12-to-6 V transition and a settling time of approximately 1.5–2 ms. In contrast, the nominal LQR controller becomes unstable under this particular operating condition.

TABLE III
QUANTITATIVE COMPARISON OF THE TRANSIENT RESPONSE OF
THE LMI AND LQR CONTROLLERS.

Disturbance scenario	Controller	t_s (ms)	$ \Delta v_o $ (V)	Max. deviat. (%)	Response
57.6 → 177.6 W	Robust	2-3	4.8	20	Stable
	LMI				
	LQR	8-10	6.8	28.3	Stable
57.6 → 177.6 W	Robust	2-3	4.8	20	Stable
	LMI				
	LQR	5-7	6	25	Stable
12 → 6 V	Robust	1.5-2	2.8	11.7	Stable
	LMI				
	LQR	-	-	-	Unstable
6 → 12 V	Robust	2	2.5	10.4	Stable
	LMI				
	LQR	-	-	-	Unstable

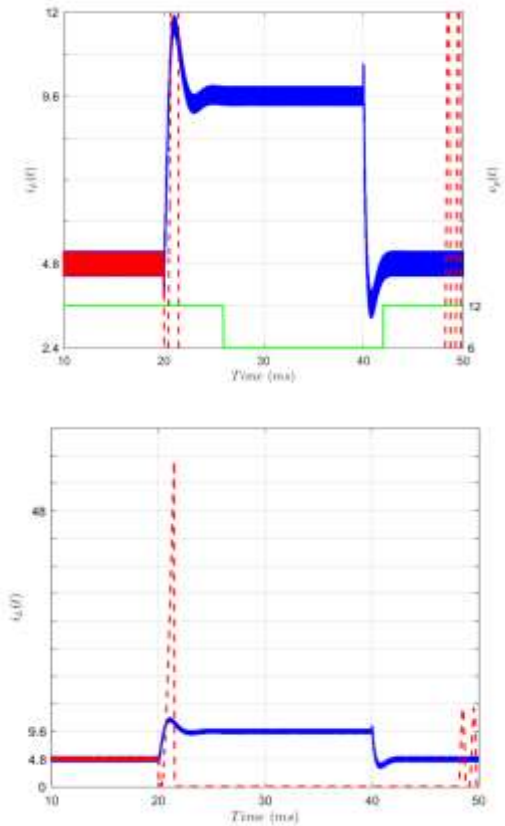


Fig. 7. Simulated inductor-current ($i_L(t)$) transient response of the boost converter with CPL under a (green line) input voltage disturbance of 6V with (solid blue line) the robust controller K and (red dashed line) the conventional LQR controller F_{LQR} .

IV. CONCLUSIONS

This work presented a robust LMI-based state-feedback controller for output-voltage regulation of a boost converter supplying a constant power load. The controller was synthesized from an uncertain polytopic representation of the linearized averaged converter model, incorporating quadratic stability, disturbance attenuation, prescribed closed-loop pole-

location constraints, integral action for zero steady-state tracking error, and a control-effort constraint. The adopted formulation yields a single fixed feedback gain obtained by enforcing the LMI conditions at the vertices of the prescribed uncertainty polytope.

The simulation results obtained with the switched converter model implemented in PSIM show that the proposed controller provides better transient damping than the nominal full-state LQR controller for the evaluated scenarios. For the load-variation stress test, the LMI controller exhibits an approximate maximum output-voltage deviation of 4.8 V (20%) and a settling time of approximately 2–3 ms, whereas the nominal LQR exhibits a maximum deviation of approximately 6.8 V (28.3%) and a settling time of approximately 8–10 ms following the load increase. Under the evaluated input-voltage stress test, the LMI controller maintains a bounded response and recovers the 24 V reference, with an approximate maximum deviation of 2.8 V (11.7%) following the 12-to-6 V transition, whereas the nominal LQR becomes unstable under this particular operating condition. The scope of these results must nevertheless be interpreted considering the limitations of the study. Controller synthesis is based on an averaged and linearized model, whereas performance assessment is conducted exclusively through simulation of a switched converter model in PSIM; no experimental implementation is reported. Furthermore, the theoretical robust-stability and performance guarantees apply only to the uncertainty set explicitly considered during the LMI synthesis. Consequently, simulation scenarios extending beyond this prescribed domain constitute stress tests and provide empirical evidence of controller behavior, but they do not extend the theoretical LMI guarantees beyond the certified uncertainty set. In addition, the comparative assessment is limited to a nominal full-state LQR controller and therefore does not establish superiority over other robust, nonlinear, LPV/LMI, or gain-scheduled control strategies reported in the literature.

Accordingly, the contribution of this work is delimited to the particular uncertainty representation and fixed-gain polytopic synthesis adopted for the considered boost-CPL system, together with its simulation-based assessment under load and input-voltage variations, rather than to the application of LMI-based robust control to boost converters with CPLs itself. Future work will address experimental validation of the proposed controller, sensitivity analysis with respect to the LMI design parameters and uncertainty bounds, extension of the certified operating domain, and comparison with additional robust and LPV/gain-scheduled control strategies.

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