

MODELING AND H_∞ CONTROL SYNTHESIS OF SERIAL DC-AC CONVERTER

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Abstract: This paper presents a robust control design methodology for a serial DC–AC converter based on H_∞ synthesis and a MATLAB/Simulink modeling framework. A mathematical model of the converter is derived and linearized around a selected operating point to obtain a plant representation suitable for robust controller synthesis. Performance objectives related to output regulation, disturbance rejection, and control effort are formulated using appropriate weighting functions. An H_∞ controller is then synthesized and evaluated under parameter variations and load disturbances. The results demonstrate improved robustness and dynamic performance compared to conventional linear control approaches, confirming the suitability of H_∞ -based design for power electronic converters operating under uncertainty.

Key words: mathematical modelling, H_∞ controller synthesis, serial DC-AC converter.

1. INTRODUCTION

Serial DC–AC converters (series inverters) are a fundamental component of modern power-electronic systems used in renewable energy interfaces, uninterruptible power supplies, electric drives, and distributed generation units. Their behavior is characterized by strong nonlinearities, switching dynamics, and sensitivity to parameter variations in passive components, semiconductor devices, and operating conditions. As emphasized in recent power electronics literature, these features make controller design particularly challenging, especially when high performance must be maintained under load disturbances and modeling uncertainties [1–3].

Conventional linear control strategies, such as PI or state-feedback controllers designed around a nominal operating point, remain attractive due to their simplicity and ease of implementation. However, contemporary studies highlight that such controllers

may exhibit degraded performance or even instability when converter parameters vary or when the system operates far from its nominal conditions [2,4]. This has motivated increasing interest in robust control methodologies that explicitly account for uncertainties during the controller synthesis phase.

Among these methodologies, H_∞ control has emerged as a powerful and systematic framework for guaranteeing closed-loop robustness and performance in the presence of bounded disturbances and modeling errors. Modern treatments of robust control emphasize the role of weighting functions in shaping sensitivity, complementary sensitivity, and control effort, allowing designers to formalize frequency-domain specifications in an optimization-based setting [5–7]. The availability of mature software environments further facilitates the practical application of H_∞ synthesis to real engineering problems [8].

For power electronic converters, robustness is not only a theoretical requirement but a practical necessity. Recent research shows that robust H_∞ -based controllers can significantly improve disturbance rejection, output voltage regulation, and transient response when compared to classical approaches, particularly in systems subject to parameter drift and uncertain loads [3,9]. In addition, advances in structured robust control and uncertainty modeling continue to reinforce the relevance of H_∞ techniques for converter-dominated energy systems [6,10].

The effectiveness of any robust control strategy, however, depends critically on the quality of the underlying mathematical model. Contemporary references stress the importance of consistent averaging, small-signal linearization, and uncertainty representation as prerequisites for meaningful robust synthesis results [1,3,4]. These modeling considerations are especially important for high-frequency switching converters, where parasitic effects and non-idealities cannot be neglected.

In line with these developments, the present work adopts a MATLAB/Simulink-based workflow for the modeling and robust control design of a power converter system. The approach follows modern robust control practice [5–8] and is conceptually aligned with recent μ -synthesis-based investigations of DC–DC converters reported by the authors [12]. The study demonstrates how robust control theory can be effectively applied to power electronic systems to achieve improved performance and guaranteed stability under uncertainty.

2. ELECTRICAL DIAGRAM AND MATHEMATICAL MODEL OF A SERIAL INVERTER

The schematic of a serial inverter is shown in Figure 1. The following notations are used: U_d – voltage of the DC power source (with a value in the specific example of 100 V, series inductance L (with a value of $10e-6$ H), series capacitor C (with a value of $10e-6$ F), load resistance R (with a value of 1Ω). The switching frequency of the semiconductor switches (transistors) is $f=80$ kHz. The given parameters define the nominal operating point used for modelling, linearization, and controller synthesis.

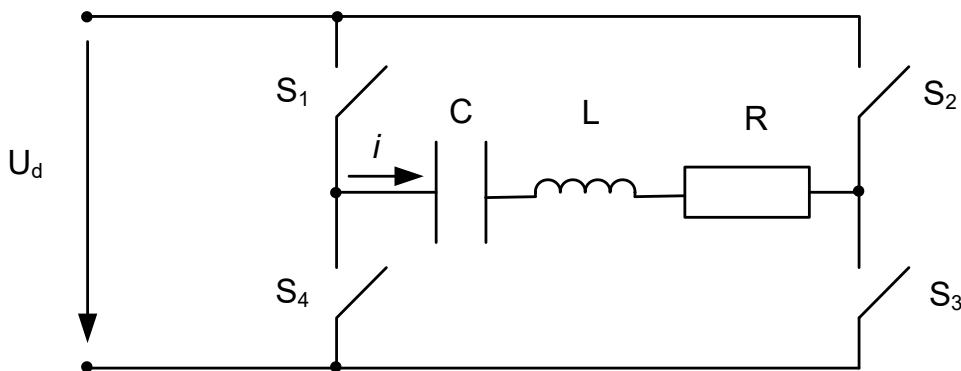


Figure 1. Structure of a serial inverter

Mathematically, the inverter is described by a system of ordinary differential equations (1), and a switching function “contr”:

$$\begin{cases} L \frac{di}{dt} = -u_c - Ri + \text{contr} \cdot U_d \\ C \frac{du_c}{dt} = i \end{cases}, \text{ for } \text{control}(t) = \begin{cases} -1, & \text{for an odd half period} \\ 1, & \text{for an even half period} \end{cases} \quad (1)$$

The power circuit and the derived mathematical model are implemented in the MATLAB/Simulink environment, forming an integrated simulation framework that enables detailed analysis of the converter dynamics and systematic evaluation of the proposed robust control strategy. This environment supports both time-domain simulations and linearized model extraction for controller synthesis, as illustrated in Figures 2 and 3.

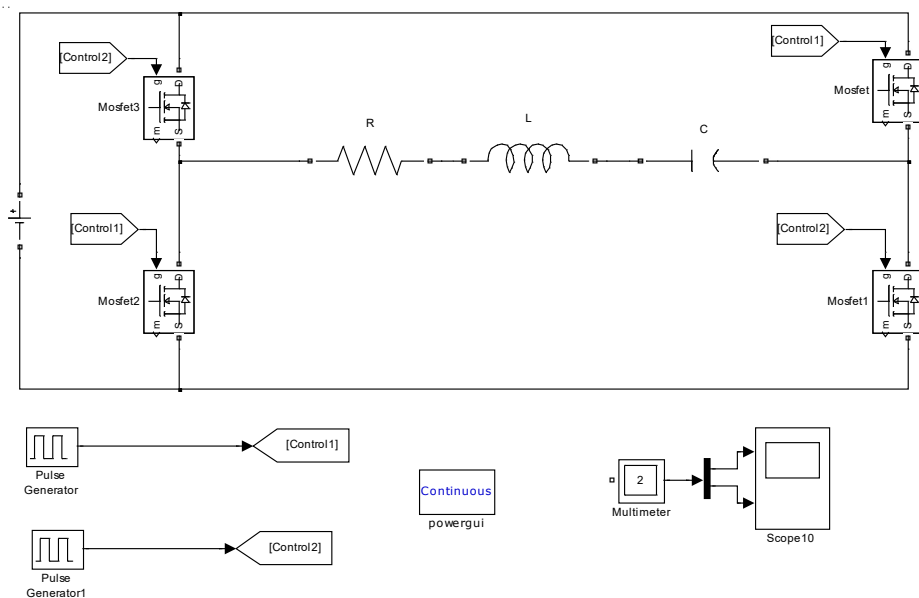


Figure 2. Simulink/MATLAB implementation of a serial inverter power circuit

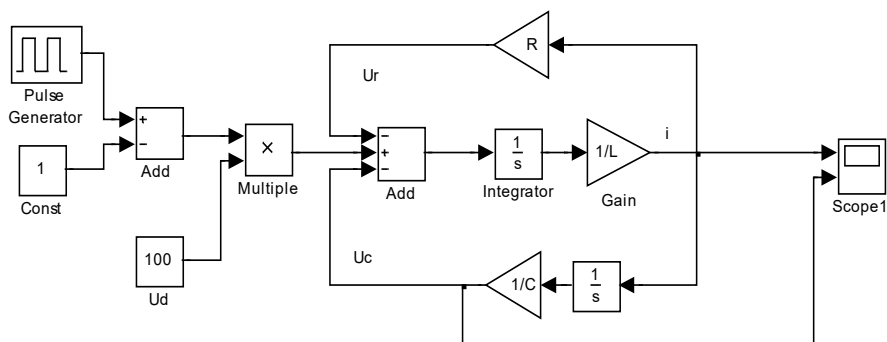


Figure 3. Simulink/MATLAB implementation of a mathematical model of a serial inverter

After simulating the operation of the circuit in Figure 3 for the output voltage u_C and the output current i , the graph shown in Figure 4 is obtained.

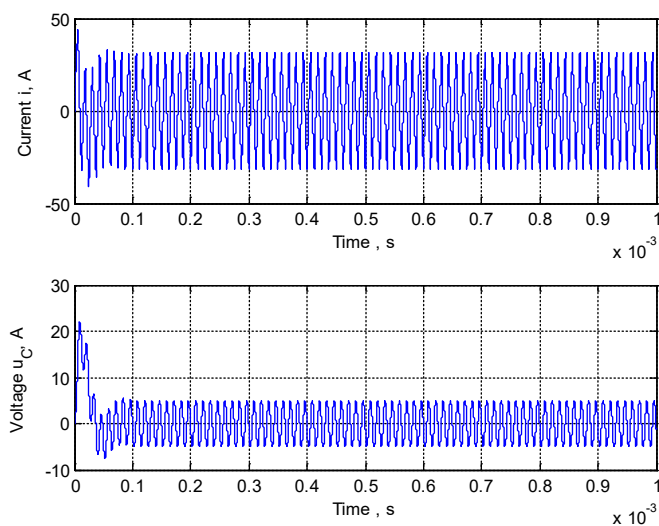


Figure 4. Output current and voltage

3. SYNTHESIS OF A LINEAR INVERTER MODEL IN A MATLAB ENVIRONMENT

A dynamical system is said to be linear (more precisely, the subsystem defined between the selected input and output points) if its behavior can be described by a linear input–output relationship. In this case, the system can be represented in the following standard form:

$$\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned} \quad (2)$$

where A , B , C and D are the transfer matrices, x – states space variable, u – input variable and y – output variable.

By isolating from Figure 5 the part between the designated input and output points, the diagram shown in Figure 6 is obtained.

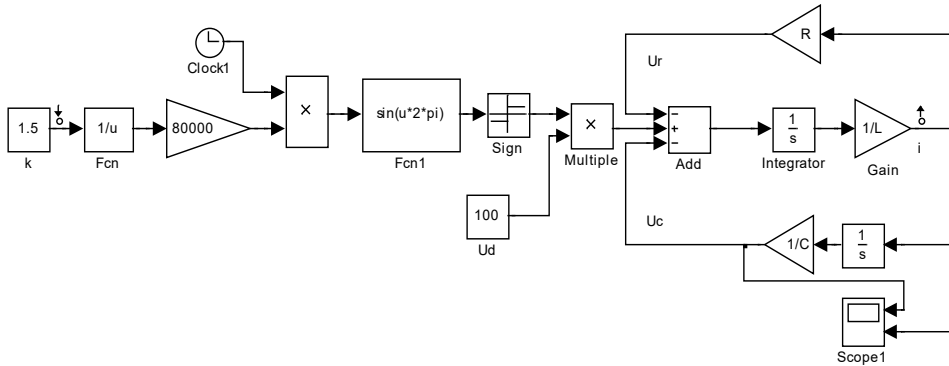


Figure 6. The part to be linearized

In the figure above, k denotes the scaling coefficient that specifies the desired change in the amplitude of the output current i . As discussed previously, it is necessary to reformulate the configuration in Figure 6 such that it produces the same output behavior, while also allowing linearization. For this purpose, an equivalent system is developed by the authors and is shown in Figure 7.

The equivalence between the systems in Figures 6 and 7 is based on the fact that the amplitude of the output current i increases by the same factor k in both cases, despite the scaling being realized through different physical variables—namely, frequency variation in Figure 6 and supply voltage variation in Figure 7. This equivalence is confirmed by the simulation results presented in Figure 8.

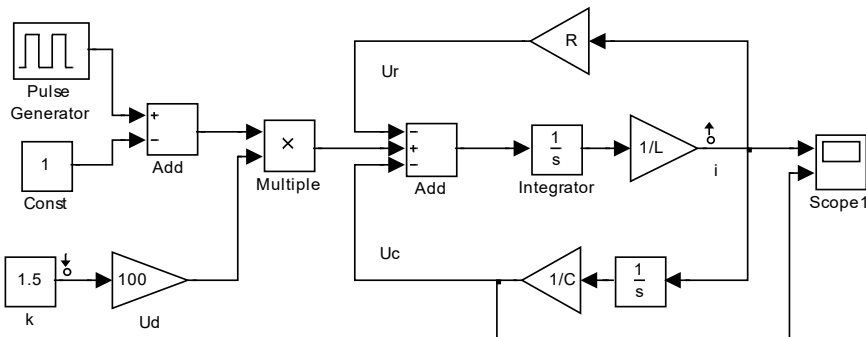


Figure 7. The “equivalent” diagram of the part to be linearized

The newly obtained equivalent circuit is linear. This is achieved by replacing the variable-structure switching behavior of the inverter with an equivalent continuous input signal. As a result, the subsystem between the selected input and output points of the equivalent configuration shown in Figure 7 coincides with the mathematical model of the inverter given by (1), which represents a linear dynamical system.

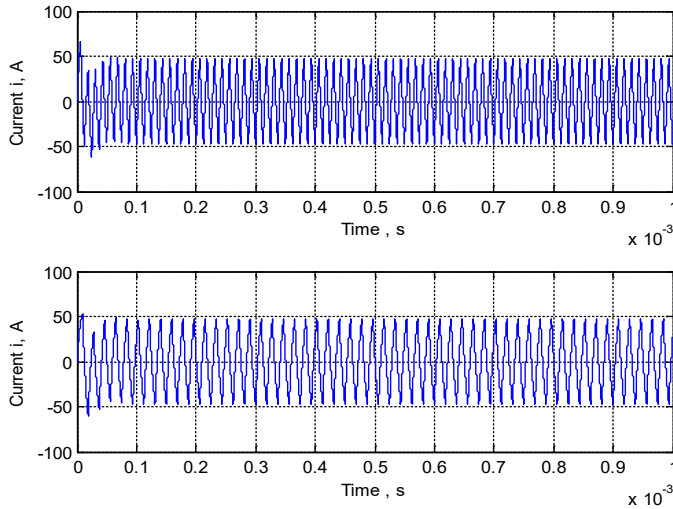


Figure 8. Output currents simulated with Figure 6 and Figure 7

By expressing (1) in matrix form, the following state-space representation is obtained:

$$\begin{pmatrix} \frac{di}{dt} \\ \frac{du_c}{dt} \end{pmatrix} = \begin{pmatrix} -\frac{R}{L} & -\frac{1}{L} \\ \frac{1}{C} & 0 \end{pmatrix} \begin{pmatrix} i \\ u_c \end{pmatrix} + \begin{pmatrix} \frac{U_d}{L} \\ 0 \end{pmatrix} \text{contr} \quad y = \begin{pmatrix} 1 & 0 \end{pmatrix} \begin{pmatrix} i \\ u_c \end{pmatrix} \quad (3)$$

We compare (3) with (2) and obtain:

$$x = \begin{pmatrix} i \\ u_c \end{pmatrix}, \quad A = \begin{pmatrix} -\frac{R}{L} & -\frac{1}{L} \\ \frac{1}{C} & 0 \end{pmatrix}, \quad B = \begin{pmatrix} \frac{U_d}{L} \\ 0 \end{pmatrix}, \quad C = \begin{pmatrix} 1 & 0 \end{pmatrix}, \quad D = 0 \quad \text{and} \quad u = \text{contr}.$$

If we use our nominal parameter values

$$L=10\text{e-}6 \text{ H}, \quad C=10\text{e-}6 \text{ F}, \quad R=1 \text{ } \Omega,$$

then for the transfer matrices we get

$$A = 10^5 \begin{pmatrix} -1 & -1 \\ 1 & 0 \end{pmatrix}, \quad B = 10^5 \begin{pmatrix} 100 \\ 0 \end{pmatrix}, \quad C = \begin{pmatrix} 1 & 0 \end{pmatrix} \quad \text{and} \quad D = 0.$$

3.2. Synthesizing a linear inverter model in the MATLAB workspace

Using the code:

```
A=1e+5*[-1, -1; 1, 0];
B=1e+5*[100; 0];
C=[1, 0];
D=0;
G=ss(A,B,C,D);
```

an object *G* of class “continuous-time state-space model” is generated.

4. μ SYNTHESIS ON TASK

For the synthesis of the TO-SI type controller K_h , the augmented system G_{syn} shown in Figure 9 is constructed. This system is obtained by extending the linearized plant model G , which includes uncertainty, with the weighting filters W_p , W_u and the reference model W_m . The resulting augmented system G_{syn} is used as the generalized plant for the subsequent H_∞ controller synthesis, following the approach described in [12].

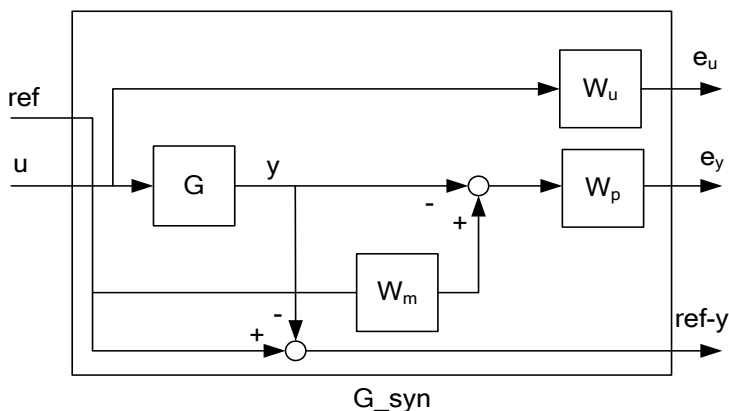


Figure 9. The expanded system G_{syn} , used for synthesis on controller K_h

In Figure 9, object G is received in the previous point.

The added weighting filters are defined as follows.

The filter W_p is introduced to scale the output signal and shape the sensitivity function in the frequency domain: $W_p(s) = \frac{s+1000}{0.001s+1}$.

The filter W_u is used to penalize the control effort and limit excessive control action and is chosen as a constant gain $W_u = 10^{-2}$.

In addition, the reference model W is defined to represent the desired closed-loop transient response. It is implemented as a first-order transfer function of the form

$$W_m(s) = \frac{1}{Ts+1}, \text{ for } T = 0.0003.$$

In the MATLAB environment, the structure of the augmented open-loop system G_{syn} is constructed using the `sysic` command, as shown in Figure 9.

After creating (in a MATLAB environment) a G_{syn} system, the H_∞ synthesis is implemented using the `hinfsyn` command [7] and the controller K_h is obtained.

In the case $n_{meas} = 1$ and $n_{cont} = 1$ this indicates that a controller K_h with one input and one output will be synthesized.

To evaluate the behavior of the synthesized controller K_h , and in particular to analyze the transient response, a new system is constructed in which the weighting filters and auxiliary connections used in Figure 9 are removed. This results in the closed-loop configuration shown in Figure 10, which is employed for time-domain simulations.

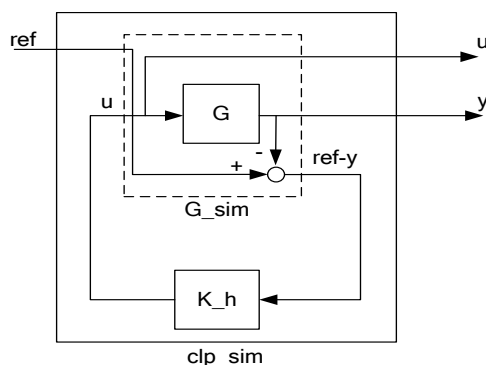


Figure 10. Closed system *clp_sim* used to simulate transients response

The synthesis of the system *G_sim*, illustrated in Figure 14, is performed in the MATLAB environment using the `sysic` command. The previously synthesized controller *K_h* is interconnected with the open-loop system *G_sim* via a lower linear fractional transformation (lft), resulting in the closed-loop system *clp_sim*, as shown in Figure 10. The corresponding MATLAB code is given below.

Using the closed-loop system *clp_sim*, the transient response is simulated. The corresponding MATLAB code is given below. A reference signal is applied to the closed-loop system in order to obtain the transient response. The resulting simulation is shown in Figure 11.

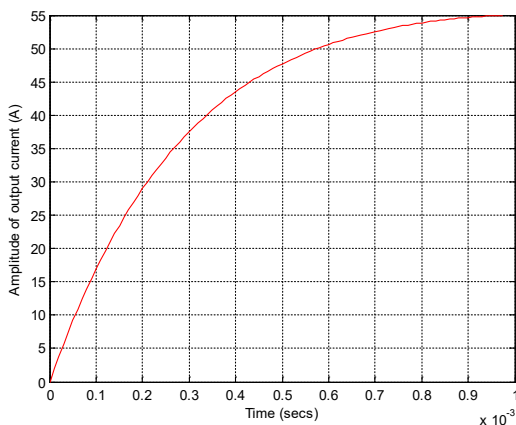


Figure 11. Transient response obtained using the *clp_sim* system

5. SIMULATING TRANSIENT RESPONSES WITH A NONLINEAR MODEL

The transient responses shown in Figure 11 are obtained using the linearized model *G_sim*, while the controller *K_h* is synthesized based on the augmented model *G_syn*. It should be noted that both *G_sim* and *G_syn* include the linearized plant model *G* as a common component.

To validate the relevance of the obtained transient responses, the behavior of the complete nonlinear closed-loop system is subsequently simulated. This system is

structurally similar to the control scheme shown in Figure 5, with the difference that the PI controller is replaced by the synthesized H_∞ controller K_h . The resulting configuration is illustrated in Figure 12.

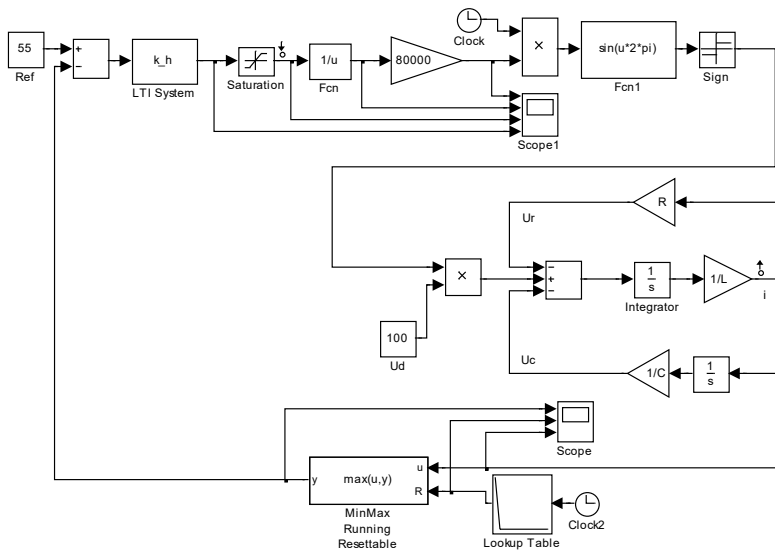


Figure 12. Closed system containing the H_∞ controller - K_h

The transient responses obtained using the nonlinear closed-loop system shown in Figure 12 are presented in Figure 13.

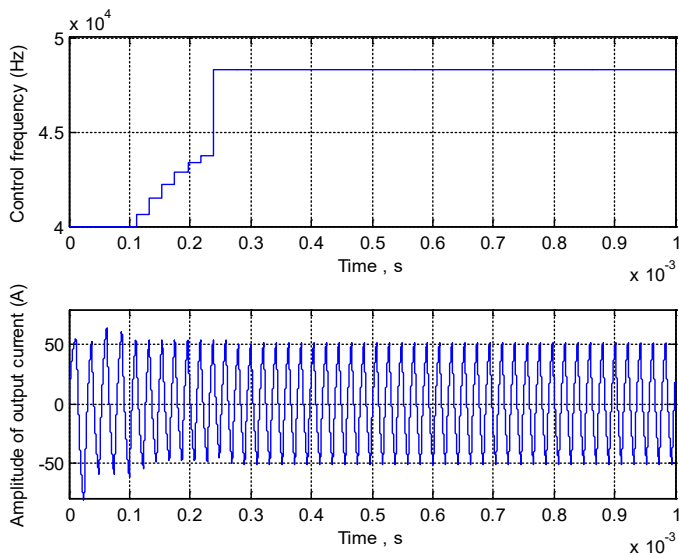


Figure 13. Control frequency and load current amplitude simulated with the model from Figure 12

6. CONCLUSION

This paper presented a MATLAB/Simulink-based workflow for modeling and robust H_∞ controller synthesis of a serial DC–AC converter. A nonlinear switching model was first implemented to reproduce the converter dynamics under nominal operating conditions. To enable robust controller design, an equivalent linearizable configuration was introduced, preserving the relevant input–output behavior between the selected linearization points. Based on this representation, a state-space model of the plant was obtained and used to construct an augmented generalized plant with appropriate weighting functions for performance shaping and control-effort limitation [13–15].

The H_∞ controller K_h was synthesized using the resulting augmented system and subsequently evaluated in both the linear simulation framework and the nonlinear closed-loop configuration. The presented results demonstrate that the proposed robust design achieves stable operation and improved transient behavior under the considered conditions, while maintaining practical implementability in a standard MATLAB/Simulink environment. Overall, the study confirms that H_∞ -based synthesis provides an effective and systematic tool for robust control of serial inverter topologies, particularly in the presence of uncertainty and load disturbances.

Future work will focus on extending the uncertainty description to include parasitic effects and wider operating ranges, as well as experimental validation on hardware prototype and digital implementation aspects (sampling, computation delay, and PWM constraints).

ACKNOWLEDGEMENT

This research was carried out within the framework of the projects: “Artificial Intelligence-Based modeling, design, control, and operation of power electronic devices and systems”, КП-06-H57/7/16.11.2021, Bulgarian National Scientific Fund.

REFERENCES

- [1] Erickson RW, Maksimović D. Fundamentals of Power Electronics. 3rd ed. Cham: Springer; 2020.
- [2] Rashid MH. Power Electronics: Circuits, Devices, and Applications. 4th ed. Boston: Pearson; 2021.
- [3] Han Y. Modeling and Control of Power Electronic Converters for Microgrid Applications. Cham: Springer; 2021.
- [4] Kazimierczuk MK. Pulse-Width Modulated DC–DC Power Converters. 2nd ed. Hoboken (NJ): Wiley; 2022.
- [5] Skogestad S. Multivariable Feedback Control: Theory and Applications. 2nd ed. Hoboken (NJ): Wiley; 2022.
- [6] Zhou K, Doyle JC, Glover K. Robust and Optimal Control. Reprint ed. London: Pearson; 2021.

- [7] Fortuna L, Frasca M, Buscarino A. *Optimal and Robust Control: Advanced Topics with MATLAB®*. 2nd ed. Boca Raton (FL): CRC Press; 2021.
- [8] MathWorks. *Robust Control Toolbox™ User's Guide*. Natick (MA): The MathWorks, Inc.; 2024.
- [9] Yin Y, Zhang J, Wang H. Robust H_∞ control of power electronic systems: A review. *IEEE Access*. Vol.9, 2021, pp:120345–120360.
- [10] Derbel N, Nouri AS, Zhu Q (eds.). *Advances in Robust Control and Applications*. Cham: Springer; 2023.
- [11] Sun J, Li Y. Robust control and impedance-based stability of power converters in modern power systems. *IEEE Transactions on Power Electronics*, vol.37, no.8, 2022 pp.9124–9138.
- [12] Hinov N, Gilev B. Mathematical modeling and μ -synthesis-based robust control of Boost DC–DC converters using MATLAB. *Contemporary Mathematics*, vol.7, no.1, 2026, pp.506–528. Available from: <https://ojs.wiserpub.com/index.php/CM/article/view/7821>.
- [13] D. I. Mutin, A. F. Kaperko, S. A. Sorokin, D. V. Sotnikov, I. V. Atlasov, N. A. Ryndin. Automation of adaptive control of complex objects states trajectories in artificial intelligence systems. *International Journal on Information Technologies and Security*, vol.16, no.1, 2024, pp. 57-64. <https://doi.org/10.59035/ZDGM9286>
- [14] A. Bardavelidze, K. Bardavelidze. Development and investigation of algorithm for the synthesis of an automatic control system of the drying process. *International Journal on Information Technologies and Security*, vol.16, no.1, 2024, pp. 15-26.
- [15] T. S. Sreedhar, S. Islam, M. Atomsa, E. Y. Doust, M. S. Elnaim, S. Mishra, V. N. Vemparala, R. Bajpai. Applications of BIG DATA in renewable energy systems based on cloud computing. *International Journal on Information Technologies and Security*, vol.16, no.3, 2024, pp. 121-128. <https://doi.org/10.59035/NALD6541>

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Manuscript received on 12 January 2026