Comparison Between Optimal Methods for Control of DC/DC Converter for Supplying of LED Lighting

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Abstract—**In the current paper a comparison between several control strategies for LED lighting application are presented. A classical method such as control with PI regulator is described. Also, several methods such as linearization, model predictive control and neural network are realized. The basic idea in this study is to find optimal solution suitable in multiple cases for control of DC-DC converters supplying LED lighting.**

Keywords—DC/DC converter, control, LED lighting.

I. INTRODUCTION

Recently, the studying of different methods for control of DC/DC converter for usage in LED lighting applications is significant interesting. In the current research several methods for control are presented and discussed. The main motivation for studying this methodology is to find optimal solution for control.

The idea of artificial intelligence has 70 years. The founders of this concept are presented this solution in an academic conference [1]. Recently, due to the improvement of the advanced technology this idea has significant usage in various applications such as power electronics, electrical engineering, lighting and etc.

The basic definition of the artificial intelligence is to allow the machine to work dependently and smart. This allows the determination of complex task even when there is a presence of incomplete data and uncertainty.

Interesting application of the artificial intelligence is the control system of the power electronics. For producing power electronic converters the significant part of this process are the design of various topologies and sizing their components. For finding optimal solution it is necessary to determine optimization task for minimization of the losses, cost and volume of electronic elements. All these methods included in artificial intelligence such as linearization, model predictive control, power converter under load disturbance, voltage prediction, neural network control and PID controller tuning are studied in this work for find an optimal solution for control of the power electronic converters for application in LED lighting[2].

II. LINEARIZATION

All control systems can characterized by two basic elements: control unit and object for regulation. The main problem of the control system is to maintain the input signal to the reference value. This quantity is affected by one or more disturbing influences, deviating it from its set value. The controller receives information about this value and by comparing it with its set value it generates the so-called regulating effect. The most commonly used means of regulating the dynamic and static characteristics of a control system is the introduction of feedback. It may cover one or more units of the management system. Negative feedback is most often used to improve the dynamics of the management process, which is why it is found in all control systems. An example of such a system is shown in Figure 1.
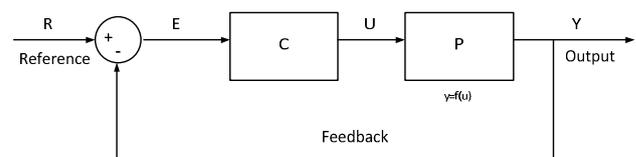

Fig. 1. Control system with feedback

The model presented in this figure is in equilibrium. Taking into account the linearization of the plane P, for this equilibrium operating point of C by changing the input signal U, with a small amount of u and measuring the change of the output signal y.

MATLAB / Simulink has a powerful tool from a series of connected blocks for modeling physical systems and control systems. Connecting input-output signals are mathematical operations. The tool developed in MATLAB / Simulink computes the matrices describing the nonlinear system in space of states A, B, C and D using linearization algorithms. A common method is by injecting a unit of relative value at the input of the system, taking into account the response of the outputs. The input interferences are described in the matrix B, and the matrix D describes the output parameters of interest.

In order to linearize the model, the parametric input points for linearization of the input and the output parameters of interest in the scheme of the model must be determined. The defined linearization input parameter will determine the output response of the linearized model. Linearized models are calculated using numerical interference, injecting a small interference into the input signal and taking into account the system's response to this interference.

The first step in the linearization process is to create or open an existing model in Simulink. The tool allows entering any number of inputs and outputs.
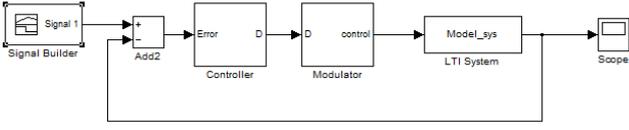

Fig. 2. Block scheme of the realized model in MATLAB/Simulink

In order for the linearized model to be accurate, it is important to interpret the results obtained. One of the methods for evaluating the results is by simulating the linearized model and comparing the output with the original model.

Comparing the simulations of the original model with the simulations of the linearized model helps to determine whether the linearized system behaves in a similar way to the original model.

The states of the inputs and outputs of the linearized model are determined as the operating point of the original model, using the following variables:

$$\delta x(t) = x(t) - x_0$$
$$\delta u(t) = u(t) - u_0 \qquad (1)$$
$$\delta y(t) = y(t) - y_0$$

This means that when the original model is at the operating point $x(t) = x0$, $u(t) = u0$, $y(t) = y0$, the linearized model will be at the operating point $\delta x(t) = 0$, $\delta u(t) = 0$, $\delta y(t) = 0$. For an accurate comparison between the models, u0 is subtracted from the input values and x0 from the initial state values in the linearized model, after which y0 is added to the output signal. In the developed model this is not necessary, as we have chosen a default operating point.
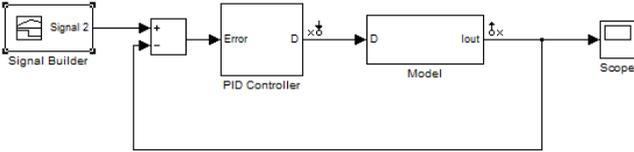

Fig. 3. Block scheme of the linearized model

Figure 4 shows the output signal and the reference of the linearized model.
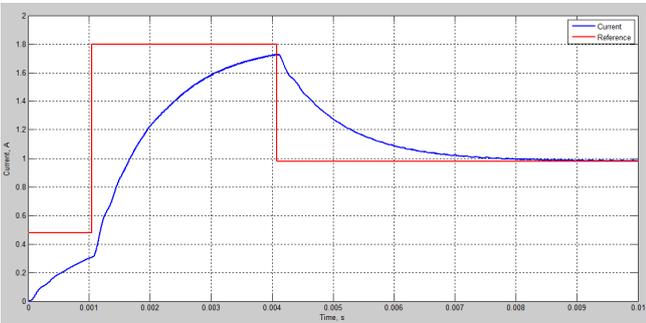

Fig. 4. Output signal of lenearized model

III. MODEL PREDICTIVE CONTROL

To synthesize this type of control, the linear (linearized) system must be represented as follows:

$$\dot{\mathbf{x}} = A\mathbf{x} + B_\beta u + B_v v$$
$$y = C\mathbf{x} \qquad (2)$$

The system is discretized over time and the new system is obtained:

$$\mathbf{x}(k+1) = E\mathbf{x}(k) + F_\beta u(k) + F_v v(k)$$
$$y(k) = G\mathbf{x}(k) \qquad (3)$$

where x is a vector of the state, y is output of the object and k is time cycle, v is a perturbation.

With recursion from (3) it is obtained

$$\mathbf{x}(k+j) = E^j \mathbf{x}(k) + \sum_{i=1}^{j} E^{i-1} F_\beta u(k+j-i) + \sum_{i=1}^{j} E^{i-1} F_v v(k+j-i) \qquad (4)$$

Where j is the forward cycle, for which is realized the predictive control.

The predicted value of the output of the system is:

$$y(k+j-1) = GE^j \mathbf{x}(k) + \sum_{i=1}^{j} GE^{i-1} F_\beta u(k+j-i) + \sum_{i=1}^{j} GE^{i-1} F_v v(k+j-i) \qquad (5)$$

From (5) is composed the vector of the predicted values of the output of the system for N_p cycles.

$$y(k) = GE^1 \mathbf{x}(k) + GF_\beta u(k+1) + GF_v v(k+1)$$
$$y(k+1) = GE^2 \mathbf{x}(k) + \sum_{i=1}^{2} GE^{i-1} F_\beta u(k+2-i) + \sum_{i=1}^{2} GE^{i-1} F_v v(k+2-i)$$
$$\vdots$$
$$y(k+Np-1) = GE^{Np} \mathbf{x}(k) + \sum_{i=1}^{Np} GE^{i-1} F_\beta u(k+Np-i) + \sum_{i=1}^{Np} GE^{i-1} F_v v(k+Np-i) \qquad (6)$$

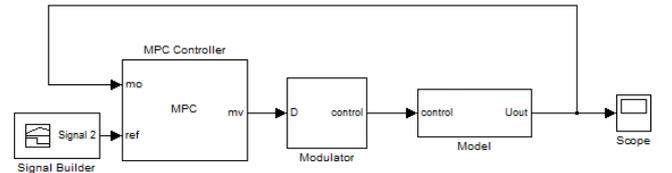Figure 5 shows the block diagram of the realized model with MPC controller.

Fig. 5. Block scheme of the MPC controller

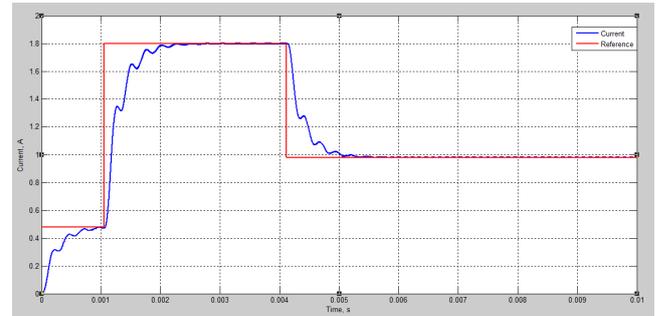The generated MPC controller is imported into the model and the following results are simulated shown in Figure 6.

Fig. 6. Output signal and reference

IV. CONTROL WITH NEURAL NETWORK

In MATLAB environment a mathematical model of nonlinear open system (Reference Model) is created.

The controller approximates the function $y_r \rightarrow u$ with a fractionally rational function. This function is realized with a two-layer neural network with a nonlinear first layer and a linear second layer.

The training of the neural network is performed with batch training. The data with which the network is trained are realizations of trajectories of the system and of the control signal. They can be submitted both at the current time and with different delays (TDL).

The realized function from this network is:

$$y(k+1) = f\big(y(k),y(k-1),y(k-2),...,u(k),u(k-1),u(k-2),...\big) + $$
$$+ g\big(y(k),y(k-1),y(k-2),...,u(k-1),u(k-2),u(k-3),...\big)u(k)$$

$$(7)$$

where y is the output of the object, u is the control action of the object, f and g are approximate functions which are obtained in the process of the network.

The neural model (6) is linear regarding $u(k)$. Therefore, if we know the reference signal $y(k+1) = \hat{y}(k+1)$, the control $u(k)$ it will be

$$u(k) = \frac{\hat{y}(k+1) - f\big(y(k),y(k-1),y(k-2),...,u(k-1),u(k-2),u(k-3),...\big)}{g\big(y(k),y(k-1),y(k-2),...,u(k-1),u(k-2),u(k-3),...\big)}$$

$$(8).$$

A. Mathematical modeling of a buck converter

In Figure 7 the block scheme of control with PI regulator is presented. The control is realized with adjustment of the output voltage and the reference value of the voltage and the PI regulator determine the signal from PWM generator.
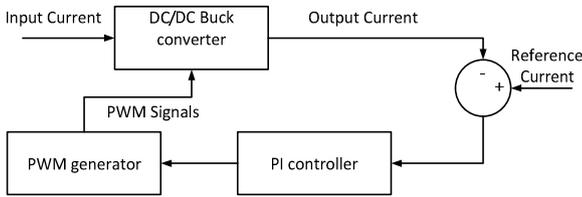
Fig. 7.   Block scheme of the control system with PI regulator

In Fig. 8 and 9 are presented the mathematical model of a buck converter with PI regulator and with neural network, respectively. It is used the differential equations describing the operation of the DC/DC converter.
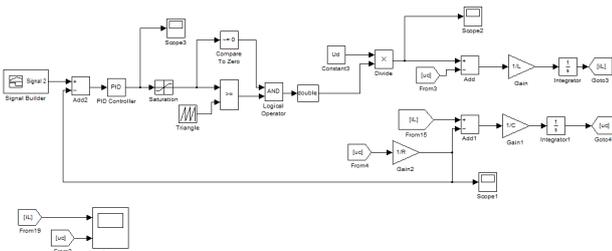
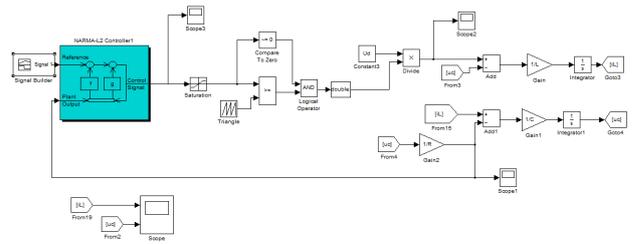Fig. 8.   Mathematical model of a buck converter with PI controller

Fig. 9.   Closed loop system used for simulation with trained neural network
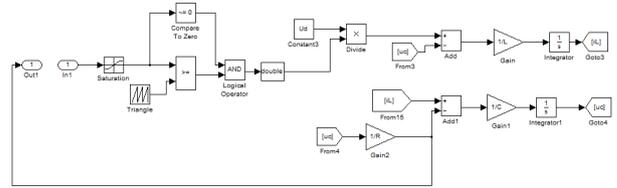
Fig. 10. Open loop system used for training the neural network

In the model in Simulink / MATLAB, where the control is based on the use of PWM and PI controller Figure 7, at this point the control with the PI controller is replaced by a neural network (NARMA controller).

The training of the neural network is carried out with a random input signal corresponding to the specified restrictions and a reference output signal calculated by the open system. Learning error, neural "Plant" output and "reference model" are presented in Figure 11.
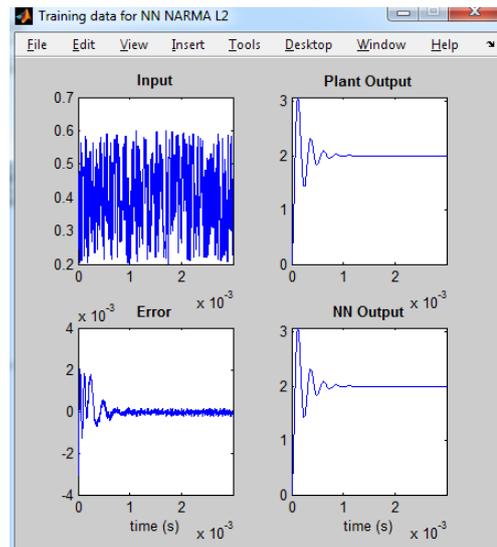
Fig. 11. Data from the neural Plant

V. RESULTS

After training the NARMA controller with a closed system from Figure 6 the following results are simulated. Figure 12 shows the output current of the neural network converter. Figure 13 shows a similar result, but realized with a PI controller. The simulation results of Figure 12 and Figure 13show that the transients in the converter are established faster using neural network control.
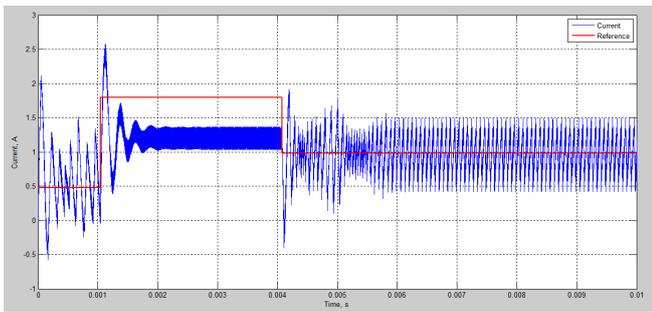
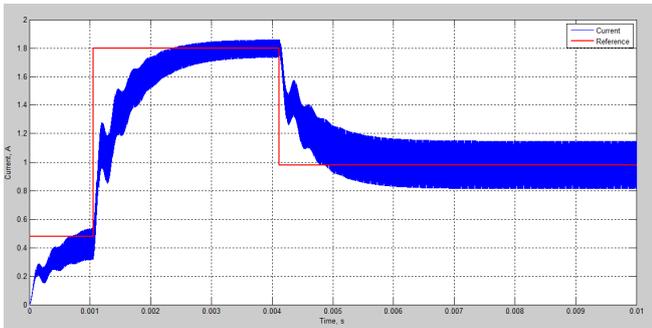Fig. 12. Output current of the converter with neural network

Fig. 13. Output curent and reference of the converter with PI controller

VI. Conclusion

By the reason of the specifics of the variable types of LED lighting and the complexity of the systems for their realization, the usage of basic control methods does not guarantee obtaining the characteristics of the devices. From this point of view, the usage of smart control systems such as linearization, neural networks, model predictive control, and model-based optimization are rather obligatory for application in the control of energy flows. This type of devices has a wide range of uncertainty related to their operation modes.

Acknowledgment

References

[1] C. Smith, B. McGuire, S. Chris, T. Huang, and G. Yang, "The histoiy of artificial intelligence (University of Washington)," Retrieved June, vol. 8, p. 2017, 2006.

[2] P. Qashqai, H. Vahedi and K. Al-Haddad, "Applications of artifical intelligence in power electronics," *2019 IEEE 28th International Symposium on Industrial Electronics (ISIE)*, Vancouver, BC, Canada, 2019, pp. 764-769, doi: 10.1109/ISIE.2019.8781216.

[3] H. K. Sayed, "Modeling and Control of a Buck DC-DC Converter Based on Artificial Neural Network", International Journal of Scientific & Engineering Research, Volume 4, Issue 11, pp. 1224 - 1233, November-2013.

[4] R. Rojas, „Neural Networks A Systematic Introduction", Springer Berlin Heidelberg New York Hong Kong London Milan Paris Tokyo Simon Haykin, "Neural Networks and Learning Machines", ISBN-13: 978-0-13-147139-9.

[5] X. Hua Yu, W. Li, Taufik, "Design and implementation of a neural network controller for real-time adaptive voltage regulation", Volume 73, Issues 1–3, December 2009, pp. 531-535.

[6] J. Rodriguez, P. Cortes, „Predictive control of power converters and electrical drives", John Wiley & Sons, Ltd.,2012.

[7] A. Raj, N. Arulgandhi, L. Patha and D. V. Bhaskar, "Fuzzy logic based master-slave controller for paralleling DC-DC converters in LED applications," *2018 International Conference on Power Energy, Environment and Intelligent Control (PEEIC)*, Greater Noida, India, 2018, pp. 676-682, doi: 10.1109/PEEIC.2018.8665426.

[8] K. Bendaoud, S. Krit, M. Kabrane and H. Ouadani, "Fuzzy logic controller(FLC): Application to control DC_DC buck converter", *ICEMIS*, pp. 1-5, Feb. 2018.

[9] I. Kasireddy and K. R. Ch, "An Efficient Selective Harmonic Based Full Bridge DC-DC Converter for LED Lighting Applications," *2019 National Power Electronics Conference (NPEC)*, Tiruchirappalli, India, 2019, pp. 1-6, doi: 10.1109/NPEC47332.2019.9034817.

[10] S. Iturriaga-Medina, P. R. Martinez-Rodriguez, M. Juarez-Balderas, J. M. Sosa and C. A. Limones, "A buck converter controller design in an electronic drive for LED lighting applications," *2015 IEEE International Autumn Meeting on Power, Electronics and Computing* (ROPEC), Ixtapa, 2015, pp. 1-5, doi: 10.1109/ROPEC.2015.7395105.

[11] H. Van der Broeck, Sauerlander Georg and M. Wendt, "Power driver topologies and control schemes for LEDs", *Applied Power Electronics Conference APEC 2007-Twenty Second Annual IEEE*, pp. 1319-1325, Feb. 25 2007-March 1 2007.

[12] S. Mahmoud Abd, Haitham El-Moniem, Z. Azazi and A. Sabry Mahmoud, "A current sensorless power factor correction control for LED lamp driver", *Alexandria Engineering Journal*, vol. 53, no. 1, pp. 69-79, March 2014, ISSN 1110-0168.

[13] D.G. Lamar, J.S. Zuniga, A.R. Alonso, M.R. Gonzalez and M.M.H. Alvarez, "A Very Simple Control Strategy for Power Factor Correctors Driving High-Brightness LEDs", *Power Electronics IEEE Transactions on*, vol. 24, no. 8, pp. 2032-2042, Aug. 2009.

[14] S. Beczkowski and S. Munk-Nielsen, "Two phase interleaved buck converter for driving high power LEDs", *Power Electronics and Applications (EPE 2011) Proceedings of the 2011-14th European Conference on*, pp. 1-6, Aug. 30 2011-Sept. 1 2011.