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Regulation characteristics of a step-down pulse regulator in continuous and discontinuous conduction mode

Introduction. *Pulse regulators (PRs) are widely used to regulate and stabilize the supply voltage of DC consumers. The main characteristic of any regulator is its regulation characteristic. In the general case, two modes of PR operation are possible: continuous conduction mode and discontinuous conduction mode in the inductance of the PR.* ***Problem****. When the PR transitions from one operating mode to another, its regulation characteristics change. In the continuous conduction mode, the regulation characteristic is a function of one variable. In the discontinuous conduction mode, the regulation characteristic becomes a function of two variables. Therefore, in such a mode, PR is described by a family of regulation characteristics. The* ***goal*** *of the work is to develop a mathematical model that describes the operation of the controller in both continuous and discontinuous conduction modes, as well as to determine the control characteristics that are valid for both of these modes.* ***Methodology****. In the work, using the example of a step-down type PR, the conditions for the PR transition from one operating mode to another are determined, as well as the dependence of the PR output voltage on the duration of the pause in the inductance current.* ***Results.*** *The influence of the parameters of the PR elements on the pause duration is analyzed. A graph of the family of PR control characteristics is constructed, which is valid for both continuous and discontinuous conduction modes.* ***Scientific novelty.*** *It is shown that when PR transitions to discontinuous conduction mode, its control characteristics shift towards higher output voltages. This shift is greater, the longer the pause duration in the inductance current.* ***Practical value.*** *It is determined that the specified ripple coefficient of the PR output voltage in the discontinuous conduction mode is provided by a smaller value of the LC product of the PR elements, compared to the continuous conduction mode.* References 17, tables 2, figures 5.

Key words: **discontinuous conduction mode, control characteristics of a pulse regulator, ripple coefficient of the output voltage.**

Вступ. *Імпульсні регулятори (ІР) широко використовують для регулювання та стабілізації напруги живлення споживачів постійного струму. Основною характеристикою будь-якого регулятора є його регулювальна характеристика. У загальному випадку можливі два режими роботи ІР – режим безперервного струму та режим переривчатого струму в індуктивності ІР.* ***Проблема.*** *При переході ІР від одного режиму роботи до іншого, його регулювальні характеристики змінюються. В режимі безперервного струму індуктивності регулювальна характеристика є функцією від однієї змінної. В режимі переривчастого струму регулювальна характеристика стає функцією двох змінних. Тому, в такому режимі, ІР описується сімейством регулювальних характеристик.* ***Метою*** *роботи є розробка математичної моделі, яка б описувала роботу ІР у режимах безперервного та переривчастого струму індуктивності, зокрема одержання регулювальних характеристик, які б були дійсними для обох вказаних режимів.* ***Методика****. В роботі на прикладі ІР понижувального типу визначено умови переходу ІР від одного режиму роботи до іншого, а також залежність вихідної напруги ІР від тривалості паузи у струмі індуктивності.* ***Результати.*** *Проаналізовано вплив параметрів елементів ІР на тривалість паузи. Побудовано графік сімейства регулювальних характеристик ІР, який є дійсним, як для режиму безперервного, так і переривчастого струму індуктивності.* ***Наукова новизна.*** *Показано, що при переході ІР до режиму переривчастого струму, його регулювальні характеристики зміщуються в сторону більших вихідних напруг. Це зміщення є тим більшим, чим більшою є тривалість паузи у струмі індуктивності.* ***Практична значимість.*** *Визначено, що заданий коефіцієнт пульсацій вихідної напруги ІР, у режимі переривчатого струму, забезпечується меншим значенням добутку LC елементів ІР, у порівнянні з режимом безперервного струму.* Бібл. 17, табл. 2, рис. 5.

Ключові слова: **режим переривчастого струму індуктивності, регулювальні характеристики імпульсного регулятора, коефіцієнт пульсації вихідної напруги.**

Introduction. Pulse regulators (PRs) are widely used to regulate and stabilize the supply voltage of DC consumers [1–4]. Due to the widespread use of non-traditional and renewable sources of electrical energy, PRs have been used to match the output resistance of the electrical energy source with the load resistance, in order to extract the maximum possible power from the source [5–9]. The main characteristic of the PR is its regulation characteristic $U_{out} = f(t^*)$ – the dependence of the PR output voltage on the regulated parameter t^*, where $t^* = t_{cl} / T$ – the relative time of the closed state of the key t_{cl} during the period T. In the general case, two modes of operation of the PR are possible [10–13].

- mode of continuous current flow in the inductance;
- mode of intermittent current in the inductance.

At the moment of transition of the PR from one operating mode to another, its regulation characteristics change.

In the continuous current mode in the operating range, the average value of the voltage across the load does not depend on its resistance R. The current flowing through the PR inductance has a relatively small ripple. Since the variable component of this current is closed through the filter capacitor, the capacitance of this capacitor can be relatively small. In the intermittent conductance mode, the shape factor of this current increases. Therefore, the power losses in the PR elements will be greater than in the continuous current mode. The capacitance of the filter capacitor also increases. An important disadvantage of such a mode is that the PR output voltage will depend on the load resistance R. Since in the intermittent conductance mode, the PR regulation characteristic $U_{out} = f(t^*; R)$ is a function of two variables, in this mode the PR is described not by one, but by a family of regulation characteristics. Taking into account the above disadvantages, PRs in various fields of application operate mainly in the continuous conductance mode. However, in certain cases, for example, to reduce switching losses in the key and valve elements of the PR, its operation in the mode of intermittent inductance current is possible and advisable [14–17].

In the listed works, the continuous and intermittent current modes are considered separately. The regulation characteristic is given only for the continuous current mode. At the same time, the converter can be used simultaneously in two modes. In such cases, it is necessary to have regulation characteristics that would be valid for both of the specified modes. Therefore, it is important to know the features of the PR operation in the intermittent conduction mode, as well as methods for determining the regulation characteristics in such a mode.

The goal of the work is to develop a mathematical model that would describe the operation of the PR in the continuous and intermittent conduction modes, in particular, to obtain regulation characteristics that would be valid for both of the specified modes.

The main part. As is known [16], the continuous current mode in the inductance L will be ensured under the condition

$$\Delta I_L / 2 \le I_L, \qquad (1)$$

where I_L is the constant component of the current through the inductance; $\Delta I_L = I_{L\max} - I_{L\min}$ is the ripple of this current.

In the intermittent current mode, as well as in the limit mode, $I_{L\min} = 0$. Therefore, for these modes $\Delta I_L = I_{L\max} = I_m$. Let us analyze the conditions for the fulfillment of inequality (1) using the example of a common PR circuit of the step-down type. In the analysis, we will assume that the output voltage of the PR is well smoothed, and the losses in its elements are insignificant [14–17].

PR of the step-down type. For PR of the step-down type (Fig. 1) in the mode of continuous current of inductance L, the following conditions are met [16]:

$$U_{out} = U_{in} t^*;\ I_{out} = I_{in} / t^*, \qquad (2)$$

where $t^* = t_{cl} / T$ is the relative time of the closed state of the key S in the period T. These are the regulation characteristics of the PR for the continuous conduction mode.

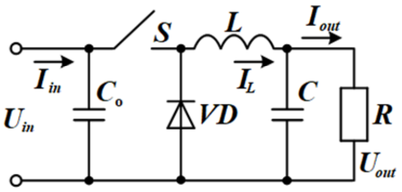

Fig. 1. Step-down type PR

In the steady-state mode of operation of the PR, the change in the inductance current in the stages of the closed and open state of the key S is the same, but has the opposite sign

$$\Delta I_{Lcl} = \Delta I_{Lop} = I_m.$$

Let's determine the value of this change:

$$I_m = \frac{U_{in} - U_{out}}{L} t_{cl} = \frac{U_{out}}{L} t_{op}. \qquad (3)$$

Then, the condition for continuous inductance current (1) can be written as follows:

$$\frac{U_{in} - U_{out}}{2L} t_{cl} \le I_L = I_{out} = \frac{U_{out}}{R}. \qquad (4)$$

Divide both sides of the inequality by T:

$$(U_{in} - U_{out}) t^* \le U_{out}\, 2\tau^*,$$

where $\tau^* = L / RT$.

Therefore, the condition for continuity of current in the inductance for the circuit (Fig. 1):

$$\tau^* \ge (1 - t^*) / 2. \qquad (5)$$

The larger the parameter t^*, the smaller the inductance L can be, at which the continuous current mode is ensured. To ensure such a mode in the entire control range ($t^* > 0$), the following condition must be met:

$$\tau^* \ge 0.5. \qquad (6)$$

If $\tau^* < 0.5$, the mode of intermittent current of inductance L will arise during the PR regulation process. Therefore, $\tau^* = 0.5$ is the critical parameter at which the PR transitions from one operating mode to another:

$$\tau^*_{cr} = L / RT = 0.5. \qquad (7)$$

To ensure continuous current mode in the entire control range, the inductance L should be selected from the condition $L \ge 0.5RT$. If the resistance R will change during operation, it is necessary to take its maximum value. Under such a condition, the inductance L is called critical:

$$L_{cr} = 0.5 R_{\max} T. \qquad (8)$$

Discontinuous conduction mode. Figure 2,*a* shows the inductor current graph in the limit mode, and Fig. 2,*b* – in the discontinuous mode. Since the voltage at the input of the PR is constant and the output voltage is well smoothed, the current in the inductance L at intervals varies linearly and has a triangular shape [14–17].

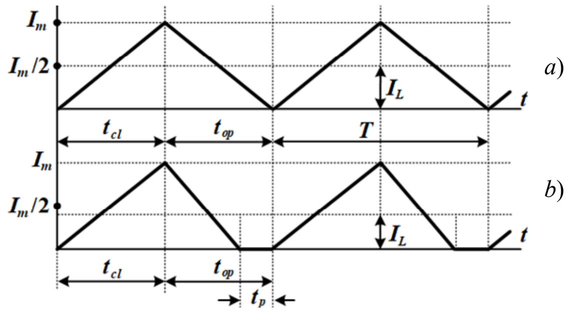

Fig. 2. Inductance current:
a) limit mode; *b*) intermittent mode

In the steady-state mode of operation of the PR, regardless of the inductance operating mode, the average value of the voltage on it for the period $U_L(T) = 0$. Therefore, the volt-second integrals at the stage of the closed and open state of the key should be the same, but with the opposite sign. According to Fig. 2,*b*, for the intermittent current mode we can write:

$$(U_{in} - U_{out}) t_{cl} = U_{out} (t_{op} - t_p), \qquad (9)$$

where t_p is the the duration of the pause in the inductance current.

Let's determine the output voltage in the intermittent current mode:

$$U_{in}\, t_{cl} = U_{out} (t_{cl} + t_{op} - t_p) = U_{out} (T - t_p).$$

Therefore:

$$U_{out} = U_{in}\, t_{cl} / (T - t_p),$$

or in relative units:

$$U^* = t^* / (1 - t_p^*), \qquad (10)$$

where $U^* = U_{out} / U_{in}$; $t_p^* = t_p / T$.

Thus, for a given value of the parameter t^*, the output voltage of the PR will be the greater, the greater the duration of the pause in the inductance current. In the continuous current mode, as well as the limit mode, $t_p = 0$ and the output voltage $U_{out} = U_{in}\, t^*$, which coincides with (2). Let us determine what the duration t_p depends on.

In the steady-state mode of operation of the PR, its output voltage is:

$$U_{out} = I_{out} R = I_L R.$$

In the limit operation mode (Fig. 2,*a*), the average value of the inductance current can be determined as:

$$I_L = I_m / 2.$$

According to Fig. 2,*b*, the average value of the inductance current in intermittent mode:

$$I_L = \frac{I_m}{2}\frac{(T - t_p)}{T} = \frac{I_m}{2}\left(1 - t_p^*\right). \qquad (11)$$

Similarly to (3), we can write:

$$\frac{I_m}{2} = \frac{U_{out}}{2L}\left(t_{op} - t_p\right) = \frac{U_{out} T}{2L}\left(1 - t^* - t_p^*\right).$$

Then, according to (11):

$$I_{out} = I_L = \frac{U_{out} T}{2L}\left(1 - t^* - t_p^*\right)\left(1 - t_p^*\right).$$

Therefore:

$$U_{out} = I_{out} R = \frac{U_{out}}{2\tau^*}\left(1 - t^* - t_p^*\right)\left(1 - t_p^*\right).$$

As a result, we obtain the following quadratic equation:

$$t_p^{*2} - t_p^*\left(2 - t^*\right) + \left(1 - t^* - 2\tau^*\right) = 0. \qquad (12)$$

The real root of this equation is the duration of the pause:

$$t_p^* = \frac{\left(2 - t^*\right) - \sqrt{t^{*2} + 8\tau^*}}{2}. \qquad (13)$$

Table 1 shows the results of calculating the interval duration t_p^* (13) and the PR output voltage (10) for different values of the parameter τ^*.

Table 1

Duration t_p^* calculations

τ^*=0.5	t^*	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
	$U^* t_p^*$=0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
τ^*=0.4	t_p^*	0.06	0	0	0	0	0	0	0	0	0
	U^*	0.106	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
τ^*=0.3	t_p^*	0.17	0.12	0.08	0	0	0	0	0	0	0
	U^*	0.12	0.23	0.33	0.4	0.5	0.6	0.7	0.8	0.9	1
τ^*=0.2	t_p^*	0.32	0.26	0.2	0.14	0.07	0	0	0	0	0
	U^*	0.15	0.27	0.38	0.46	0.54	0.6	0.7	0.8	0.9	1
τ^*= 0.1	t_p^*	0.5	0.44	0.37	0.31	0.24	0.16	0.08	0	0	0
	U^*	0.2	0.36	0.48	0.58	0.66	0.71	0.76	0.8	0.9	1
τ^*=0.05	t_p^*	0.63	0.57	0.5	0.42	0.34	0.27	0.18	0.09	0	0
	U^*	0.27	0.46	0.6	0.69	0.75	0.82	0.85	0.88	0.9	1

Based on the results of these calculations, in Fig. 3, graphs of the regulation characteristics of the step-down type PR are plotted, which are valid for both the continuous conduction mode and the intermittent mode.

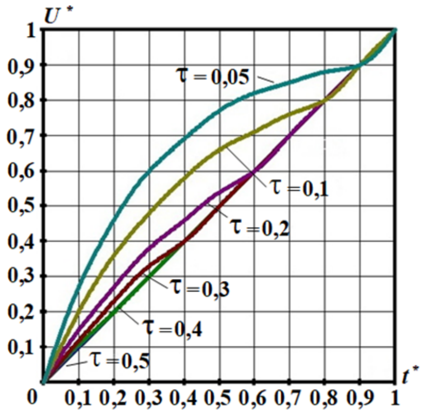

Fig. 3 Regulation characteristics of PR of step-down type

According to these graphs, in the case of $\tau^* < 0.5$ the PR switches to the mode of intermittent current of inductance L. With a decrease in the parameter τ^*, the regulation characteristics will deviate towards higher output voltages compared to the continuous current mode. However, smoothing of the output voltage of PR is provided not only by the inductance L, but also by the capacitance C, or rather by their product LC [16]. Let us determine how the transition of PR to the mode of intermittent current will affect the value of this product.

Let the ripple coefficient of the output voltage of PR be given:

$$K_p = \Delta U_{out} / 2U_{out}, \qquad (14)$$

which must be provided on the load R.

Let us consider in more detail one period of the inductance current i_L in intermittent mode (Fig. 4).

Under the influence of the shaded part of this current, the voltage on the capacitance C will increase by the value:

$$\Delta U_C = \Delta q / C, \qquad (15)$$

where Δq is the change in charge on a capacitor.

This current has the shape of a triangle with height $(I_m - I_L)$ and duration t_x. The average value of this current, which is proportional to the area of the triangle, will determine the change in charge on the capacitor:

$$\Delta q = \frac{(I_m - I_L)t_x}{2} = \frac{(I_m - I_L)T t_x^*}{2}. \qquad (16)$$

Taking into account (11):

$$I_m - I_L = I_m - \frac{I_m}{2}\left(1 - t_p^*\right) = \frac{I_m}{2}\left(1 + t_p^*\right). \qquad (17)$$

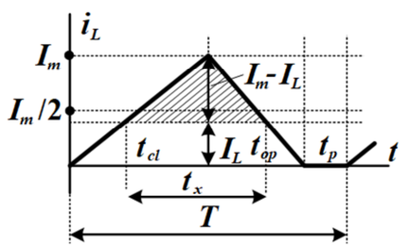

Fig. 4. Inductance current in intermittent mode

Using the properties of similar triangles, we can write:

$$\frac{I_m}{I_m - I_L} = \frac{T - t_p}{t_x} = \frac{1 - t_p^*}{t_x^*}. \qquad (18)$$

Therefore, taking into account (17):

$$t_x^* = \frac{(I_m - I_L)\cdot(1-t_p^*)}{I_m} = \frac{I_m(1+t_p^*)\cdot(1-t_p^*)}{2I_m} = \frac{1-t_p^{*2}}{2}. \quad (19)$$

Then, according to (16):

$$\Delta q = \frac{I_m(1+t_p^*)\cdot T\cdot(1-t_p^{*2})}{2\cdot 2\cdot 2} = \frac{I_m T(1+t_p^*)\cdot(1-t_p^{*2})}{8}. \quad (20)$$

Taking into account (9) and (15), we finally obtain:

$$\Delta U_{out} = \Delta U_C = \frac{\Delta q}{C} = \frac{U_{out}T^2}{8LC}(t_{op}^* - t_p^*)(1+t_p^*)(1-t_p^{*2}). \quad (21)$$

Then, according to (14), we obtain the formula for determining the ripple coefficient of the output voltage of PR of the step-down type, which is valid for the modes of continuous and intermittent current of inductance L:

$$K_p = \frac{\Delta U_{out}}{2U_{out}} = \frac{T^2}{16LC}(t_{op}^* - t_p^*)(1+t_p^*)(1-t_p^{*2}). \quad (22)$$

In particular, for the continuous conduction mode ($t_p = 0$), we obtain the well-known formula [16]:

$$K_p = \frac{T^2}{16LC}t_{op}^*. \quad (23)$$

Thus, in the continuous current mode, in particular in the limit mode, for a given value of the LC product, the ripple coefficient of the output voltage will depend on the duration of the open state of the key t_{op}^* and, in the worst case ($t_{op}^* \to 1$), reaches the maximum value:

$$K_{p\max} = \frac{T^2}{16LC}. \quad (24)$$

Suppose that the task is to provide a given value of the ripple coefficient of the PR output voltage K_p. In the continuous current mode, to provide a given K_p, the product LC:

$$(LC)_{CCM} = \frac{T^2}{16K_p}t_{op}^*, \quad (25)$$

and the given K_p can be obtained by increasing the inductance and decreasing the capacitance, and vice versa.

In the intermittent current mode, the required product LC:

$$(LC)_{DCM} = \frac{T^2}{16K_p}(t_{op}^* - t_p^*)(1+t_p^*)(1-t_p^{*2}), \quad (26)$$

will depend not only on the duration of the open state of the key t_{op}^*, but also on the duration of the pause t_p^*. To analyze this dependence, we define the relation:

$$(LC)^* = \frac{(LC)_{DCM}}{(LC)_{CCM}} = \frac{(t_{op}^* - t_p^*)(1+t_p^*)(1-t_p^{*2})}{t_{op}^*}. \quad (27)$$

Taking into account the results presented in Table 1, Table 2 shows the results of the calculations of the relation $(LC)^*$. Figure 5 shows the graphs of the dependence $(LC)^* = f(t_{op}^*)$ for different values of the parameter τ^*, on which the duration of the pause t_p^* depends at a given t_{op}^*.

Table 2

Calculation results of $(LC)^*$

τ^*=0.5	t_{op}^*	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1
	$(LC)^*$ t_p^*=0	1	1	1	1	1	1	1	1	1
τ^*=0.4	t_p^*	0.06	0	0	0	0	0	0	0	0
	$(LC)^*$	0.97	1	1	1	1	1	1	1	1
τ^*=0.3	t_p^*	0.17	0.12	0.08	0	0	0	0	0	0
	$(LC)^*$	0.92	0.93	0.95	1	1	1	1	1	1
τ^*=0.2	t_p^*	0.32	0.26	0.2	0.14	0.07	0	0	0	0
	$(LC)^*$	0.77	0.79	0.82	0.84	0.91	1	1	1	1
τ^*=0.1	t_p^*	0.5	0.44	0.37	0.31	0.24	0.16	0.08	0	0
	(LC)*	0.5	0.52	0.54	0.57	0.62	0.68	0.78	1	1
τ^*=0.05	t_p^*	0.63	0.574	0.5	0.42	0.34	0.27	0.18	0.09	0
	$(LC)^*$	0.3	0.305	0.321	0.34	0.35	0.38	0.46	0.59	1

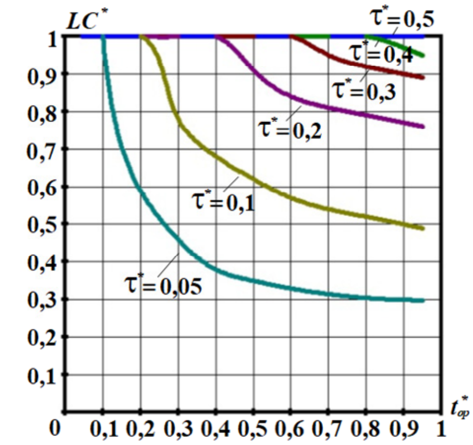

Fig. 5 Dependence $(LC)^* = f(t_{op}^*)$ for different values τ^*

Analysis of the obtained graphs shows:

- in the intermittent conduction mode, the specified ripple coefficient of the PR output voltage K_p is provided by a smaller value of the product LC of its elements;
- with a decrease in the parameter $\tau^* = L/RT$, the required value of the product decreases;
- with an increase in the duration of the interval t_{op}^*, the required product LC decreases. In the extreme case ($t_{op}^* \to 1$)

$$(LC)^* \to (1-t_p^{*2})^2. \quad (28)$$

In the continuous current mode, by changing the inductance L to kL, we can reduce the capacitance C by C/k. The intermittent current mode occurs when the inductance $L < L_{cr}$ decreases. However, in this case, the necessary increase in the capacitance C will be less than in the continuous current mode. For example, in the case of $\tau^* = 0.05$, $L < L_c$ by a factor of 10. At the same time, according to the graphs (Fig. 5), to ensure the same K_p, in the case of $t_{op}^* > 0.4$, the capacitance will have to be increased only by a factor of 3.5. This can be explained by the fact that in the discontinuous mode, at a given input voltage, the output voltage increases, which, according to (14), reduces K_p. Therefore, the given ripple coefficient can be obtained using a smaller value of the product LC.

Conclusions.

1. A mathematical model is proposed that describes the behavior of the PR in the continuous and intermittent conduction modes, which made it possible to unify the description of both modes within a single theoretical basis.

2. A family of regulation characteristics is determined that are valid for both modes of operation of the PR and show that when the PR transitions to the mode of intermittent conduction current, its regulation characteristics are shifted towards higher output voltages. This shift is greater, the longer the duration of the pause in the inductance current.

3. It is shown that to ensure a given ripple coefficient of the PR output voltage, in the intermittent current mode, a smaller value of the *LC* product of the PR elements is required than in the continuous current mode, which makes it possible to reduce the size and cost of the PR element base.

Conflict of interest. The authors declare no conflict of interest.

REFERENCES

1. Valarmathy A.S., Prabhakar M. High gain interleaved boost-derived DC-DC converters – A review on structural variations, gain extension mechanisms and applications. *E-Prime - Advances in Electrical Engineering, Electronics and Energy*, 2024, vol. 8, art. no. 100618. doi: https://doi.org/10.1016/j.prime.2024.100618.

2. Romashko V.Y., Batrak L.M., Abakumova O.O. Features of the work of pulse regulators in the maximum power transmission mode, with the presence of an accumulator at their output. *Electrical Engineering & Electromechanics*, 2023, no. 6, pp. 63-66. doi: https://doi.org/10.20998/2074-272X.2023.6.11

3. Sarowar G., Ahmed I., Rahman S., Al Mamun A., Salim K.M. Investigation of a power factor correction converter utilizing SEPIC topology with input current switching. *Results in Engineering*, 2024, vol. 22, art. no. 102271. doi: https://doi.org/10.1016/j.rineng.2024.102271.

4. Pallekonda A.K., Ch R.K. High gain interleaved PFC converter for torque ripple minimization in industrial PMBLDC motor based drives. *Results in Engineering*, 2024, vol. 23, art. no. 102413. doi: https://doi.org/10.1016/j.rineng.2024.102413.

5. Bushra E., Zeb K., Ahmad I., Khalid M. A comprehensive review on recent trends and future prospects of PWM techniques for harmonic suppression in renewable energies based power converters. *Results in Engineering*, 2024, vol. 22, art. no. 102213. doi: https://doi.org/10.1016/j.rineng.2024.102213.

6. Pirashanthiyah L., Edirisinghe H.N., De Silva W.M.P., Bolonne S.R.A., Logeeshan V., Wanigasekara C. Design and Analysis of a Three-Phase Interleaved DC-DC Boost Converter with an Energy Storage System for a PV System. *Energies*, 2024, vol. 17, no. 1, art. no. 250. doi: https://doi.org/10.3390/en17010250.

7. Oliver J.S., David P.W., Balachandran P.K., Mihet-Popa L. Analysis of Grid-Interactive PV-Fed BLDC Pump Using Optimized MPPT in DC–DC Converters. *Sustainability*, 2022, vol. 14, no. 12, art. no. 7205. doi: https://doi.org/10.3390/su14127205.

8. Srividya S., Praveena A., TatiReddy Ravi, SathishKumar K. Single Switch DC-DC Boost Converter with MPPT Control for Fuel Cell Electric Vehicle Applications. *2023 Innovations in Power and Advanced Computing Technologies (i-PACT)*, 2023, pp. 1-6. doi: https://doi.org/10.1109/i-PACT58649.2023.10434573.

9. Romashko V.Y., Batrak L.M., Abakumova O.O. Step-up/step-down regulators in maximum power transmission mode. *Electrical Engineering & Electromechanics*, 2022, no. 2, pp. 18-22. doi: https://doi.org/10.20998/2074-272X.2022.2.03.

10. Huang L. Reduced-order discrete modeling method and nonlinear analysis of a discontinuous conduction mode buck converter with a constant power load. *Energy Reports*, 2023, vol. 9, pp. 1021-1036. doi: https://doi.org/10.1016/j.egyr.2023.04.133.

11. Serra F.M., Esteban F.D., Montoya O.D. Control of DC-DC boost converter in discontinuous conduction mode feeding a constant power load. *Results in Engineering*, 2024, vol. 23, art. no. 102732. doi: https://doi.org/10.1016/j.rineng.2024.102732.

12. Veeramraju K.J., Eisen J., Rovey J.L., Kimball J.W. A New Discontinuous Conduction Mode in a Transformer Coupled High Gain DC-DC Converter. *2022 IEEE Applied Power Electronics Conference and Exposition (APEC)*, 2022, pp. 237-244. doi: https://doi.org/10.1109/APEC43599.2022.9773417.

13. Madrid E., Murillo-Yarce D., Restrepo C., Muñoz J., Giral R. Modelling of SEPIC, Ćuk and Zeta Converters in Discontinuous Conduction Mode and Performance Evaluation. *Sensors*, 2021, vol. 21, no. 22, art. no. 7434. doi: https://doi.org/10.3390/s21227434.

14. Parada Salado J.G., Herrera Ramírez C.A., Soriano Sánchez A.G., Rodríguez Licea M.A. Nonlinear Stabilization Controller for the Boost Converter with a Constant Power Load in Both Continuous and Discontinuous Conduction Modes. *Micromachines*, 2021, vol. 12, no. 5, art. no. 522. doi: https://doi.org/10.3390/mi12050522.

15. González I., Sánchez-Squella A., Langarica-Cordoba D., Yanine-Misleh F., Ramirez V. A PI + Sliding-Mode Controller Based on the Discontinuous Conduction Mode for an Unidirectional Buck–Boost Converter with Electric Vehicle Applications. *Energies*, 2021, vol. 14, no. 20, art. no. 6785. doi: https://doi.org/10.3390/en14206785.

16. Goncharov Y.P., Budonny O.V., Morozov V.G., Panasenko M.V, Romashko V.Y., Rudenko V.S. *Peretovyuvalna technicala. Navchalnyi posibnyk. Chastyna 2* [Power conversion equipment. Text book. Part 2]. Kharkiv, Folio Publ., 2000. 360 p. (Ukr).

17. Serra F.M., Magaldi G.L., Martin Fernandez L.L., Larregay G.O., De Angelo C.H. IDA-PBC controller of a DC-DC boost converter for continuous and discontinuous conduction mode. *IEEE Latin America Transactions*, 2018, vol. 16, no. 1, pp. 52-58. doi: https://doi.org/10.1109/TLA.2018.8291454.

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