Crossref
DOI: 10.31643/2028/6445.04
Mining & Mineral Processing

Qualitative Analysis of the Circuits of Au-Tonomous Inverters with Shut-off Valves

[1] Toshov J.B., [2*] Zheldikbayeva A.T., [3] Sarsenbayev Y., [2] Smagulova K.K., [1] Umarov Sh., [1] Pulatov A. [2] Abdykenov Y.K.

[1] *Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan*
[2] *Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan*
[3] *Satbayev University, Almaty, Kazakhstan*

** Corresponding author email: aisaule89@mail.ru*

Received: *May 17, 2025*
Peer-reviewed: *June 2, 2025*
Accepted: *April 24, 2026*

ABSTRACT
The article presents the results of a qualitative analysis of circuits of autonomous current and voltage inverters with cut-off valves. The influence of the charge on the switching capacitor in parallel and series equivalent circuits on the restoration of the switching properties of the thyristors in the inverter power circuit is studied. It is shown that, due to the energy periodically accumulated in the inductive elements of the load, the voltage across the switching capacitor in the cut-off state is higher than in a conventional parallel autonomous current inverter. This ensures increased switching stability of the inverter. Consequently, the circuit of an autonomous current inverter with cut-off valves remains operational in valve converters for variable-frequency electric drives and maintains performance during sudden load surges and short circuits, since the voltage on the switching capacitor does not depend on the load voltage. Thus, the charge on the switching capacitor is preserved even when the load voltage drops sharply between thyristor commutations.

Keywords: autonomous current inverter, inductive load, valve frequency converter, variable-frequency electric drive, cut-off valves, commutation capacitor charge.

Information about authors:

Toshov Javokhir Buriewicz	*Doctor of Technical Sciences, Professor, Islam Karim Tashkent State Technical University, 100095, Almazar district, Universitetskaya street 2, Tashkent, Uzbekistan. E-mail: j.toshov@tdtu.uz; ORCID ID: https://orcid.org/0000-0003-4278-1557*
Zheldikbayeva Aisaule Takenovna	*PhD student of the Department of Automation of manufacturing processes, Abylkas Saginov Karaganda Technical University, 100027, Ave. Nursultan Nazarbayev, 56, Karaganda, Kazakhstan. E-mail: aisaule89@mail.ru; ORCID ID: https://orcid.org/0009-0005-1325-5576*
Sarsenbayev Yerlan	*PhD, Associate Professor, Head of Department of Power Engineering, Satbayev University, 050013, Satbayev str. 22, Almaty, Kazakhstan. E-mail: y.sarsenbayev@satbayev.university; ORCID ID: https://orcid.org/0000-0002-8887-1171*
Smagulova Karshiga Kanatovna	*Ph.D., Acting Associate Professor of the Department of Automation of manufacturing processes, Abylkas Saginov Karaganda Technical University, 100027, Ave. Nursultan Nazarbayev, 56, Karaganda, Kazakhstan. E-mail: smagulovakk@mail.ru; ORCID ID: https://orcid.org/0000-0001-6834-8490*
Umarov Shukhrat	*Doctor of Technical Sciences, Professor of the department Electrical machines and drivers engineering, Islam Karim Tashkent State Technical University, 100095, Almazar district, Universitetskaya street 2, Tashkent, Uzbekistan. E-mail: shumarov1951@mail.ru; ORCID ID: https://orcid.org/0000-0002-9262-4683*
Pulatov Abror	*Ph.D., Associate Professor, Head of the department Electrical machines and drivers engineering, Islam Karim Tashkent State Technical University, 100095, Almazar district, Universitetskaya street 2, Tashkent, Uzbekistan. E-mail:abrorobidovich@mail.ru; ORCID ID: https://orcid.org/0000-0002-2641-571X*
Abdykenov Yerzhan Kanatuly	*PhD student of the Department of Automation of manufacturing processes, Abylkas Saginov Karaganda Technical University, 100027, Ave. Nursultan Nazarbayev, 56, Karaganda, Kazakhstan. E-mail: erzhan_aiu@mail.ru; ORCID ID: https://orcid.org/0009-0008-0095-576X*

Introduction

In modern industry, variable-frequency electric drives based on valve converters play a critical role in ensuring energy efficiency, precise speed control, and operational reliability of technological processes. However, traditional autonomous current inverters (ACI) using thyristors encounter significant challenges in achieving reliable forced commutation, particularly under variable or shock loads, low operating frequencies, and during overloads or short circuits. In conventional parallel ACI circuits, the voltage across the commutation capacitor depends directly on the load voltage. This often results in insufficient reverse bias for thyristor turn-off, leading to commutation failures and reduced operational stability [[1], [2], [3], [4]].

These limitations are especially pronounced in high-power applications in mining, metallurgy, and transport sectors, where sudden load changes are common and high commutation reliability is essential. Although various auxiliary commutation circuits have been proposed in the literature, many of them still suffer from strong dependence on load parameters, require oversized capacitors, or exhibit limited overload capability.

A promising approach to overcome these drawbacks is the use of cut-off valves (auxiliary diodes or thyristors), which decouple the commutation capacitor from the load during critical intervals. This allows independent charging of the capacitor and retention of a higher voltage.

Despite numerous studies devoted to modeling and simulation of ACI [[2], [5], [6]], a detailed qualitative analysis of the influence of cut-off valve circuits on commutation processes — particularly the charge dynamics of the switching capacitor in series and parallel equivalent circuits under real operating conditions, including overloads — remains insufficiently addressed. This research gap motivates the present study, which performs a physico-mathematical qualitative analysis of such circuits.

This study aims to conduct a qualitative analysis of autonomous inverter circuits with cut-off valves and to evaluate the effect of the switching capacitor charge on the restoration of thyristor switching properties, thereby enhancing the stability and reliability of inverters for variable-frequency electric drives.

The experimental part

Theoretical Analysis and Equivalent Circuits.

In quasi-steady-state mode, the capacitors in the power circuit of an autonomous current inverter (ACI) act as the primary source for compensating the reactive power of the load and restoring the blocking properties of the thyristors, thereby maintaining the reactive energy balance:

$$Q_{\text{H}} = Q_{\delta} \quad (1)$$

where: Q_{δ} - is the reactive power required to restore the thyristors' blocking capability;

Q_{H}- is the reactive power of the load.

Figures 1 and 2 illustrate that the voltage waveform across the capacitors in a conventional ACI without cut-off valves is nearly sinusoidal, whereas in circuits with cut-off valves, it approaches a trapezoidal shape. Reducing the capacitance value leads to steeper voltage fronts and enrichment of the load voltage with higher harmonics. This redistribution of reactive energy significantly affects commutation stability [[7], [8], [9], [10]].

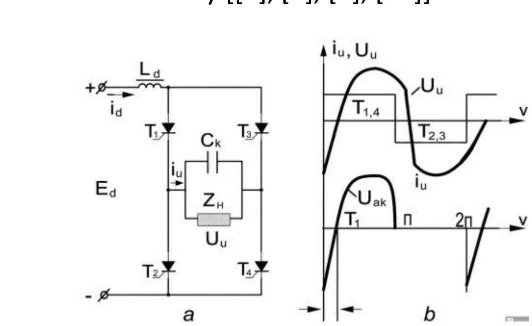
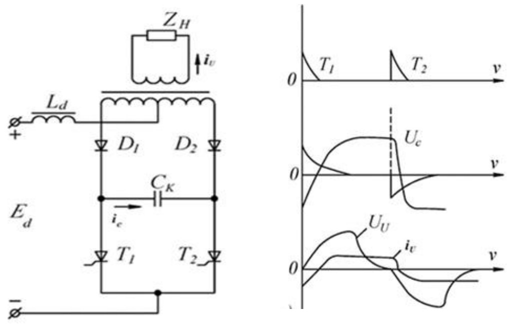


Figure 1 - Scheme (a) and time diagrams (b) of a single-phase ACI



a) b)

Figure 2 - Scheme (a) and time diagrams (b) of a single-phase ACI with OV

A detailed analysis of the single-phase bridge circuit with cut-off valves (Fig. 3) shows that at the instant of commutation (t = 0), the reverse voltage across the outgoing thyristors is higher due to the energy stored in the load inductance. This enables the cut-off diodes (or thyristors) to maintain the charge on the switching capacitor independently of the instantaneous load voltage.

Equivalent circuits (series and parallel) were derived, and analytical expressions describing the capacitor voltage and current during the recharge intervals were obtained. The structure of the single-phase ACI with DC cut-off is illustrated in Figure 4.

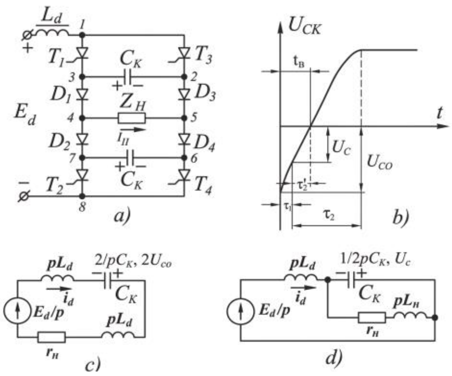


Figure 3 - ACI with S: circuit (a); time diagram of the capacitor voltage (b); replacement circuits (c, d).

Detailed Operation of the ACI with Cut-off Valves

Consider the operation of a single-phase bridge ACI with cut-off valves in quasi-steady-state mode (Fig. 3). At the instant t = 0, when thyristors T3 and T2 are turned on by the control system, thyristors T1 and T4 are instantly reverse-biased and turn off. However, the cut-off diodes do not conduct immediately because the absolute value of the capacitor voltage exceeds the load voltage. The capacitor discharge occurs through the series LC circuit (contour 1-2-3-4-5-6-7-8, see equivalent circuit in Fig. 3c).

When the capacitor voltage reaches zero, the cut-off diodes open, and the load current and capacitor voltage change polarity. The interval for restoring the blocking properties of the outgoing thyristors ends when the capacitor voltage reaches a certain negative value.

To investigate the influence of the switching capacitor charge in series and parallel equivalent circuits, the cut-off diodes were replaced with controlled thyristors, allowing a deliberate delay in their turn-on. This makes it possible to adjust the duration of the series and parallel recharge intervals.

Under simplifying assumptions, the system of equations describing the circuit behavior was derived as follows:

$$\tau_1 < \tau_{11} < (\tau_1 + \tau_2) \quad (2)$$

For the case of replacing cut-off diodes with thyristors, under the simplifying assumption $i_d(\mathrm{t}) = I_d = const$, the following system of calculation expressions can be obtained for a single-phase ACI with cut-off thyristors:

$$U'_{11} = r_{\text{н}} I_d$$

$$\tau_2 = \frac{\left[\pi - arctg\left(\frac{\Omega_1}{6_1}\right)\right]}{\Omega_1}$$

$$U_{11} = r_{\text{н}} I_d + \frac{[2\Omega_1 L_H I_d \cdot \exp(-6_1 \tau_2)]}{\sin \Omega_1 \tau_2} \tau_1 = C\left(\frac{U_{11}}{I_d - r_{\text{н}}}\right)$$

where:

(3)

$$6_1 = \frac{r_{\text{н}}}{2L_H}\ ; \quad \Omega_1 = \left[\frac{1}{(2L_H C) - 6_1^2}\right]^{\frac{1}{2}}.$$

$$U_{11} = |U_{C0}| = |u_C(\tau_1 + \tau_2)|$$

$$U'_{11} = u_C(\tau_1) = u_{\text{н}}(\tau_1) = u_{\text{н}}(0)$$

Here, τ_1 is characterized as the moment of transition from a serial to a parallel recharge circuit of a switching capacitor Sk.

Suppose the switching on of the cut-off thyristors is delayed relative to the moment t=0 until $u_C(\tau_{11}) = 0.$ is obtained. Then, in the interval τ_{11}, a sequential replacement circuit of the charge Cк operates. If you enter the intervalτ_{21} for a parallel circuit, then you can write the inequality:

$$\tau_{11} + \tau_{21} \neq \tau_1 + \tau_2$$

Under the above assumptions, the system of calculation ratios for ACI with cut-off thyristors has the form:

$$U_{11}^1 = 0\,,$$

$$\tau_{21} = \frac{\text{п}}{2\Omega_1}\,,$$

$$U_{11} = r_H\ I_d + 2\Omega_1 L_H I_d * exp\,(\text{-}6_1\ \tau_{21})\,,$$

(4)

$$\tau_{11} = C * U_{11}/I_d\,.$$

In the circuit with cut-off thyristorst_{B1} = τ_{11},, and in the circuit with cut-off diodest_B = $\tau_1 + \tau'_2$ Obviously, in the latter case, it is necessary to have the expression U_c (t) on the recharge interval in a parallel circuit, and then the value of τ'_2 ' is found from the solution of the equation:

$$U_c(\tau'_2) = 0. \quad (5)$$

Analysis of the obtained expressions reveals the following key advantages of ACI circuits with cut-off valves:

a) Due to the energy stored in the load inductance, the voltage across the switching capacitor in the cut-off state is higher than in a conventional parallel ACI at the moment of commutation.

b) The capacitor voltage is independent of the load voltage and operating frequency, which ensures reliable operation of the inverter in variable-frequency drives, even at low frequencies.

c) The charge on the switching capacitor is preserved even during sharp decreases in load voltage between commutations. This provides stable switching under sudden load surges and short-circuit conditions.

d) The use of cut-off thyristors allows controlled variation of the ratio between series and parallel recharge durations, offering additional flexibility in circuit design.

Complete decoupling of the commutation circuit from the load circuit in a single-phase ACI is achieved only when cut-off valves are used [[11], [12]].

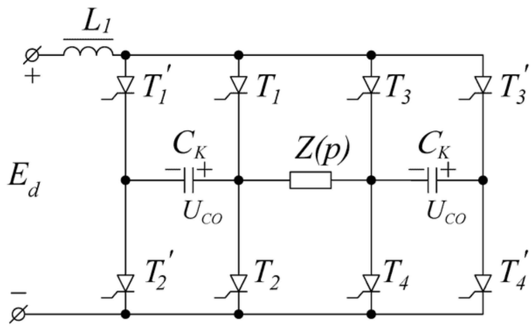


Figure 4 - Single-phase ACI circuit with DC cut-off.

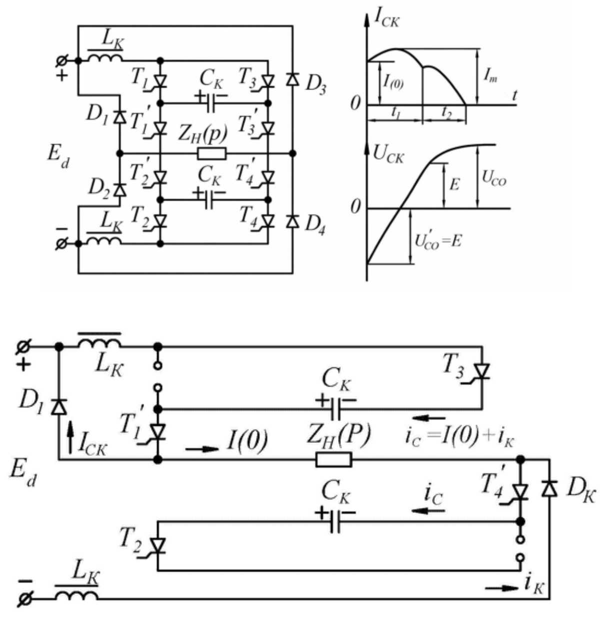


Figure 5 - Single-phase bridge ACI with cut-off valves: (a) circuit diagram; (b) switching circuit through D1 and Dк; (c) switching circuit through D2 and D3; (d) time diagrams.

Compensation of the reactivity of the load in the AIS is carried out due to the reactive current valves and the capacitance of the filter C_{Φ} connected to the power source E_d or due to inter-phase interactions. It will be shown below that the separation of the $L_{\text{к}}$ From the $C_{\text{к}}$ circuit is possible in a single-phase AIS only in the presence of OF [[13], [14]].

Let's consider the operation of a single-phase bridge circuit of an AI with an OV (Fig. 5).

Discussion of the results

The qualitative analysis demonstrates that the introduction of cut-off valves (diodes or auxiliary thyristors) fundamentally improves the commutation process in autonomous current inverters. The main advantage arises from the decoupling of the switching capacitor recharge circuit from the load during critical intervals. As a result, the voltage across the capacitor at the moment of thyristor turn-off is significantly higher than in conventional parallel autonomous current inverters (ACI), which directly enhances switching stability.

Interpretation of the results shows that the voltage on the commutation capacitor becomes largely independent of the instantaneous load voltage and operating frequency. This property is particularly valuable for variable-frequency electric drives operating at low speeds or under fluctuating loads, where traditional circuits often lose commutation reliability.

Comparison with previous research confirms the obtained findings. In conventional ACI schemes, commutation depends heavily on load parameters, which frequently leads to failures during overloads and short circuits [[15], [16]]. The analyzed circuits with cut-off valves successfully overcome this limitation, which is consistent with earlier reports on auxiliary commutation techniques [[17], [18], [19], [20]]. The observed increase in stored energy from the load inductance further supports the higher reverse bias voltage, aligning with theoretical expectations for forced-commutated thyristor inverters.

Limitations of the study

The present work is based on qualitative theoretical analysis and idealized equivalent circuits, assuming ideal circuit elements. In real devices, losses, parasitic parameters, and non-ideal thyristor recovery characteristics exist, which may quantitatively affect the predicted commutation margins. No new laboratory experiments on a physical prototype were conducted in this study; validation relied on analytical consistency and data from previously published works.

Future research plans

The next stage of the research should include detailed numerical simulation using SPICE or MATLAB/Simulink models with real thyristor parameters, followed by experimental testing on a scaled laboratory prototype under controlled overload and short-circuit conditions. Quantitative comparison of commutation margins, efficiency, and harmonic distortion with conventional circuits will provide stronger practical recommendations for industrial implementation, particularly in mining and other heavy industries.

Conclusion

The conducted qualitative analysis has shown that the use of shut-off valves in autonomous inverter circuits provides a significant improvement in commutation stability and overall operating reliability. Owing to the decoupling of the commutation capacitor from the load circuit, the capacitor is able to retain its maximum voltage between switching intervals, which makes the commutation process substantially less dependent on load conditions. This feature is especially important under variable load operation, overloads, and short-circuit modes, where conventional inverter circuits may experience a deterioration of switching performance. The study confirms that the proposed circuit solutions create more favorable conditions for restoring the blocking properties of thyristors and ensuring stable inverter operation over a wider range of operating regimes. Therefore, inverter circuits with shut-off valves can be considered a promising technical solution for valve frequency converters used in adjustable-speed electric drives, particularly in high-power industrial applications characterized by severe and rapidly changing load conditions. In addition, the identified operating principles may be extended to the development of both current-source and voltage-source inverter systems with enhanced reliability and improved dynamic characteristics. Future research may be directed toward detailed quantitative evaluation, simulation-based verification, and experimental validation of the proposed circuit approaches under real operating conditions.

Conflict of interest. On behalf of all the authors, the corresponding author declares that there is no conflict of interest.

CRediT author statement:

J. Toshov, Y. Abdykenov: Conceptualization, Methodology, Software. **K. Smagulova, A. Zheldikbayeva**: Data curation, Writing draft preparation. **Y. Sarsenbayev, Sh. Umarov**: Visualization, Investigation. **A. Pulatov**: Supervision. **A. Zheldikbayeva**: Software, Validation. **J. Toshov**: Reviewing and Editing.

Cite this article as: Toshov JB, Zheldikbayeva AT, Sarsenbayev Y, Smagulova KK, Umarov Sh, Pulatov A, Abdykenov YK. Qualitative Analysis of the Circuits of Au-Tonomous Inverters with Shut-off Valves. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2028; 344(1):38-45. https://doi.org/10.31643/2028/6445.04

Сөндіру клапандары бар автономды инверторлық схемасының сапалық талдауы

[1] Тошов Ж.Б., [2] Желдикбаева А.Т.,[3] Сарсенбаев Е.А.,[2] Смагулова К.К., [1] Умаров Ш.Б., [1] Пулатов А.А., [2] Абдыкенов Е.К.

[1] *Ислам Кәрім атындағы Ташкент Мемлекеттік Техникалық Университеті, Ташкент, Өзбекстан*
[2] *Ә. Сағынов атындағы Қарағанды техникалық университеті, Қарағанды, Қазақстан*
[3] *Сәтбаев университеті, Алматы, Қазақстан*

Мақала келді: *17 мамыр 2025*
Сараптамадан өтті: *2 маусым 2025*
Қабылданды: *24 сәуір 2026*

ТҮЙІНДЕМЕ
Мақалада ажыратқыш (сөндіру) клапандары бар автономды ток және кернеу инверторларының схемаларын сапалық талдау нәтижелері келтірілген. Параллель және тізбекті эквивалентті схемалардағы коммутациялық конденсатордың зарядының инвертордың қуат тізбегіндегі тиристорлардың коммутациялық қасиеттерін қалпына келтіруге әсері зерттелген. Жүктеменің индуктивті элементтерінде мезгіл-мезгіл жинақталатын энергияның арқасында ажыратылған күйдегі коммутациялық конденсатордағы кернеу әдеттегі параллельді автономды ток инверторына қарағанда жоғары болатыны көрсетілген. Бұл инвертордың коммутациялық тұрақтылығын арттырады.

Нәтижесінде ажыратқыш клапандары бар автономды ток инверторының схемасы айнымалы жиілікті электр жетектеріне арналған вентильді түрлендіргіштерде жұмыс істейді және кенеттен жүктеме секірістері мен қысқа тұйықталулар кезінде де өзінің жұмыс қабілеттілігін сақтайды, өйткені коммутациялық конденсатордағы кернеу жүктеме кернеуіне тәуелді емес. Сонымен, коммутациялық конденсатордың заряды тиристорларды ауыстыру аралығында жүктеме кернеуі күрт төмендеген кезде де сақталады.

Түйін сөздер: автономды тоқ инверторы, ажыратқыш клапандар, коммутациялық конденсатор, коммутациялық тұрақтылық, айнымалы жиілікті электр жетегі.

Авторлар туралы ақпарат:

Тошов Жавохир Буриевич — *Техника ғылымдарының докторы, Ислам Кәрім атындағы Ташкент Мемлекеттік Техникалық Университетінің профессоры, 100095, Алмазар ауданы, Университетская көшесі 2, Ташкент, Өзбекстан. E-mail: j.toshov@tdtu.uz;ORCID ID: https://orcid.org/0000-0003-4278-1557*

Желдикбаева Айсауле Такеновна — *Әбілқас Сағынов атындағы Қарағанды техникалық университеті, Өндірістік процестерді автоматтандыру кафедрасының PhD докторанты, 100027, Нұрсұлтан Назарбаев даңғ. 56, Қарағанды, Қазақстан. E-mail: aisaule89@mail.ru; ORCID ID: https://orcid.org/0009-0005-1325-5576*

Сарсенбаев Ерлан Алиаскарович — *PhD, доцент, Сәтбаев Университеті, Энергетика кафедрасының меңгерушісі, 050013, Сәтбаев көшесі, 22, Алматы, Қазақстан. E-mail: y.sarsenbayev@satbayev.university; ORCID ID: https://orcid.org/0000-0002-8887-1171*

Смагулова Каршыга Канатовна — *PhD докторы, Әбілқас Сағынов атындағы Қарағанды техникалық университеті, Өндірістік процестерді автоматтандыру кафедрасының PhD доценті, 100027, Нұрсұлтан Назарбаев даңғ. 56, Қарағанды, Қазақстан. E-mail: smagulovakk@mail.ru; ORCID ID: https://orcid.org/0000-0001-6834-8490*

Омаров Шухрат Бадретдинович — *Техника ғылымдарының докторы, Электр машиналары және жүргізушілер техникасы кафедрасының профессоры, Ислам Кәрім атындағы Ташкент Мемлекеттік Техникалық Университеті, 100095, Алмазар ауданы, Университетская көшесі 2, Ташкент Өзбекстан. E-mail: shumarov1951@mail.ru; ORCID ID: https://orcid.org/0000-0002-9262-4683*

Пулатов Аброр Абидович — *Ph.D., доцент, Электр машиналары және жүргізушілер техникасы кафедрасының меңгерушісі, Ислам Кәрім атындағы Ташкент Мемлекеттік Техникалық Университеті, 100095, Алмазар ауданы, Университетская көшесі 2, Ташкент, Өзбекстан. E-mail: abrorobidovich@mail.ru; ORCID ID: https://orcid.org/0000-0002-2641-571X*

Абдыкенов Ержан Канатулы — *Әбілқас Сағынов атындағы Қарағанды техникалық университеті, Өндірістік процестерді автоматтандыру кафедрасының PhD докторанты, 100027, Нұрсұлтан Назарбаев даңғ. 56, Қарағанды, Қазақстан. E-mail: erzhan_aiu@mail.ru; ORCID ID: https://orcid.org/0009-0008-0095-576X*

Качественный анализ схем автономных инверторов с запорными клапанами

[1] Тошов Ж.Б., [2] Желдикбаева А.Т., [3] Сарсенбаев Е.А., [2] Смагулова К.К., [1] Умаров Ш.Б., [1] Пулатов А.А., [2] Абдыкенов Е.К.

[1] Ташкентский государственный технический университет имени Ислама Карима, Ташкент, Узбекистан
[2] Карагандинский технический университет имени А. Сагинова, Караганда, Казахстан
[3] Satbayev University, Алматы, Казахстан

Поступила: *17 мая 2025*
Рецензирование: *2 июня 2025*
Принята в печать: *24 апреля 2026*

АННОТАЦИЯ

В статье представлены результаты качественного анализа схем автономных инверторов тока и напряжения с запорными (отсечными) вентилями. Исследовано влияние величины заряда коммутирующего конденсатора в параллельных и последовательных схемах замещения на восстановление коммутационных свойств тиристоров силовой цепи инвертора. Показано, что благодаря энергии, периодически накапливаемой в индуктивных элементах нагрузки, напряжение на коммутирующем конденсаторе в отключённом состоянии выше, чем в обычном параллельном автономном инверторе тока. Это обеспечивает повышение коммутационной устойчивости инвертора. В результате схема автономного инвертора тока с запорными вентилями сохраняет работоспособность в вентильных преобразователях для частотно-регулируемых электроприводов и остаётся работоспособной при внезапных бросках нагрузки и коротких замыканиях, поскольку напряжение на коммутирующем конденсаторе не зависит от напряжения нагрузки. Таким образом, заряд коммутирующего конденсатора сохраняется даже при резком снижении напряжения нагрузки в промежутках между коммутациями тиристоров.

Ключевые слова: автономный инвертор тока, запорные вентили, коммутирующий конденсатор, коммутационная устойчивость, частотно-регулируемый электропривод.

Тошов Жавохир Буриевич	***Информация об авторах:*** *Доктор технических наук, профессор Ташкентского государственного технического университета имени Ислама Карима, 100095, Алмазарский район, улица Университетская 2, Ташкент, Узбекистан. E-mail: j.toshov@tdtu.uz; ORCID ID: https://orcid.org/0000-0003-4278-1557*
Желдикбаева Айсауле Такеновна	*PhD докторант кафедры Автоматизации производственных процессов, Карагандинский технический университет имени А. Сагинова, 100027, пр. Нурсултана Назарбаева, 56, Караганда, Казахстан. E-mail: aisaule89@mail.ru; ORCID ID: https://orcid.org/0009-0005-1325-5576*
Сарсенбаев Ерлан Алиаскарович	*PhD, Доцент, заведующий кафедрой энергетики, Satbayev University, 050013, ул. Сатбаева. 22, Алматы, Казахстан. E-mail: y.sarsenbayev@satbayev.university; ORCID ID: https://orcid.org/0000-0002-8887-1171*
Смагулова Каршыга Канатовна	*Доктор PhD, доцент кафедры Автоматизации производственных процессов, Карагандинский технический университет имени А. Сагинова, 100027, пр. Нурсултана Назарбаева, 56, Караганда, Казахстан. E-mail: smagulovakk@mail.ru; ORCID ID: https://orcid.org/0000-0001-6834-8490*
Омаров Шухрат Бадретдинович	*Доктор технических наук, профессор кафедры Электрические машины и приводное оборудование, Ташкентский государственный технический университет имени Ислама Карима, 100095, Алмазарский район, улица Университетская 2, Ташкент, Узбекистан. E-mail: shumarov1951@mail.ru; ORCID ID: https://orcid.org/0000-0002-9262-4683*
Пулатов Аброр Абидович	*Ph.D., доцент, заведующий кафедрой Электрические машины и приводное оборудование, Ташкентский государственный технический университет имени Ислама Карима, 100095, Алмазарский район, улица Университетская 2, Ташкент, Узбекистан. E-mail: abrorobidovich@mail.ru; ORCID ID: https://orcid.org/0000-0002-2641-571X*
Абдыкенов Ержан Канатулы	*PhD докторант кафедры Автоматизации производственных процессов, Карагандинский технический университет имени А. Сагинова, 100027, пр. Нурсултана Назарбаева, 56, Караганда, Казахстан. E-mail: erzhan_aiu@mail.ru; ORCID ID: https://orcid.org/0009-0008-0095-576X*

References

[1] Volkov AV, Kosenko AI. Issledovanie energeticheskikh parametrov asinkhronnogo elektroprivoda na baze avtonomnogo invertora toka [Investigation of the energy parameters of an asynchronous electric drive based on an autonomous current inverter]. Electrotechnical and Computer Systems. 2011; 3(79):40-42. (In Russ).

[2] Umarov Sh, Sapaev Kh, Mirsaidov M, Ruzmatov A. Ensuring design reliability of three phase parallel inverter with cut-off valves by improving the efficiency of its mathematical modeling. Meterials of compliance with AIP Conf. Proc. 2023; 2552(1). https://doi.org/10.1063/5.0111343

[3] Egorov AN, Semenov AS, Fedorov OV. Prakticheskiy opyt ispolzovaniya pribora POWER FLEX 7000 v gornodobyvayushchey promyshlennosti [Practical experience of using the POWER FLEX 7000 device in the mining industry]. NSTU Publishing House. 2017; 4:86-93. (In Russ).

[4] Rakhmonov IU, Ushakov VYa, Niyozov NN, Kurbonov NN. Prognozirovanie elektropotrebleniya s pomoshchyu neyronnykh setey c LSTM [Forecasting electricity consumption by LSTM neural network. Bulletin of the Tomsk Polytechnic University. Geo Assets Engineering]. 2023; 334(12):125–133. (In Russ.). https://doi.org/10.18799/24131830/2023/12/4407

[5] Cahyana Y, Verrell C, Kriswanda D, Aulia GA, Yusra NA, Marta H, Sukri N, Safarov JE, Sultanova ShA. Properties comparison of oxidized and heat moisture treated (HMT) starch-based biodegradable films. Polymers. 2023; 15(9):2046. https://doi.org/10.3390/polym15092046

[6] Rakhmonov IU, Ushakov VYa, Niyozov NN, Kurbonov NN. Prognozirovanie elektropotrebleniya na osnove metoda glavnykh komponent (PCA) [Forecasting electricity consumption using the principal component analysis method. Bulletin of the Tomsk Polytechnic University]. Geo Assets Engineering. 2024; 335(12):198–209. (In Russ.) https://doi.org/10.18799/24131830/2024/12/4731

[7] Zhu S, Liu K, Qin L, et al. 'Global assessment of the asymptotic stability of three-phase inverters with saturation', electron energy analysis. 2018; 11(9):1556-1565.

[8] Mekhtiyev A, Dunayev P, Neshina Y, Alkina A, Aimagambetova R, Mukhambetov G, et al. Power supply via fiber-optical conductor for sensors of mine working monitoring system. Eastern-European Journal of Enterprise Technologies. 2023; 5(5(125)): 15–23. https://doi.org/10.15587/1729-4061.2023.289775

[9] Chen SL, Gerner FM, Tien CL. General film condensation correlations, Exp. Heat Transfer. 1987; 1:93–107. http://dx.doi.org/10.1080/08916158708946334

[10] Toshov ZhB, Rahutin MG, Toshov BR, Baratov BN. Tracking prevention in roller cone bit drilling. Eurasian Mining. 2024; 1:62–66. https://doi.org/10.17580/em.2024.01.15

[11] Kubín M, Hirš J, Plášek J. Experimental analysis of steam condensation in vertical tube with small diameter. Int. J. Heat Mass Transfer. 2016; 94:403-410.

[12] Rabatuly M, Myrzathan SA, Toshov JB, Nasimov J, Khamzaev A. Views on drilling effectiveness and sampling estimation for solid ore minerals. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2026; 336(1):5-14. https://doi.org/10.31643/2026/6445.01

[13] Roetzel W. Laminar film condensation in tubes; calculation of local film resistance and local adiabatic mixing temperature, Int. J. Heat Mass Transfer. 1973; 16:2297–2304. http://dx.doi.org/10.1016/0017-9310(73)90015-X

[14] Seban RA, Hodgson JA. Laminar film condensation in a tube with upward vapor flow, Int. J. Heat Mass Transfer. 1982; 25:1291–1300. http://dx.doi.org/10.1016/0017-9310(82)90123-5

[15] Chen SL, Gerner FM, Tien CL. General film condensation correlations, Exp. Heat Transfer. 1987; 1:93–107. http://dx.doi.org/10.1080/08916158708946334

[16] Toshov JB, Eshkuvatov LM, Smagulova KK, Zheldikbayeva AT, Rabatuly M, Tashbayev NN, Madaminova G. Study of Steam Condensation on Vertical Finned Tubes. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2026; 338(3):21-28. https://doi.org/10.31643/2026/6445.25

[17] Liao Y, Guentay S, Suckow D, Dehbi A. Reflux condensation of flowing vapor and non-condensable gases counter-current to laminar liquid film in a vertical tube, Nuclear Eng. Des. 2009; 239:2409–2416.

[18] Rabatuly M, Demin VF, Kenetaeva AA, Steflyuk YuYu, Toshov JB. Evaluation of modern methods and techniques for calculating parameters during coal bed degassing. Kompleksnoe Ispolzovanie Mineralnogo Syra = Complex Use of Mineral Resources. 2025; 334(3):110-120. https://doi.org/10.31643/2025/6445.33

[19] Toshov JB, Fozilov DM, Yelemessov KK, Ruziev UN, Abdullayev DN, Baskanbayeva DD, Bekirova LR. Povysheniye stoykosti zub'yev burovykh dolot za schet izmeneniya tekhnologii ikh izgotovleniya [Increasing the durability of drill bit teeth by changing their manufacturing technology]. Obrabotka metallov (tekhnologiya, oborudovaniye, instrumenty) [Metal processing (technology, equipment, tools)]. 2024; 26(4):112–124. (In Russ.). http://dx.doi.org/10.17212/1994-6309-2024-26.4-112-124

[20] Oumayma Boukria, El Mestafa El Hadrami, Aysha Sameen, Amna Sahar, Sipper Khan, Jasur Safarov, Shakhnoza Sultanova, Françoise Leriche, Abderrahmane Aït-Kaddour. Biochemical, physicochemical and sensory properties of yoghurts made from mixing milks of different mammalian species: a review. Foods. 2020; 9(11):1722.