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# Soft start use analysis in conditions of limited power supply systems

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**Abstract.** The analysis of soft-start systems of asynchronous motors used on ships is carried out. As a result of the literature analysis, the problem of reducing the quality of electricity in terms of harmonic distortion during operation of thyristor soft-start devices has been identified. It is also determined that the amplitude values of overvoltage peaks in a common section of the cable network when using a soft starter are almost three times higher than the nominal value of the amplitude of the supply voltage. A simulation model of a soft-start device has been compiled, taking into account operation in power supply systems of limited capacity. The main nodes of the model are thyristor blocks and a pulse-phase control system. In order to obtain a comparative characteristic of direct start-up and start-up with a soft-start device, the direct start of an asynchronous motor with similar winding and network parameters is additionally modeled. The simulation results and their analysis showed the presence of odd harmonics in the network and a significant increase in the total coefficient of harmonic components of the current when starting an asynchronous motor using a soft starter. During the simulation, it was revealed that the use of soft-start devices in ship systems, along with a decrease in inrush currents and voltage drops, negatively affects the quality of electricity. The obtained simulation results will allow for accurate calculation and rational adjustment of passive and active filters used on ships to ensure high quality of electric power. It is planned to further search for innovative ways and devices to improve the quality of electricity on ships to ensure efficient distribution and consumption of electricity.

**Keywords:** soft start device, asynchronous motor, simulation, harmonics, power quality indicators

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Научная статья

# Анализ применения плавного пуска в условиях систем электроснабжения ограниченной мощности

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**Аннотация.** Произведен анализ систем плавного пуска асинхронных двигателей, применяемых на судах. В результате литературного анализа определена проблема снижения показателей качества электроэнергии в части гармонического искажения при работе тиристорных устройств плавного пуска. Также определено, что амплитудные значения пиков перенапряжений в общем участке кабельной сети при применении устройства плавного пуска составляют почти трехкратное превышение номинального значения амплитуды питающего напряжения. Составлена имитационная модель устройства плавного пуска с учетом работы в системах электроснабжения ограниченной мощности. Основными узлами модели являются тиристорные блоки и система импульсно-фазового управления. Для получения сравнительной характеристики прямого пуска и с устройством плавного пуска дополнительно смоделирован прямой пуск асинхронного двигателя с аналогичными параметрами обмоток и сети. Результаты моделирования и их анализ показали наличие в сети нечетных гармоник и значительное повышение суммарного коэффициента гармонических составляющих тока при пуске асинхронного двигателя с помощью устройства плавного пуска. В процессе имитационного моделирования выявлено, что применение устройств плавного пуска в судовых системах наряду со снижением пусковых токов и провалов напряжения негативно влияет на показатели качества электроэнергии. Полученные результаты моделирования позволят обеспечить точный расчет и рациональную настройку пассивных и активных фильтров, применяемых на судах для обеспечения высоких показателей качества электроэнергии. Предполагается дальнейший поиск инновационных способов и устройств повышения показателей качества электроэнергии на судах для обеспечения эффективного распределения и потребления электроэнергии.

**Ключевые слова:** устройство плавного пуска, асинхронный двигатель, моделирование, гармоники, показатели качества электроэнергии

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**Introduction**

Induction motor (IM) is the most common consumer of electrical energy on ships. It makes up the main group of electric drives in marine power generation systems, consuming more than 70% of the capacity of a marine power plant. Induction motor is used in electric drives of various mechanisms on ships, such as powerful electric drives with short-term operation (anchor and mooring devices, thrusters), electric drives of ship lifting mechanisms (winches, cranes, elevators, hoists), electromechanical steering electric drive, positional electric drives (shut-off valve drive, remote activation automatic machines) and others. Induction motor is characterized by simplicity of maintenance and low cost, due to the absence of a brush-collector mechanism, as well as, based on the principle of operation, it is designed to operate in three-phase networks. One of the most significant disadvantages of IM is high starting currents exceeding the rated motor current by 5-7 times, and in some cases by 10 times.

Induction motor soft-starter (SS) are widely used to reduce the negative impact of inrush currents on the power system and switching equipment. They ensure smooth start and stop of the engine, keeping its parameters (current, voltage, etc.) within safe limits. In addition to reducing the starting currents of the motor, the SS is also designed to reduce mechanical loads on the drive mechanism, protect the electric motor from overloads and emergencies, and increase the service life of the equipment.

**Problem statement**

The principle of operation of most SS is based on pulse-phase control of the opening of pairs of thyristors or triacs. The use of this method reduces electric currents and voltage dips in the transients of high-power start-up, but consumes non-sinusoidal currents from the network, which leads to a change in the shape of the voltage curve. Also, switching ranges with counter-parallel connection to the network can create peak overvoltages and asymmetry of the three-phase network. Consequently, in the conditions of power systems of limited power, which are marine electric power systems, there is a problem of using SS for powerful electric drives, the operation of which can negatively affect the quality of electricity in the network as a whole and disrupt the operation of other equipment.

**Research objectives**

To find a solution to this problem, it is necessary to thoroughly investigate the effect of the operation of high-power electric drives on the quality of electricity in the ship's network. The objectives of the work are a literary analysis of the principles of SS operation and their impact on the quality of electricity in limited-capacity networks, the design of a simulation model and modeling of SS for a comparative analysis of the quality of electricity at the start of IM. To solve the tasks set, methods of literary data analysis, mathematical and simulation modeling, and system analysis were applied.

**Literature analysis**

The ship's electricity quality indicators characterize the suitability of electricity for powering shipboard electrical equipment. They determine the permissible range of deviation from the nominal values, expressed as a percentage. These indicators are important for evaluating the operation of the ship's electric power system (SEPS) and the protection of electrical equipment during all modes of ship operation, including emergency ones. The analysis of the indicators is carried out on the basis of an analysis of steady-state and transient processes that may occur when the load changes, powerful consumers turn on and off, and generators turn on for parallel operation.

The article [1] discusses the main indicators of electricity quality (voltage deviation, frequency deviation, non-sinusoidal coefficient, etc.) and the requirements for them by the International Electrotechnical Commission (IEC) and the Russian Maritime Register of Shipping. The authors of [2] describe the problems of the quality of electrical power in marine power systems, such as the influence of conductive electromagnetic interference and inrush currents of energy-intensive consumers, which worsen the quality of electricity. A comparative analysis of electricity quality indicators of different standards is also provided, which shows the differences in requirements.

The main indicators of the quality of electric power, which can be affected by the operation of the SS of high-power electric drives, are voltage deviations, the coefficient of non-sinusoidal linear voltage and deviations from the sinusoidal shape of the voltage at the terminals of electric power receivers. According to the Rules of the Register of Shipping [3], the value of the total harmonic distortion (THD) of the voltage curve should not exceed 8%. The value is regulated for a fully equipped ship's electric power system. For alternating current sources, a long-term deviation from the nominal voltage value should be no more than ±5%, a short-term deviation should be no more than ±10%, and the recovery time should be no more than 1 s. For electric power receivers, the steady-state voltage deviation relative to the nominal value should be in the range from +6 to –10%, the short-term voltage deviation should be ±20% with a recovery time of no more than 1.5.

The impact of the SS on the quality of power grids is extensively studied by modern domestic and foreign scientists. The author of [4] demonstrated the differences between IM start-up technologies and provided a comparative analysis of their impact on neighboring consumers who are in a single power supply system with them. It is determined that the amplitude values of the overvoltage peaks in the general section of the cable network when using the SS are almost three times higher than the nominal value of the amplitude of the supply voltage, and the frequency of overvoltages is 6 bursts per period. Such overvoltages can create a significant danger for the insulation of the entire complex of the power supply system (insulation failures), including for the insulation of other motors located in the same power supply system. In [5], the authors proposed some methods and devices to solve the problem of reducing the quality of electricity when using semi-conductor SS. The effectiveness of using a filter-compensating device with a thyristor voltage converter used for soft-starting the motor is considered. A method for calculating filter parameters is described, and simulation results are presented showing a significant decrease in the level of higher harmonics.

Increased attention to the issue of improving the quality of electricity in the use of SS allows us to assess its relevance. However, most scientific papers are devoted to the study of SS operation in traditional power supply networks [6]. In this paper, we consider the operation of an electric drive with an SS as part of a ship's electric power system. The main difference between a ship's network and coastal networks in the context of the issue under consideration is the demands placed on the quality of electricity, and the limited power described by the high internal resistance of the power source.

**Designing the SS model**

A system of differential equations of a generalized electric machine is used to describe the operation of the SS. The main task of the SS is to limit the inrush current.

To determine the impact of the SS operation on the quality of electricity, a simulation model was compiled in the MatLab Simulink system. Figure 1 shows the functional diagram of the compiled model, which includes: 6 thyristors connected in parallel to the mains, an asynchronous motor, a pulse-phase control system (PPCS), a power source with internal resistance and resistance of the power line and measuring instruments. The parameters of the thyristors and IM installed in the model are shown in the Table. In order to obtain a comparative characteristic of direct start-up and start-up with SS, the model additionally performs direct start-up with similar engine and network parameters.

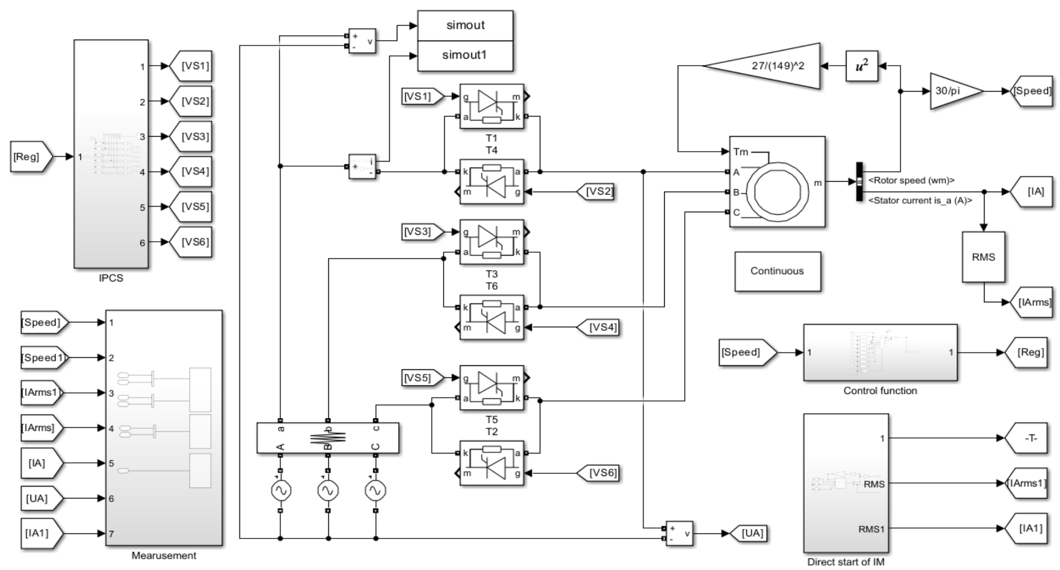


Fig. 1. Simulation model of a thyristor soft-start system

**Parameters of the simulation model components**

| Component | Parameter | Value |
|---|---|---|
| Thyristors | Open state resistance, Ohm | 0.001 |
| | Forward voltage drop, V | 0.8 |
| | Snubber resistance, Ohm | 500 |
| Induction motor | Nominal rotation speed, rpm | 1 430 |
| | Power, kW | 4 |
| | Nominal voltage, V | 400 |
| Power supply | Phase voltage amplitude, V | 310 |
| | Internal resistance, Ohm | 0.1 |

**Simulation results and discussion**

To obtain comparative characteristics of power quality indicators during direct start-up and during start-up of IM with SS, two methods were simultaneously simulated. Since the main problem identified is the presence of harmonics during start-up using semiconductor switches, it is proposed to use current and voltage THD as the main evaluation parameter. Figure 2 shows the time characteristic of the change in the rotation speed and current of the electric motor when it is started. The figure shows that the duration of the transient IM start-up process is more than 8 times longer than the direct IM start-up. It is also seen that with a decrease in the amplitude of the inrush current during the operation of the SS, the sinusoidal current curve is significantly disrupted [7-9]. Modeling of various IM start-up functions (time functions, current limiting functions, and speed functions) has shown that it is not possible to reduce the non-sinusoidal stator current by applying various control algorithms for the SS.

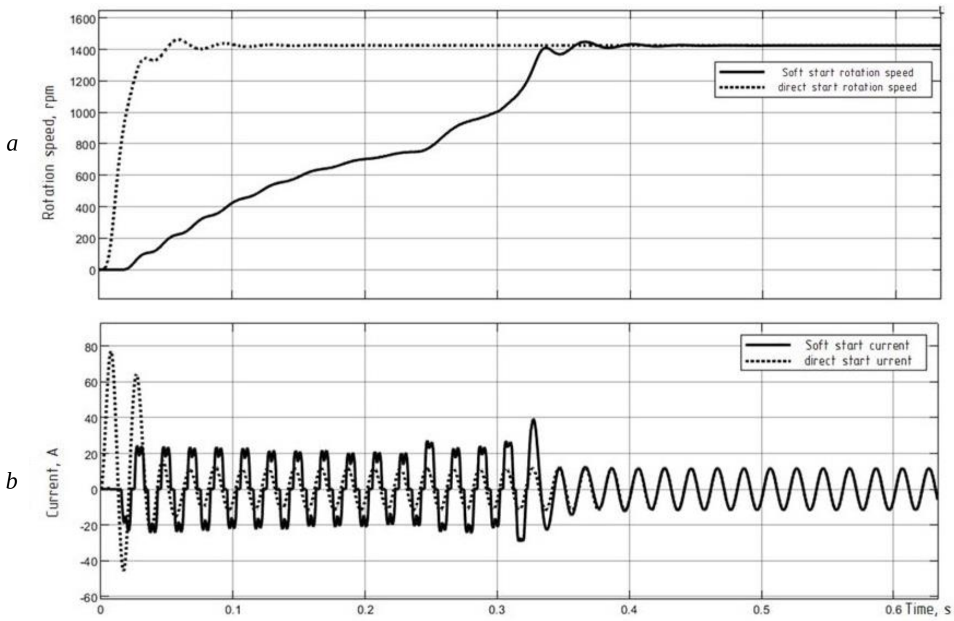


Fig. 2. Comparative simulation results of direct start-up of IM and start-up with SS:
*a* – IM rotational speed; *b* – IM current

An increase in the start-up time of IM and a decrease in the distortion of the shape of the current curve lead to a less shock, but longer-lasting effect of the device's operation on the ship's electric power system. The absence of a voltage drop on the busbars of the switchboard or generator is replaced by a longer presence of harmonic distortion. Figure 3 shows the harmonic composition of the motor current at start-up with a THD of 26.22%. The effect of changing the shape of the current curve on the harmonic composition of the busbar voltage largely depends on the power of the generator sets, the internal resistance of the power supplies, and the length and resistance of the cable runs and MSB busbars [10, 11].

*a*

*b*

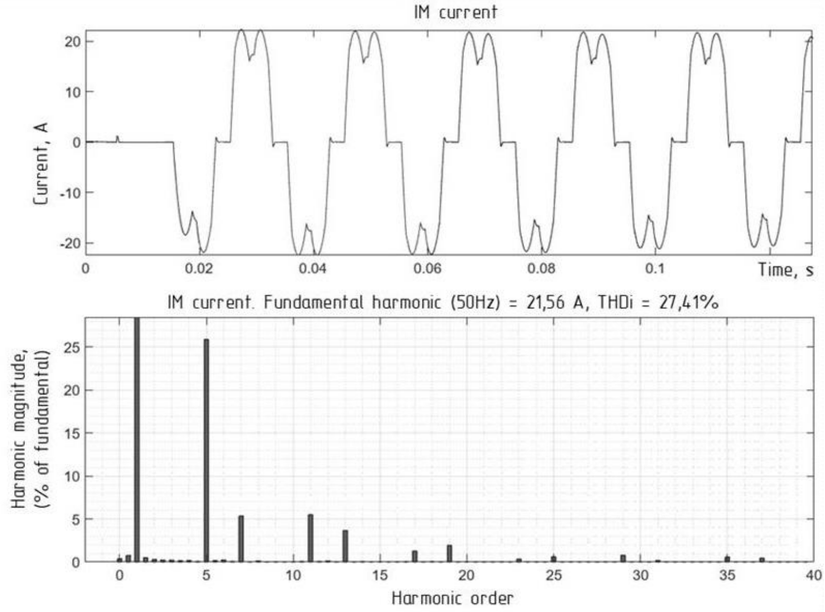


Fig. 3. Harmonic spectrum of the stator AD current: *a* – waveform of SS current; *b* – current harmonic spectrum

Fig. 4 shows the harmonic composition of the voltage at the connection point of the SS to the panel of the switchboard. As in the current spectrum, the presence of odd 5th and 9th harmonics is expected in this figure. Odd harmonics, including the 5th and 9th harmonics, can negatively affect the power supply system. Increased heating of power cables, transformers, and motors due to harmonics can lead to premature insulation wear, shortened service life, and even equipment failure. Harmonics can also interfere with sensitive electronics such as computers, controllers, and measuring instruments. This can lead to failures, errors, and even equipment damage. In some cases, harmonics can cause resonance in electrical networks, which can lead to a significant increase in voltage and current, and consequently, failure or unintentional activation of the protection of generator units.

*a*

*b*

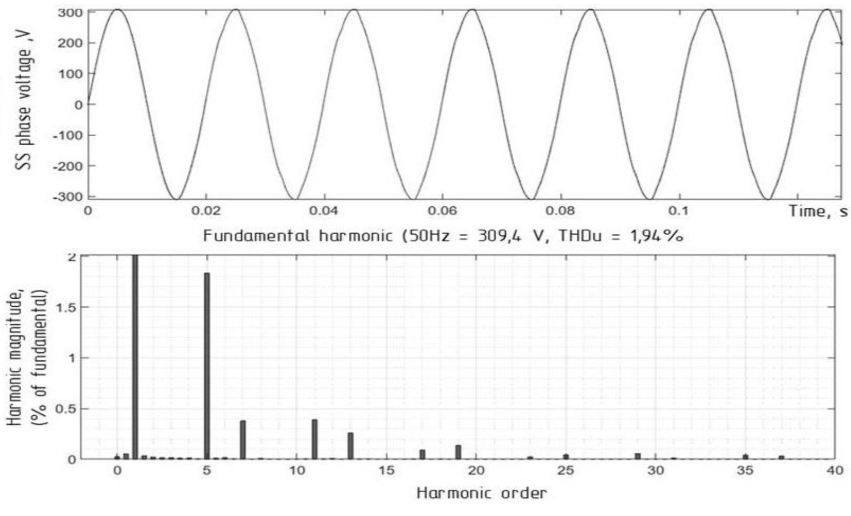


Fig. 4. Harmonic spectrum of the phase voltage at the connection point of the SS:
*a* – waveform of SS phase voltage; *b* – voltage harmonic spectrum

To prevent negative consequences, harmonic protection is installed at power plants, three-phase cables and other equipment. For this purpose, devices with active and passive elements are used that absorb or compensate for harmonics in the supply grid.

Also, one of the ways to improve the quality of electricity during a smooth start of IM is the use of the latest SS configurations with integrated active filtration systems. Further research by the authors will be devoted to the development and design of a combined adaptive soft-start device for an asynchronous motor with control of power quality indicators. This device differs in that transistor H-bridges and capacitors storing reactive energy are installed parallel to the power thyristors. During the operation of the device, the distortion of the flowing current will be compensated directly inside the SS, thereby reducing the cost of external compensating devices. One of the most important stages of the algorithm of operation of the designed device is to identify patterns of current and voltage distortion during start-up for further use in the inverter control system. The harmonic composition of currents and voltages, as well as waveforms, revealed in the course of the modeling presented in this paper, will later be used by the authors to form an optimal control system for the H-bridges of a combined adaptive soft-starter device to further compensate for voltage distortion during the operation of the SS.

**Conclusion**

The paper analyzes the use of SS in marine electric drives, considers theoretical provisions, and designs a simulation model to obtain comparative characteristics of power quality indicators during start-up. The simulation results and their analysis showed the presence of odd harmonics in the network and a significant increase in the THD current when starting IM using the SS. It is concluded that the use of SS in marine systems, along with a decrease in inrush currents and voltage drops, negatively affects the quality of electricity. Therefore, it is necessary to find ways to reduce the level of harmonic components when starting high-power electric drives with SS. The laws and distortion values identified by the authors will make it possible to rationally adjust the parameters of active and passive filters to install them at the connection point of the SS and reduce the level of THD when starting blood pressure. Reducing the harmonic distortion of current and voltage increases the energy efficiency of marine power supply systems. Further research by the authors will be devoted to the search for innovative ways and devices to improve the quality of electricity on ships to ensure efficient distribution and consumption of electricity.

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