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MODERN METHODS OF SMOOTH STARTING OF ASYNCHRONOUS MOTORS: THEIR TECHNOLOGIES AND INDUSTRIAL APPLICATIONS

ISHNAZAROV OYBEK

Professor, Institute of Energy Problems, Tashkent, Uzbekistan
Phone.: (0890) 968-8067

OTABAYEV BOBURXON

PhD student, Namangan Institute of Engineering and Technology, Namangan, Uzbekistan
Phone.: (0899) 003-7097, E-mail.: 11bobur20@gmail.com
Corresponding author

KURVONBOYEV BOTIRJON

PhD student, Namangan Institute of Engineering and Technology, Namangan, Uzbekistan
Phone.: (0897) 371-3595, E-mail.: qurvonboyevbotirjon@gmail.com

Abstract: This article analyzes modern methods for the smooth starting of asynchronous motors. The problems that arise during the startup process of asynchronous motors and various effective methods to address them are discussed in detail, including soft starters, star-delta control, inverter-based control, and other technologies. The advantages, disadvantages, and industrial applications of each method are explained, along with the conditions and systems where they are most effective. Modern control systems and intelligent technologies are examined for their role in increasing motor efficiency, ensuring stable power supply, and optimizing production processes. The article provides important recommendations for optimizing asynchronous motors in various industrial sectors, contributing to energy efficiency, safety, and the long-term operation of equipment. This study serves as a valuable resource for implementing advanced technologies in asynchronous motor control.

Keywords: Asynchronous motor, soft starter, starting current, voltage, inverter, thyristor.

Introduction. Asynchronous motors are among the most widely used electric motors in industry and technology. However, the startup process of asynchronous motors can present certain challenges, as these motors require a high starting current, which can negatively affect the system's operation. Soft starters are designed to ensure precision and flexibility during motor startup. Soft starting technologies regulate the motor's speed or voltage to smooth out the startup process. These devices reduce the inrush current of asynchronous motors and facilitate a smoother startup. The primary goals of such devices are to reduce energy consumption, protect the system, and extend the operational lifespan of asynchronous motors. Modern technologies are used to decrease the starting current, optimize the startup process, and conserve energy. A proper and smooth startup process ensures the long-term operation of an asynchronous motor. If an asynchronous motor starts too quickly, it can impose excessive loads on its mechanical and electrical components, leading to energy waste and accelerated wear. If such conditions persist, they can cause disruptions in production processes, catastrophic motor failure, and significant financial losses[1.1, 1]. Therefore, soft-starting systems play a crucial role.

Asynchronous motors are superior to other types of motors due to their reliability, durability, brushless design (which reduces frictional forces), and ease of installation, use, and maintenance[1, 2]. They are widely used as primary drive components in pumps, fans, compressors, transportation systems, and similar equipment. Approximately 40-50% of the electricity generated is consumed by asynchronous motors. These motors operate using alternating current, and their working principle is based on the force generated by the changing magnetic field between the rotor and the stator. However, during startup, significant attraction forces are generated between the stator and rotor, leading to high current surges and mechanical stresses. To mitigate these issues, various methods for the smooth starting of asynchronous motors have been developed. This article presents information on the advantages of smooth start methods and improvements to thyristor-based voltage regulators.

The main objectives of smooth starting of asynchronous motors include:

- Ensuring uniform acceleration and deceleration;
- Reducing starting current;
- Matching motor torque with load torque.

Depending on the nature of the load, smooth start technologies offer various motor control modes[5, 3]. Currently, several methods exist for the smooth starting of asynchronous motors, including:

- Direct connection to the power grid;
- Star-to-delta switching;
- Starting via an autotransformer;
- Starting via a frequency converter (which also regulates motor operation);
- Starting via a thyristor-based voltage regulator.

Additionally, methods such as reactor-based starting and capacitor-assisted starting exist. However, these do not fully achieve the primary objectives of smooth starting.

Direct connection to the power grid for starting. According to source **[1.1]**, directly connecting an asynchronous motor to the power grid is the simplest method of starting. However, the current drawn from the power grid can be **5 to 8 times** higher than the nominal current, and the motor torque can increase by **0.5 to 1.5 times**. The direct connection startup method is one of the simplest and most cost-effective ways to start a motor. In this method, the motor is directly connected to the power source, requiring only a **magnetic starter (MIT)** and a few protective components for control. A **Q1 protection device** (a circuit breaker or fuse switch) is connected to the power grid. Then, a **three-phase magnetic starter (KM1)** is activated. The magnetic starter allows the motor to be switched on and off. Additionally, an **F2 thermal relay** is used to protect the motor from overheating **(Figure 1)**. Although the direct connection method is simple and cost-effective, it has both **advantages and disadvantages**. Below is a summary of its key **pros and cons**.

Advantages.

1. **Simplicity and cost-effectiveness:**
   - This method is very simple to implement and has low costs. It does not require special devices or complex control systems;

- The motor can be started quickly by directly connecting it to the power grid, without the need for additional equipment.

2. **Fast startup:**
   - An asynchronous motor can be started quickly by direct connection, as this method requires only a contactor and protective systems for operation.
3. **Simple maintenance:**
   - This method is very straightforward and does not require automated control systems, making maintenance easier;
   - The initial installation and connection process are relatively inexpensive. This method is the most cost-effective for small and medium-power motors.

Disadvantages.

1. **High starting current:**
   - When the motor is directly connected to the power grid, it generates a very high starting current, which puts significant stress on the system components. This current can be **5 to 8 times** higher than the nominal current;
   - High starting current can be harmful to the power network, potentially causing **overloading and failures** in the system.
2. **Low energy efficiency:**
   - Due to the high starting current, energy consumption is also high, as there is no mechanism to improve energy efficiency;
   - This method may lead to increased energy losses and excessive heat generation during motor operation.
3. **Potential damage to the motor and system:**
   - High starting currents and excessive stress can damage the motor's **mechanical components,** as well as transformers and other electrical equipment in the network. Over time, this can shorten the motor's lifespan.
4. **Impact on the power grid:**
   - This method can negatively affect other equipment and systems connected to the same power network. The high inrush current may **cause voltage drops or disturbances** in the system.
5. **Unsuitable for high-power motors:**
   - This method is not recommended for **high-power asynchronous motors,** as excessive starting currents can weaken the system and create risks. For such motors, **soft starters or frequency converters** are preferred as more efficient alternatives.
6. **No speed control capability:**

With direct connection, it is impossible to **control the motor's speed.** For example, during startup, there is no way to optimize the acceleration or reduce the load.

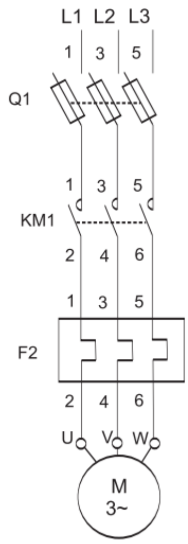

Figure 1. Direct connection startup of an asynchronous motor to the power grid

Application areas of direct connection startup method.

Despite its drawbacks, this method is **widely used** in various industrial and technical fields due to its simplicity and affordability. It is most effective for **small and medium-power motors**, while for high-power motors, alternative smooth-starting methods are preferable.

1. Small and medium-power mechanical systems:

• This method is used in mechanical systems operating with small motors, where the impact of high starting currents on the power grid is minimal.

• Examples include **ventilators, pumps, compressors, small crushers, and other simple mechanical systems.**

2. Industrial assembly and production lines:

• Asynchronous motors are commonly used in manufacturing and assembly processes due to their **simple working principle.**

• They are suitable for applications requiring initial torque, such as **conveyor belts, small-scale transmission systems, and simple mechanical operations**.

3**. Water pumps and irrigation systems:**

• This method is used in **agriculture and irrigation systems** to start water pumps.

• For basic pumps and systems, **direct connection is an economical and efficient choice**.

• Examples include **agricultural pumps, water extraction systems, and irrigation motors**.

According to **source [1.1],** this method is recommended when:

• The **motor's power** is significantly lower than the **capacity of the power grid.**

• The **connected machine does not require gradual acceleration.**

• The **high starting torque does not negatively impact other equipment.**

Starting an asynchronous motor using a frequency converter (VFD). Starting asynchronous motors using a frequency converter (Variable Frequency Drive - VFD) is an effective method for controlling motor startup and operation. Frequency converters allow precise control over the motor’s speed, torque, and startup current. This method is mainly used to optimize motor performance, increase energy efficiency, and ensure the reliable operation of the system.

Principle of starting with a frequency converter.

1. Reduction of initial frequency:

• Frequency converters adjust the frequency of the supplied voltage to control the motor’s speed;

• At startup, the frequency converter operates at a low frequency (low rotational speed);

• This initial low frequency reduces the motor's starting speed and, consequently, the starting current.

2. Control of frequency and torque:

• The frequency converter controls the motor’s speed and torque throughout the startup process;

• Initially, the motor operates at a low frequency and speed, and the frequency is gradually increased;

• This smooth acceleration ensures that the motor starts efficiently with optimal torque, reducing startup current and preventing sudden electrical surges in the power supply.

According to source [1.1], the frequency converter is considered the best option for seamless and stepless starting of three-phase asynchronous motors. It minimizes the startup current, prevents voltage fluctuations in the power grid, and avoids sudden load changes in mechanical systems. In addition to starting the motor, a frequency converter allows smooth and continuous speed control. This technology is especially useful in applications where precise speed regulation is required. The frequency converter can adjust the supply frequency from 0 to 400 Hz.

Advantages of starting with a frequency converter.

1. **Reduced starting current:**

o Using a frequency converter significantly lowers the starting current of the motor. By starting the motor at a lower frequency, sudden current and voltage surges are prevented.

2. **Precise speed and torque control:**

o A frequency converter allows for accurate control of the motor’s rotational speed and torque. This ensures high efficiency for systems, as the motor can be started and operated at the required speed.

3. **Energy savings:**

o Frequency converters help significantly reduce energy consumption. When operating at lower speeds, the motor uses less energy, which enhances the system’s overall energy efficiency in the long run.

4. **Reduced mechanical stress:**

- The gradual increase in the motor's rotational speed reduces the load on mechanical components and enables a smooth startup. This contributes to the system's long-term reliability.

5. **System monitoring and optimization:**
   - Frequency converters not only assist in starting the motor but also optimize its operating modes. This allows for greater efficiency over prolonged use.

Disadvantages of starting with a frequency converter.

1. **High cost:**
   - Frequency converters are relatively expensive. These devices are based on advanced technologies and can significantly increase system costs in some cases.
2. **Complex control system:**
   - Using frequency converters requires complex control systems. The initial installation and configuration of these systems can be challenging in certain situations.
3. **Operational uncertainties:**
   - The setup and adjustment of frequency converters can sometimes be uncertain. If the device is not configured correctly, operational issues may arise when running the motor.

Applications of starting with a frequency converter.

- **Industrial production lines:**
  - Controlling asynchronous motors with frequency converters allows for precise speed and torque control in manufacturing processes.
- **Elevators and lifts:**
  - Frequency converters are used in elevator and lift systems, where precise speed control is essential for smooth and efficient operation.
- **Fans, pumps, and compressors:**
  - In systems such as fans, pumps, and compressors, frequency converters ensure efficient motor operation and reduce energy consumption.
- **Small and medium power energy generation systems:**
  - In small and medium-scale power generation plants, controlling motors with frequency converters enhances energy efficiency.
- **High-power mechanical systems:**
  - Frequency converters are used in industries such as metallurgy, construction, and other heavy industries where high-power mechanical systems are required.

Starting asynchronous motors using a frequency converter is a highly efficient and reliable method, particularly in applications requiring precise speed control and energy efficiency. While the initial investment cost is high, the benefits of reduced startup current, improved system control, and lower energy consumption make it a valuable technology in modern industrial and commercial applications.

Starting an induction motor using a thyristor voltage converter. Starting and controlling induction motors using a thyristor voltage converter is a highly efficient and precise method. With the help of thyristor voltage converters (SCR – Silicon-Controlled Rectifier), the initial voltage and speed of the motor are regulated. This method is used to ensure smooth motor startup and high efficiency.

In [4], it is stated that after the development of high-power electronic components, their application in power systems has increased. Both DC and AC circuits are now controlled using power electronics components. One example of this is the thyristor voltage converter. The core components of a thyristor voltage converter are thyristors and a control block. Typically, a thyristor voltage converter consists of six thyristors, arranged in pairs for each phase in an antiparallel configuration (Figure 2). This method allows for the control of the starting torque and current of the motor. One of the key advantages of this method over others is the use of thyristors, which enable contactless switching.

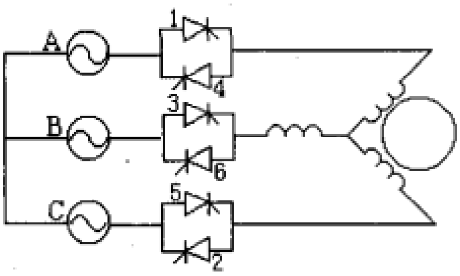

Figure 2. Arrangement of thyristors in a thyristor voltage converter

Principle of starting an induction motor using a thyristor voltage converter

1. **Controlling the Initial Voltage:**

• Using thyristor voltage converters, the voltage supplied to the stator of the motor can be regulated.

• At startup, the voltage is reduced through the converter, which helps to minimize high current and voltage surges during motor startup.

2. **Flexible voltage control:**

• Thyristor voltage converters allow precise adjustment of the initial voltage of the motor;

• This variable voltage enables control over the motor’s rotational speed and torque;

• By gradually increasing the voltage through thyristors, the motor can be controlled with accurate parameters.

3. Smooth startup:

• When starting the motor with a thyristor voltage converter, the initial voltage is low, reducing inrush current and minimizing impact on the system;

• The motor's speed gradually increases, ensuring a smooth startup process.

4. Transition to normal operation mode:

• After the motor starts, the voltage supplied through the thyristor converter is gradually increased;

• Once the motor reaches its nominal speed, the normal voltage is connected to the system (via MIT), allowing the motor to operate at full voltage.

Advantages of starting with a thyristor voltage converter

1. Reduced starting current:

• The initial voltage can be reduced using a thyristor voltage converter, which decreases the starting current;

• This minimizes power surges in the network and ensures a smooth startup process.

2. Smooth startup:

• The motor speed increases gradually, reducing mechanical stress and ensuring long-term operation.

3. High torque startup:

• Motors can start with high initial torque using thyristor converters;

• This is useful for handling heavy loads effectively.

4. Energy Savings:

• Thyristor voltage converters optimize power consumption, improving motor efficiency and reducing energy costs.

5. Precise speed and torque control:

• Thyristor converters enable accurate control of motor speed and torque, ensuring optimal system performance.

Disadvantages of starting with a thyristor voltage converter.

1. System complexity:

• Using thyristor converters requires complex control systems, making installation and configuration challenging.

2. High cost:

• Thyristor voltage converters are relatively expensive due to their advanced technology, increasing overall system costs.

3. High technical requirements:

• Skilled specialists are required for proper installation and operation, as incorrect settings may negatively impact the system.

4. Electrical interference:

• When thyristors operate, voltage conversion can cause electrical disturbances that may affect system performance.

Applications of thyristor voltage converter-based startup

• **Industrial production lines:**

o Ensures smooth and efficient startup by operating motors at reduced initial voltage.

• **Elevators and lifts:**

o Provides precise control over speed and torque, making it ideal for elevator systems.

- **Compressors and pumps:**
  o Improves energy efficiency and ensures a smooth startup process.
- **High-power mechanical systems:**
  o Used in heavy industries such as metallurgy and construction for high-power mechanical applications.
- **Energy generation and distribution systems:**
  o Helps regulate and optimize voltage in power generation and distribution networks.

The article [8] describes the development of a thyristor-based voltage converter for a single-phase motor. It consists of two single-phase full bridges, with the single-phase motor placed between the bridges (Figure 3). Each bridge comprises four thyristors controlled by a microcontroller. If the input frequency of this device is F, the output can provide frequencies of F, F/2, and F/3. This allows for controlling the motor's rotation speed. If the conduction time of the first bridge is 20ms and the conduction time of the second bridge is also 20ms, then a complete cycle takes 40ms. As a result, the output frequency is F/2 (if connected to a 50 Hz power grid, the output frequency will be 25 Hz).

In study [9], a new, simple, and reliable digital control circuit has been developed for controlling the speed of a three-phase asynchronous motor using a thyristor-based voltage converter. A zero-crossing detector is required for the precise operation of the thyristor-based voltage converter. The article also provides information about the zero-crossing detector. According to it, the control system requires a signal with two pulses for each cycle. The first pulse occurs when the signal changes from 0 to +V, and the second pulse occurs when it changes from +V to 0 [12].

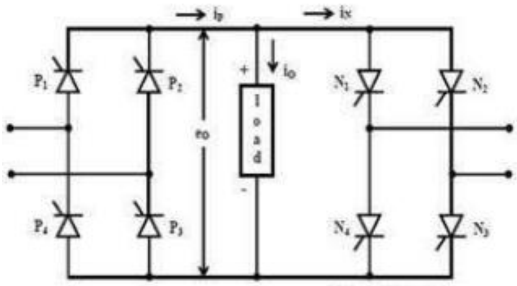

Figure 3. Arrangement of thyristors in a single-phase voltage converter

In [10], the electrical schematic, operating principle, and virtual implementation of a two-phase controlled thyristor voltage converter using computer software, along with the obtained results, are presented (Figure 4).

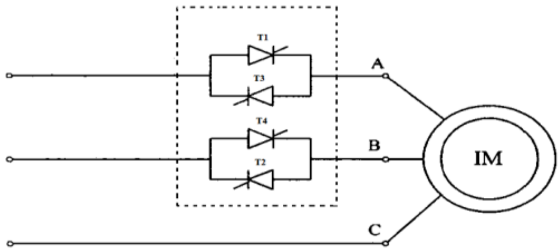

Figure 4. Arrangement of thyristors in a two-phase controlled TVC

In [11], it is demonstrated that motors operating in high-humidity environments, such as oil refining, chemical processing, water and wastewater treatment, marine transportation, and similar industries, can be protected using a thyristor voltage converter. In these environments, high humidity leads to moisture condensation inside the motor, which can cause severe damage. The biggest risk for the motor is insulation failure in the windings. To prevent moisture condensation, the temperature of the motor windings should be at least 5˚C higher than the ambient temperature. In [11], it is explained that an idle motor can be periodically connected to the power supply using thyristors to generate heat. The sequentially applied voltage does not create a rotational torque in the motor. This process can be implemented by programming the microcontroller in the control unit of any thyristor voltage converter (Figure 5).

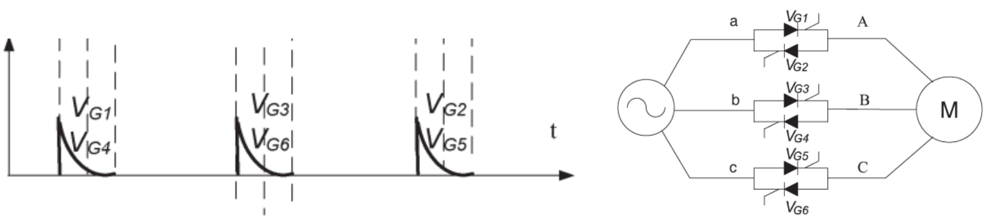

Figure 5. Arrangement of thyristors and signal application graph

In [14], the necessity of a smooth start-up device for belt conveyors is discussed in detail. According to the technological characteristics of the transportation process, directly starting a loaded conveyor increases inertial forces, leading to excessive loads on the drive system and traction chains. Due to the increase in starting torque, issues such as belt slippage and oscillations may occur, and there is a risk of slipping between the conveyor belt and the drum. This significantly affects the belt and can disrupt the technological process. The study suggests that if the conveyor speed needs to be regulated, a frequency converter should be used. However, if the conveyor operates at a constant speed throughout its working cycle, an asynchronous motor with a thyristor voltage converter can be used for starting and stopping the system smoothly, eliminating the mentioned problems.

Table 1

Model	SIEMENS 3RW30	ABB PSR3-600-70	OMRON G3JT405BL	SCHNEIDER Electric ATS01N109FT
Power (kW)	1.5	1.5	2.2	4
Controlled phases	A-C	A-C	A-B-C	A-C
Nominal voltage (V)	380-400	380-400	380-400	380-400
Nominal current (A)	3.6	3.9	5.5	9
Starting torque (%)	16…100	16…49	33…75	30…80
Starting time (s)	0…20	0…20	1…25	1…5

In [13], research was conducted on detecting rotor faults in squirrel-cage asynchronous motors. More than 600 experiments were carried out using a 1.1 kW, 4-pole asynchronous motor operated with a thyristor voltage converter. The experiments were performed using thyristor voltage converters from well-known brands, and three types of faults were successfully identified. The study obtained successful results in fault detection. Additionally, the article provides the technical specifications of branded thyristor voltage converters (Table 1).

Latest trends and innovations in soft starters. Recent trends and developments in soft starter technologies are primarily focused on automation and control systems, the application of new materials and technologies, and improving overall efficiency. These advancements aim to make the motor starting process more efficient, precise, and energy-saving. Below, we examine the latest trends in soft starter technology that contribute to enhancing the performance and energy efficiency of asynchronous motor starting methods.

Development of electronic devices and technologies. Electronic devices and technologies are evolving to make the smooth startup process more efficient. The following technologies are particularly emerging as key development areas:

- **Intelligent Control Systems for Smooth Startup:**
  - Intelligent control systems are being developed for smooth startup. These systems primarily analyze the motor's startup process in detail and automatically adjust the settings accordingly.
- **Control units and electronic relays:**
  - Using electronic control units and relays allows for more precise and reliable motor control. Automation of mechanical operations through electronic systems increases system efficiency.
- **High-tech sensors:**

Advanced sensors are used to monitor the operational status of motors. These sensors enable real-time monitoring of parameters such as temperature, voltage, and current.

Energy saving and efficiency improvement. Innovations in technology and materials are also driving improvements in energy saving and efficiency. The following trends focus on enhancing energy efficiency:

- **Energy recovery systems:**
  - Some systems offer the ability to recover and store the energy used by motors. By reusing energy, these innovations contribute to energy-saving efforts.
- **High-efficiency startup current reduction systems:**
  - New electronic devices and materials are being developed to reduce startup current. These systems not only decrease startup current but also improve overall efficiency.
- **Modular systems:**

Modular control systems and voltage converters enhance energy efficiency. These systems optimize power supply and ensure reliable operation.

The increasing demand for electrical energy and the need to optimize existing power networks require the implementation of energy-efficient and smooth startup technologies for motors. Among the most economical and adaptable methods for smooth startup of asynchronous motors are frequency converters and thyristor-based voltage regulators. Despite their advantages, these technologies have certain limitations. Addressing these drawbacks, improving reliability, and introducing new functionalities are crucial tasks for enhancing the efficiency of these systems in the future.

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