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Control of Squirrel-Cage Asynchronous Motor Using Star-Delta Starting Method and Monitoring of Parameters Through Computer Interface

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Anahtar Kelimeler

Asenkron Motor
Yıldız-Üçgen Yolverme
OPC Server
Programlanabilir Denetleyici

Graphical/Tabular Abstract (Grafik Özet)

In this study, an asynchronous motor is controlled using the star-delta starting method and circuit parameters are monitored. / Bu çalışmada, bir asenkron motor yıldız-üçgen yol verme yöntemi kullanılarak kontrol edilmiş ve devre parametreleri izlenmiştir.

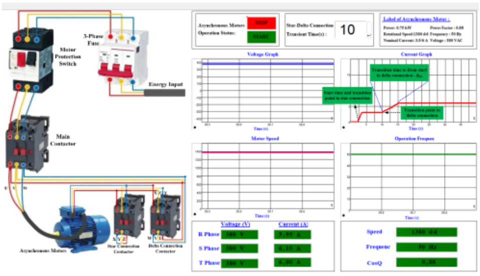

***Figure A**: Screenshot when the star-delta transition time is 10s / **Şekil A:** Yıldız-delta geçiş süresi 10s olduğunda ekran görüntüsü*

Highlights (Önemli noktalar)

- *A computer-controlled monitoring system has been developed for asynchronous motors operating with star-delta starting method. / Yıldız üçgen yol verme yöntemi ile çalışan asenkron motorlar için bilgisayar kontrollü izleme sistemi geliştirilmiştir.*
- *Computer-controlled operation of asynchronous motors operated by the star-delta starting method is developed a safe working environment. / Yıldız-üçgen yol verme yöntemi ile çalıştırılan asenkron motorların bilgisayar kontrollü çalıştırılması ile güvenli bir çalışma ortamı geliştirilmiştir.*
- *The proposed method provided much better performance than the classic methods in the literature. / Önerilen yöntem, literatürdeki klasik yöntemlere göre çok daha iyi performans sağlamıştır.*

Aim (Amaç): *The steady state and dynamic behavior of the system when starting asynchronous motor with the star-delta starting method is monitoried. / Asenkron motora yıldız-üçgen yol verme yöntemi ile yol verilirken sistemin kararlı durum ve dinamik davranışı izlenmiştir.*

Originality (Özgünlük): *The star-delta starting method of the asynchronous motor has realized through the computer interface. The steady-state performance comparison of this method, its behavior in the initial start-up, the dynamic response of the asynchronous motor in the transition from star connection to delta connection are presented. / Asenkron motorun yıldız-üçgen yol verme yöntemi bilgisayar arayüzü aracılığıyla gerçekleştirilmiştir. Bu yöntemin kararlı durum performans karşılaştırması, ilk kalkıştaki davranışı, yıldız bağlantıdan üçgen bağlantıya geçişte asenkron motorun dinamik tepkisi sunulmuştur.*

Results (Bulgular): *The user could simultaneously monitored the motor parameters, the dynamic response of the asynchronous motor in the transition from star connection to delta connection and the changes in the parameters in the running state. / Kullanıcı eş zamanlı olarak motor parametrelerini, asenkron motorun yıldız bağlantıdan üçgen bağlantıya geçişteki dinamik tepkisini ve çalışma durumundaki parametrelerdeki değişimleri izleyebilmektedir.*

Conclusion (Sonuç): *The steady state and dynamic behavior of the system when starting asynchronous motor with the star-delta starting method is monitoried. / Asenkron motora yıldız-üçgen yol verme yöntemi ile yol verilirken sistemin kararlı durum ve dinamik davranışı izlenmiştir.*

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Abstract

Asynchronous motors widely used in industry. The motors draw very high currents until the motor reaches its rated speed and torque. These excessive currents can damage the motor itself and other equipment in the system. A starting method is needed as an initial control to start the motor. These starting methods limit these overcurrents and help the motor to reach its rated speed gradually without drawing too much current. In this study, an asynchronous motor is controlled using the star-delta starting method and circuit parameters are monitored such as three phase current and voltage values, frequency, power coefficient, motor speed. These parameters are sent to the computer with PLC(Programmable Logic Control) over OPC(Ole for Process Control) Server in real time. The parameters are processed and monitored on the user interface prepared on the Profi-LAB platform and the motor parameters are controlled.

Sincap Kafesli Asenkron Motorun Yıldız-Üçgen Yol Verme Yöntemi ile Kontrolü ve Parametrelerin Bilgisayar Arayüzü ile İzlenmesi

Makale Bilgisi

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Öz

Asenkron motorlar endüstride yaygın olarak kullanılmaktadır. Motorlar, motor nominal hızına ve torkuna ulaşana kadar çok yüksek akımlar çeker. Bu aşırı akımlar motorun kendisine ve sistemdeki diğer ekipmanlara zarar verebilir. Motoru başlatmak için ilk kontrol olarak bir başlatma yöntemine ihtiyaç vardır. Bu yol verme yöntemleri bu aşırı akımları sınırlar ve motorun çok fazla akım çekmeden kademeli olarak nominal hızına ulaşmasına yardımcı olur. Bu çalışmada asenkron bir motor yıldız-üçgen yol verme yöntemi kullanılarak kontrol edilmekte ve üç faz akım ve gerilim değerleri, frekans, güç katsayısı, motor hızı gibi devre parametreleri izlenmektedir. Bu parametreler gerçek zamanlı olarak OPC (Ole for Process Control) Server üzerinden PLC (Programmable Logic Control) ile bilgisayara gönderilmektedir. Profi-LAB platformunda hazırlanan kullanıcı arayüzü üzerinde parametreler işlenip izlenmekte ve motor parametreleri kontrol edilmektedir.

1. INTRODUCTION (GİRİŞ)

Recently, thanks to digitalization in the industrial field, the need for modernization of existing systems or the use for up-to-date devices has emerged. Since the preference of up-to-date devices will create additional high costs for businesses, modernization of the existing infrastructure comes to the fore. Thus, both the improvement of the systems at low cost and the efficient use of energy will be ensured. Asynchronous motors, which are the basis of moving systems in the industry, constitute the majority of energy consumption. Therefore, improvement studies on these motors will be of great importance to the private sector[1]. These engines find use in different sectors such as food, chemistry, metallurgy, paper and water purification or drawing systems. These applications include equipment for machine components operating at constant or variable speeds, such as elevators, conveyor systems, ventilation and air conditioning systems, pumps and compressors[2]. A three-phase

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asynchronous motor can have a ring rotor or a short-circuit rotor. The motors better used with a squirrel-cage rotor. The main difference between these two types comes from the construction of the motor.

The motor of the first type consists of real windings as in the stator, exhibits a more complex and fragile structure, requires periodic maintenance, has large dimensions. In the second type, the rotor is made up of rods short-circuited at both ends. Thanks to its high structural simplicity, it forms simple, robust and cost-effective motor type. The principle of operation of the asynchronous motor is to convert electrical energy into mechanical energy by rotating the motor shaft in the induced magnetic field[3]. The cross-sectional plane and components of the asynchronous motor are shown in Figure 1.

Asynchronous motors are widely used in industry due to their numerous advantages over other types of motors. They are practically maintenance-free and have easily accessible spare parts, making them highly convenient. Additionally, they are more cost-effective compared to motors with the same power output and are known for their robustness. Unlike some motor types, asynchronous motors do not produce arcs or sparks during operation, enhancing safety. Furthermore, they can be produced in single-phase and three-phase configurations, offering flexibility for various applications.

The asynchronous motors are preferred in the industry due to the development of control methods that enable speed adjustment in simple and effective way. This is an advantage for asynchronous motors. The most important disadvantage of the motor is that it draws 5-7 times more current from the grid than the nominal current value at the first start-up moment. The asynchronous motors are operated with the starting method to prevent this negative situation. This method provides a smoother start-up of the asynchronous motor. For this purpose, direct starting, star-delta starting, auto transformer starting, resistor starting, soft starting and driver starting methods are used in the literature[4].

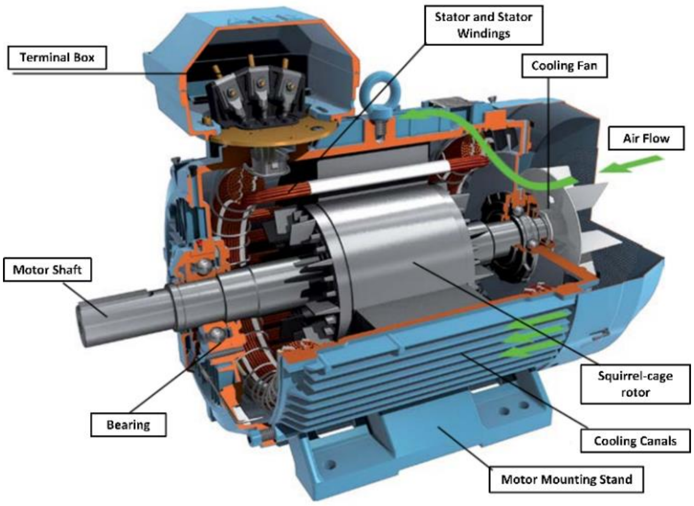

Figure 1. Components of an asynchronous motor (Asenkron motorun bileşenleri)

The most suitable starting method of asynchronous motors should be preferred to speed adjustment, continuous operation, protect against overload operation. Direct starters are a starting method that connects line voltage across the motor terminals in a single step and accelerating it to its rated speed. This method is used according to the permissible switching method for the motor by providing switching and protection functions[5].

Direct starting is the most conventional starting method for starting a squirrel-cage asynchronous motor and involves connecting the motor directly to the supply network and starting at maximum voltage. Direct starting is the simplest and most economical system and is the most commonly used method. Since it provides a direct connection to the supply network, the starting process takes place at maximum voltage and constant frequency, generating a high starting torque with greatly reduced acceleration times[6]. Reduced-voltage starting systems involve connecting the motor directly to the electrical supply network and thus performing a reduced-voltage starting. This results in a reduction in starting current, but also a reduction in instantaneous torque [6,7].

Star-delta starting is the most familiar system and the most common starting method at reduced voltage; it is used to start the motor by reducing mechanical stresses during starting and limiting current ratings. On the other hand, it provides a reduced instantaneous torque. Star-delta starters are used to start a three-phase motor in star connection and to ensure continuous operation in delta connection[7].

Starting with an autotransformer, the reduction of the supply voltage is realized by means of a fixed-stage autotransformer or a variable voltage transformer[9]. In the stator resistance or reactor starting method, the voltage drop is achieved by using reactors or resistors connected in series with the stator during starting. The voltage supplying the motor in the first stage is reduced by a determined coefficient with respect to the mains voltage, which corresponds to a torque reduction. The starting current is limited to approximately half of the current required for starting at maximum voltage. At the end of the acceleration phase, the reactors or resistors are deactivated and the motor returns to full voltage parameters. The disadvantages of this method are the significant reduction in power factor due to the reactors or the high temperature rise caused by the power distribution in the resistors [10]. Soft starters provide soft starting of motors by limiting the starting current. The use of this method is to ensure a soft start, avoiding the electrical and mechanical stresses that characterize direct start and Y/Δ start. It allows limiting the starting current, determining the torque and setting the starting time so that the increased motor supply is smooth throughout the entire process. This is a modern method that can require a rather high initial investment cost [11].

The starting method with inverter of asynchronous motor is carried out together with the control and management of the electrical and mechanical parameters of the application. Also, this method provides in energy savings of 20 to 50%. Inverters offer highly reliable systems with high efficiency and low maintenance requirements. They are categorized by semiconductors and converters and are suitable for precise speed and torque control of squirrel-cage motors. These inverters based on PWM technology can be used in both for the simplest applications with quadrature torque (pumps and fans) and more complex applications[12]. The advantages and disadvantages of these methods in terms of cost, advantages and disadvantages compared to each other are given in Table 1.

Table 1. Comparison table of starting methods for asynchronous motors (Asenkron motorlara yolverme yöntemlerinin karşılaştırma tablosu)

Ref.	Starting method	Cost	Advantages	Disadvantages
13	Direct Starting Method	Very Low	This method can be used in small power motors or in self-powered generation installations. It is the cheapest method as the installation can be realized with the minimum number of equipment. It is the simplest starting method.	Since the starting torque is very high, it may cause mechanical stress at the connection points of the motor, high-level selection of installation and protection elements, energy losses on line impedance. The operating speed of the motor is constant.
14	Star-Delta Starting Method	Low	Suitable for late accelerating loads.	If the load torque is greater than the star connection torque of the motor, the motor cannot accelerate under load. There is no control of current and torque. During the transition from star to delta, there are sudden current and moment transients. This may damage the system by creating mechanical and electrical shocks. The operating speed of the motor is constant.
15	Starting Method with	Low	They work more efficiently. Less current passes through the primary of the	Instantaneous torque changes due to gradual voltage transients. Adaptation to varying load

	Auto Transformer		transformer due to the number of windings.	conditions is difficult. Due to the limited number of voltage stages, the ideal starting current cannot be controlled within wide limits.
16	Starting Method with Resistance	Medium	Since some of the mains voltage consumes on the resistors, the voltage applied to the motor is low. The motor does not draw excessive current at start-up.	Energy loss is high. The operating speed of the motor is constant.
17	Starting Method with Soft Starter	High	Flexible and simple control of the current and torque during start-up, providing stepless change of voltage and current without sudden changes, suitable for frequent starting. Ability to operate under variable starting conditions. Controlling the motor stopping time with the use of the soft stop feature, shortening the motor stopping time with the braking feature. Advanced motor protection and operator interface features.	They generate harmonics during starting. The operation speed of the motor is variable. Acceleration and deceleration time is highly dependent on the load.
18	Starting Method with Inverter	Very High	Provides speed control within wide limits and reduces maintenance costs. Energy saving, can control more than one motor.	First installation cost is high. They have 5% losses since they are on a continuous line. Heat increase occurs in motors at low speeds and they produce harmonics.

An important consideration in the selection and construction of a system for motor starting and motor control is the safety and reliability of the solution to be achieved. The main causes of motor failure are due to short circuits and are caused by moisture, oil, dust between windings or overload. The overcurrent resulting from faults can cause a temperature rise, which can cause irreversible damage to the motor and can also cause fires in the surrounding environment. As a result, starting of an asynchronous motor is a critical situation, especially for the motor and the supplying network. Thus, the nominal operation needs to be properly monitored and protected to motor against possible faulty operation [19].

The aim of this study is to provide instantaneous monitoring and control of all data of asynchronous motors operating with classical methods in moving systems through digital communication and technology. Thus, an advanced protection feature is provided to the asynchronous motor. In addition, the digital microprocessor-controlled control unit has been designed to reduce the electrical and mechanical stresses that may occur in the motor during starting and stop. The parameters (three phase current and voltage values, frequency, power coefficient, motor speed, etc.) of the asynchronous motor operated with the star-delta starting method are transferred to the computer environment via PLC over OPC Server in real time. These parameters are processed and presented to the users through the interface prepared on the Profi-LAB platform. Thus, monitoring and control of motor parameters are provided.

The motor is controlled by starting and stopping the asynchronous motor through the user interface. The user can simultaneously monitor the motor parameters and the changes in the parameters in the running state. The star-delta starting method of the asynchronous motor is realized through the computer interface. The steady-state performance comparison of this method, its behavior in the initial start-up, the dynamic response of the asynchronous motor in the transition from star connection to delta connection are presented. The general block diagram of the experimental setup is shown in Figure 2. According to this diagram, the hardware set was installed and the hardware specific software required for the operation of the system was prepared. The system was then calibrated and tested for operation.

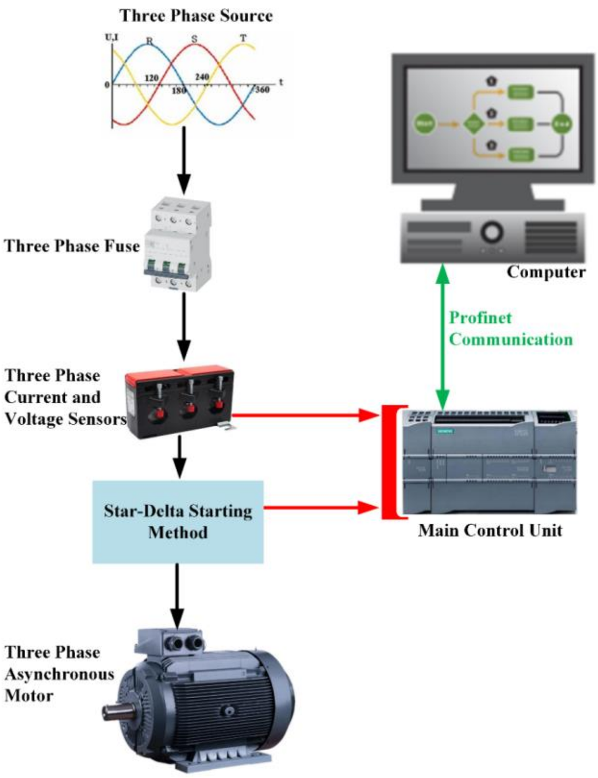

Figure 2. General block diagram of the system
(Sistemin genel blok diyagramı)

2.STAR-DELTA STARTING METHOD
(YILDIZ-ÜÇGEN YOL VERME YÖNTEMİ)

This method is widely used, especially for no-load starting or starting with low and constant load torque or slightly increasing load torque (such as fans or low-power centrifugal pumps). As shown in the diagram in Figure 3, the starting method is realized by the star connection of the windings, the line contactor KL and the star contactor KY, the first phase of which is realized by the closing of the circuit breaker. After a predetermined period of time, the opening of the KY contactor and the closing of KΔ allows the transition to the delta connection, which is also the configuration of the normal operating position.

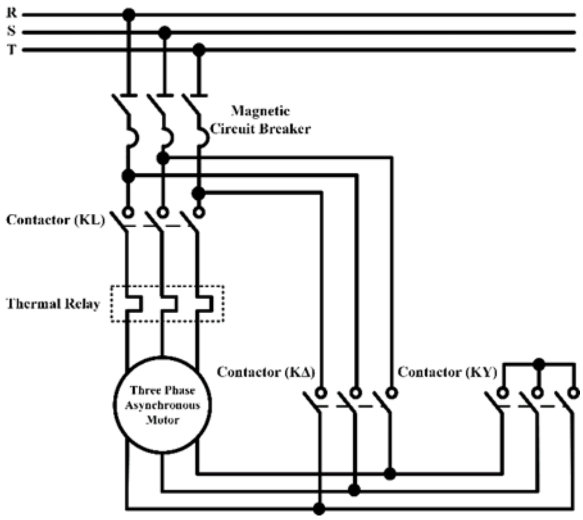

Figure 3. Principle diagram of star-delta starting method (Yıldız-üçgen yolverme yönteminin prensip şeması)

Star phase (Y) is the starting phase. The motor windings are star connected and the voltage across them is expressed as VL/√3. The motor winding and line current are given in Eq. 1. Zw is the motor winding impedance.

$$I_{MY} = \frac{VL}{\sqrt{3}\ x\ Z_w} (1)$$

In this method, the starting phase coincides with the acceleration phase and continues in this way until the steady-state speed is reached. Too short a duration of this state will not allow a reduction in the stresses that characterize the type of starting; consequently, such stresses will reappear in the subsequent triangle phase, thus recreating conditions similar to those of the direct starting method. This method is used on a small-scale motor. Star connection configuration and motor terminal is shown in Fig. 4.

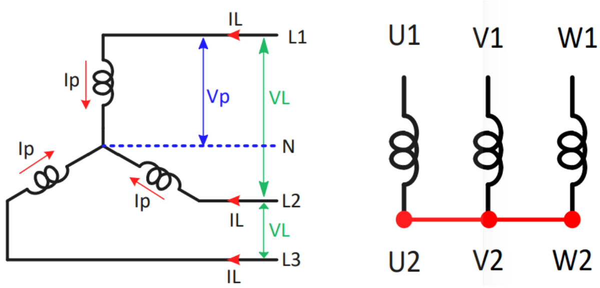

Figure 4. Star connection configuration and motor terminal (Yıldız bağlantı konfigürasyonu ve motor terminali)

The changing phase is the phase in which the transition from the star position to the delta position takes place by opening and closing the contactors. The duration and calibration of the changing phase are important: the duration of the changing must be such as to extinguish the electric arc in the star contactor and prevent a short-circuit condition caused by the delta contactor closing too much. On the other hand, a long transition from Y to Δ will cause the motor to slow down, resulting in large current peaks in the delta phase.

The transition is regulated by analog or digital timers and, just like an indicator, the transition time can be set to an average of 50 ms. On the timer, the duration of the star phase is also set, which in general terms is the acceleration or starting time that can be considered as a function of the difference between the average driving torque and the average load torque of the motor-machine unit.

Delta phase (Δ), is the last phase of the starting method. It also represents the steady-state operating condition where the stator windings are delta-connected and subject to the full grid voltage VL and the motor reaches full torque again and the current flowing through the windings is given in equation-2.

$$\mathrm{I}_{\mathrm{M}\Delta} = \frac{\mathrm{VL}}{\mathrm{Z_W}} \quad (2)$$

The equation for the line current is given in Equation-3.

$$I_{LM\Delta} = \frac{VL}{Z_W} x\sqrt{3} \quad (3)$$

Delta connection configuration and motor terminal is shown in Fig.5.

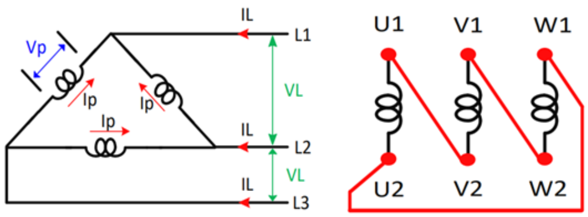

Figure 5. Delta connection configuration and motor terminal (Üçgen bağlantı konfigürasyonu ve motor terminali)

3.EXPERIMENTAL RESULTS (DENEYSEL SONUÇLAR)

The purpose of the star-delta starting method is to get rid of the excessive current and power consumption due to the high voltage that the stator windings will be exposed to in the delta connection. In general, starting methods are applied to asynchronous motors due to the excessive current draw at starting moment. One of these methods is the star-delta starting method. According to this method, 220 V voltage is applied to the asynchronous motor stator windings when connected to star and 380 V (normal operating voltage) when connected to delta. In the star-delta starting method, the transition process is delayed. Otherwise, dangerous situations arise as the phases will be short-circuited.

The control circuit of the three-phase asynchronous motor established using the star/delta starting method is shown in Figure 6. Siemens S7-1200 CPU 1214C (DC/DC/DC) programmable controller was used for monitoring and controlling the system and communicating with the computer. Since this controller operates with 24V DC voltage, a power supply with 220V input and 24V/5A feature was used as the supply voltage. Since the outputs of these controllers are transistor outputs, contactors can burn out in case of high current draw from the output. To eliminate this negative situation, three 24V DC relays were installed on the outputs. Star, delta and main contactors were driven via these relays. The conductor connections required for the energy flow of the controller, relays and contactors were selected considering the current capacities they can carry.

The digital input/output unit of the PLC is used for On/Off control of the system and the analog module unit is used for transferring analog signals to the processor environment. Digital output unit is used for energizing relays and contactors, digital input unit is used for starting and stopping the system. The analog module is used to obtain three-phase current and voltage information of the asynchronous motor and to transfer analog signals such as frequency and speed etc. to the microcontroller environment. LEM's LV-25P voltage sensor was used to measure the voltage applied to the asynchronous motor windings, and LEM's HAS-50 current sensor was used to measure the amount of current drawn by the asynchronous motor from the grid. In order to use current and voltage sensors, an electronic card was designed and a measurement unit was developed. The energy supply card with this feature was designed since the measurement system works with +/-12V symmetrical power supply. By ensuring that these cards can work in harmony with the system, input to the microcontroller is provided as an integrated design. The main energy input of the system is provided by a 6A double pole fuse to protect both the system and the user. Data exchange between OPC Server and PLC is provided by Profi-NET communication method. A photograph of the experimental setup including the hardware units is given in Figure 6.

The user interface prepared on the Profi-LAB platform is shown in Figure 7. The interface design is designed in a flow considering the one-to-one system model. The user can perform both monitoring and control operations as real-time through the interface. System data (three-phase motor operating voltages, phase currents, active-reactive-visible power, frequency, speed and power factor etc.) can be monitored both digitally and graphically.

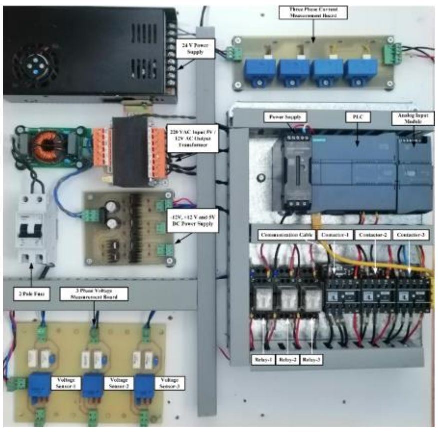

Figure 6. Experimental setup (Deney düzeneği)

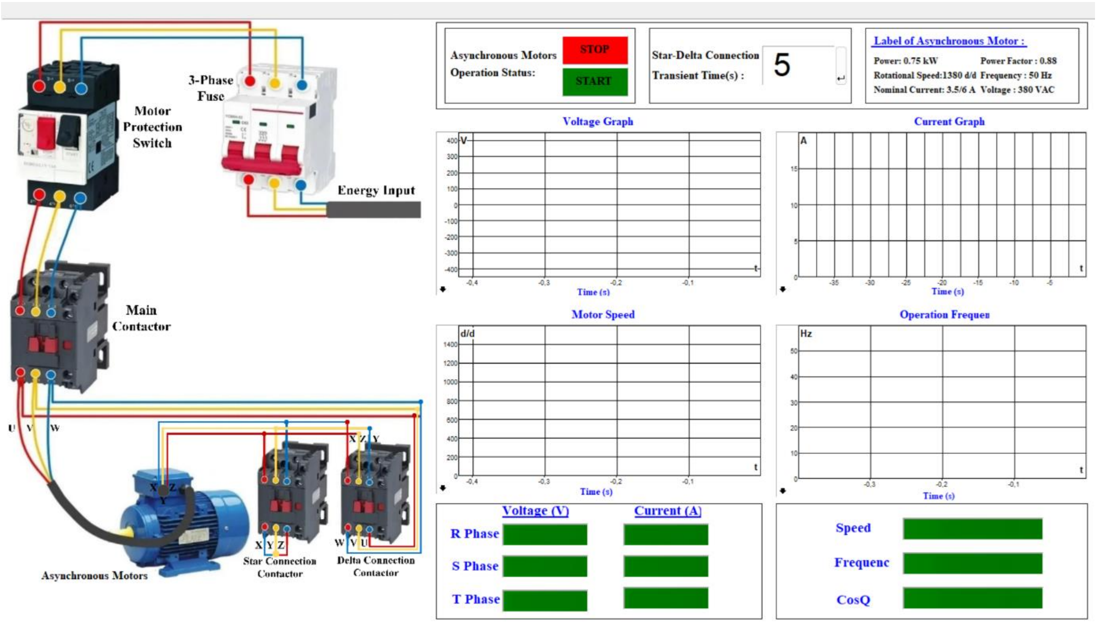

Figure 7. User computer interface (Kullanıcı bilgisayar arayüzü)

The transition time of the asynchronous motor from star connection to delta connection can be set dynamically by setting the transition time via the interface. The user is required to enter this transition time before starting the system. Otherwise, the system continues to stop with a warning. In Figure 8, the star-delta transition time is set to 5s on the user interface. The responses of the asynchronous motor at the first starting moment are shown graphically. The nominal current value of the motor is 3.5A for the star connection. When the wavelength of the current signal is analyzed in Figure 8, it is seen that the maximum point is approximately 6A. In this case, it is seen from the current graph that the motor draws more current from the grid in delta mode than in star mode. It is seen from the current graph that the current value drawn by the motor is approximately 5 times the nominal current value when the asynchronous motor transitions from star connection mode to delta connection mode. When the asynchronous motor is transited to delta connection, the nominal speed is 1380 rpm, the power coefficient is 0.88 and the motor operating frequency is 50 Hz. In this transition, the behavior of other parameters of the motor is also seen both digitally and graphically on the interface.

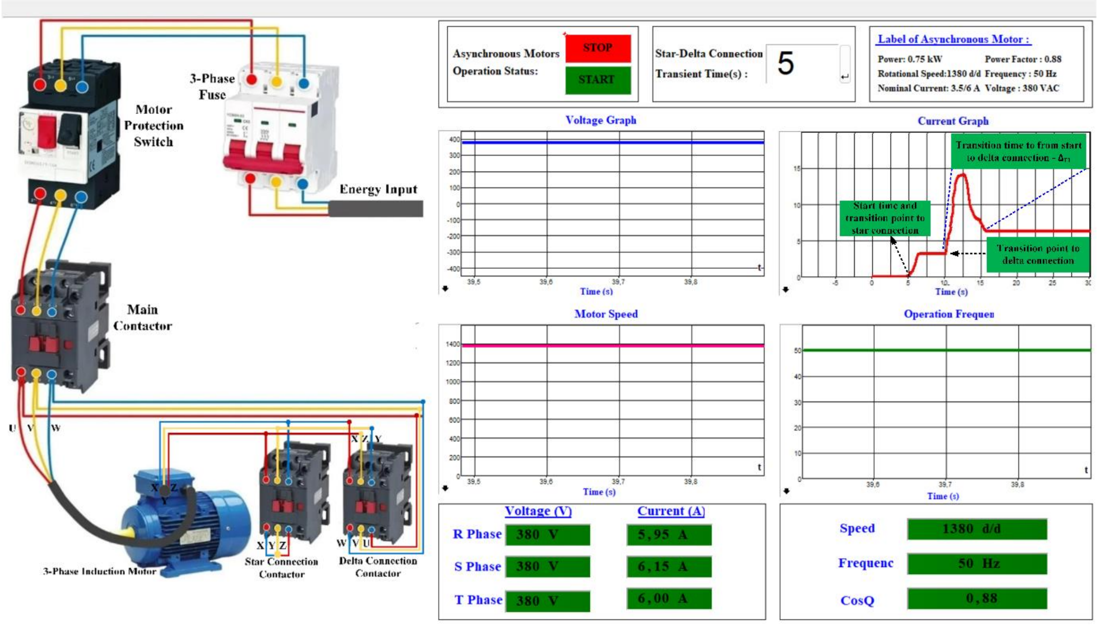

Figure 8. Screenshot when the star-delta transition time is 5s (Yıldız-delta geçiş süresi 5s olduğunda ekran görüntüsü)

The steady state and dynamic behavior of the system is shown in Figure 9 when the asynchronous motor is started using the star-delta starting method with a transition time of 10 seconds. It is seen from the current graph that the current value drawn by the motor is approximately 5 times the nominal current value when the asynchronous motor transitions from star connection mode to delta connection mode. It is seen from the result graphs that the effect of transition time is effective on the current drawn from the grid.

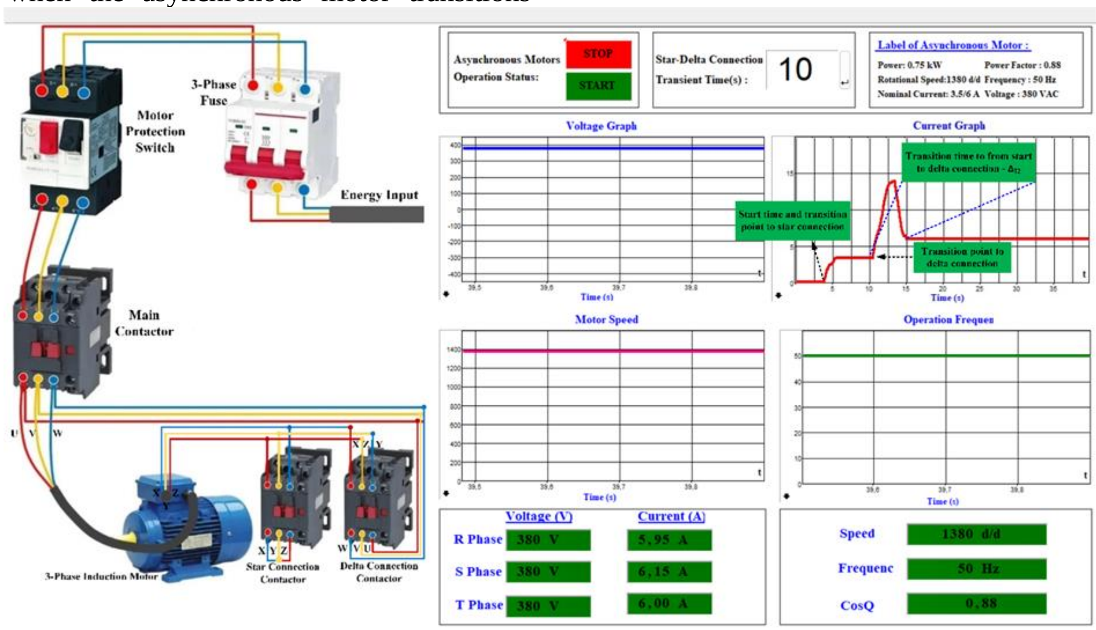

Figure 9. Screenshot when the star-delta transition time is 10s (Yıldız-delta geçiş süresi 10s olduğunda ekran görüntüsü)

4.CONCLUSIONS (SONUÇLAR)

Asynchronous motors, which constitute the majority of the industrial load, draw too much current at start-up. Starting methods are used to eliminate this situation. The star-delta starting method, which is simple and inexpensive, is one of these methods. Thanks to this work that has been implemented;

• Determination of the steady state and dynamic behavior of the system when starting an asynchronous motor with the star-delta starting method,

• With this study, it can guide production in R&D studies, as well as provide convenience to employees in experimental studies and in selecting the most appropriate routing method,

• It can be used as an auxiliary course tool in the Electrical Machines course given in technical and vocational education institutions. Thus, it contributes to the more permanent learning of the formulas related to the subject and to see the effects of parameter change graphically,

• The star-delta starting method, on the other hand, is preferred mostly in simple applications due to the jumps in current and knocking in the motor due to the abruptness of the transitions,

• Computer-controlled operation of asynchronous motors operated by the star-delta starting method creates a safe working environment,

The disadvantage of the star- delta starting method is;

• Since this method provides a two-stage control process consisting of start and stop operation, it does not offer different speed control options,

• Inadequate control of the initial development speed of the asynchronous motor, inability to control torque, as well as the occurrence of vibrations on the machine shaft due to the high currents generated during the transition from star to triangle,

• In the selection of circuit elements such as residual current relay, fuse, motor protection switch and thermal switch used for protection purposes while using asynchronous motors operated with star-delta starting method in the market, it should be selected to be 5-6 times more than the nominal current value,

was identified in the application results.

ACKNOWLEDGMENTS (TEŞEKKÜR)

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AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

Seyfettin VADİ: He conducted the experiments, analyzed the results and performed the writing process.

Deneyleri yapmış, sonuçlarını analiz etmiş ve maklenin yazım işlemini gerçekleştirmiştir.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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