SZÉCHENYI ISTVÁN EGYETEM
AUDI HUNGÁRI JÁRMŰMÉRNÖKI
KAR

INVESTIGATE VARIABLE FREQUENCY DRIVE (VFD) SYSTEM

Measurement practice V.

FOR VEHICLE ENGINEER STUDENTS

Version: 1.0

Széchényi István University
Department of Power Electronics and Drives

The equipment operates on mains voltage (400V). They can only be connected with the permission of the measuring supervisor!!!

<u>Do not touch the high voltage!</u>

<u>Never touch moving parts during operation!</u>

1. Introduction

In this measurement exercise we will investigate the principle of operation of a variable frequency drive (VFD) system.

1.1 Objectives

- connecting, setting up and operating of variable frequency drive system/inverter;
- decoding and interprets of motor nameplate;
- connection of 3 phase motor (star/delta);
- investigation and connection of 3 phase plug;

1.2 Required instruments and components

- ABB ACS880-01-14A3 inverter (see Fig. 1.);
- Induction motor.

Fig.1. ABB ACS880-01-14A3, 3 phase inverter

2. Literature review

2.1 Asynchronous (induction) motor

The asynchronous motor is described in "Electrical engineering-Students book_Form Four", chapter five.

2.2 Inverter

To better understand inverters, let's review what type of energy conversions are available in power electronics: we can define conversions between DC and AC signals. To examine this, let's check Fig. 2.

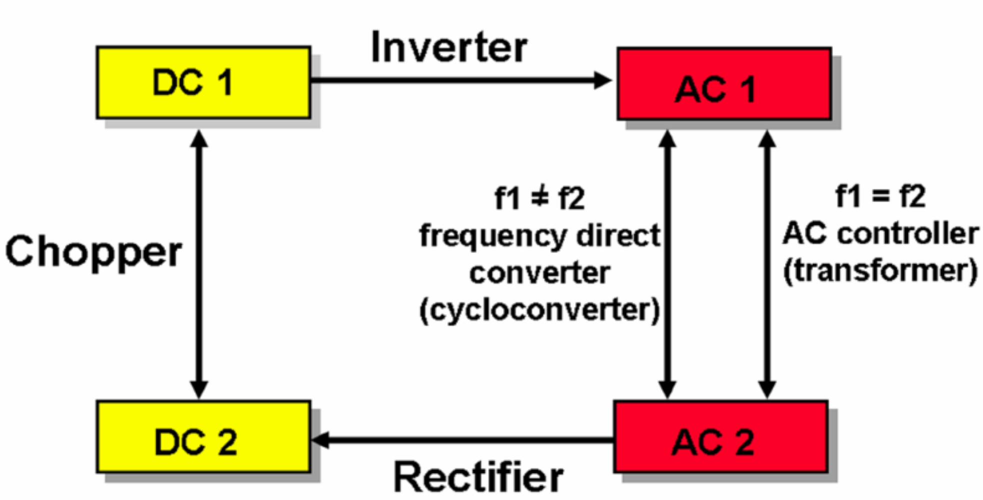

Fig.2. Energy conversions in power electronics

Two of these were covered in detail last semester: AC/DC (rectifiers) converters and DC/DC (choppers) converters. In the classical way, DC/AC converters are called inverters. Their main function is to convert direct current into alternating current. The last large group is AC/AC converters, often called frequency converter. The latter two will be examined in detail.

2.3. Variable frequency drive system

In the case of electric rotating machines, different manipulations can be performed, such as starting, braking, speed, or torque control, changing the direction of rotation, etc. Different electric rotating machines offer different possibilities for performing these manipulations. The VFD system will be investigated through the induction machine as a case study (interested students can research other rotating machines).

The most effective solution to varying the speed of an AC asynchronous or synchronous machine is to vary the frequency of the supply, which allows a continuously variable drive over a wide speed range (there are other solutions, such as pole-pairing, slip-changing, etc., The principle has been known for a long time, but only the rapid development of power electronics has made it possible to develop and manufacture inverters that meet all technical requirements, are reliable and cost-effective.

Powering from an inverter has made it possible that the nominal frequency f of the motors does not have to match the mains frequency of 50/60 Hz. This has given rise to high-speed motors, typically single pole, with a supply frequency in the hundreds or even above kHz, and thus a rated speed of tens or even hundreds of thousands of rotations per minute. Such drives are used, for example, in machine tools. Motors in hybrid and electric cars have a similarly high rated frequency f. However, because of the higher torque they can deliver, these motors have more pole pairs, so their rated speed per minute is typically around 10,000 rpm. Fig. 3. shows a typical block diagram of a VFD.

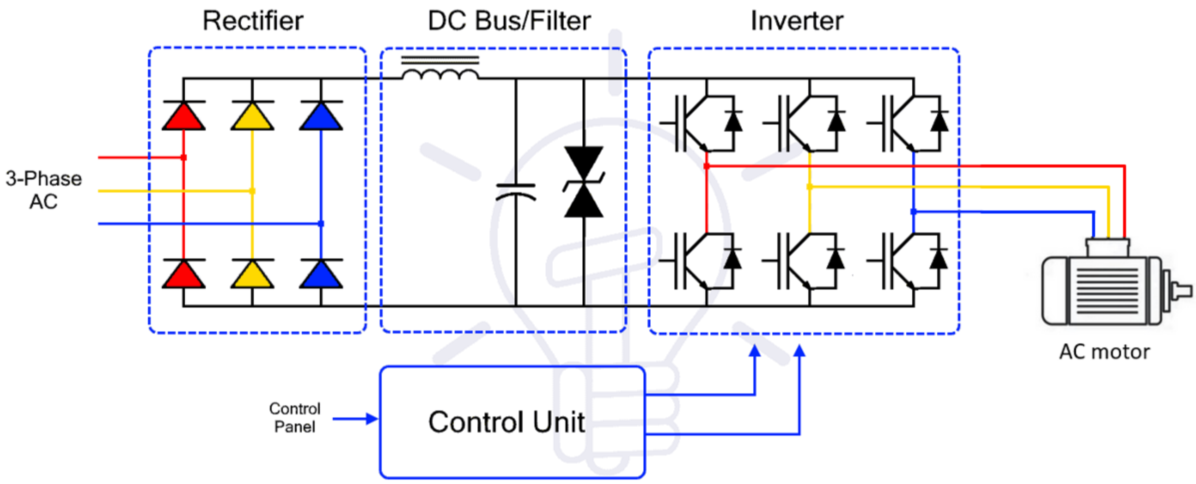

Fig.3. Block scheme of VFD system

2.3.1 3-phase rectifier and filter unit

If the motor is operated from the mains, the mains voltage must be rectified. Fig. 4. clearly shows that each phase is connected with a half-bridge of diodes. Accordingly, as we learned in the previous semester, the input AC voltage can be separated into a + and a - part. Also, we have already studied that the output signal of the rectifier is highly rippled. This can be reduced by capacitance (capacitor) and another different electrical parts (inductor, TVS diode etc.). The DC Bus/Filter block is used to supply a stable DC power to the inverter.

Note that in the case of electric cars, the first block (rectifier) can be skipped, as the battery of the vehicles is inherently DC.

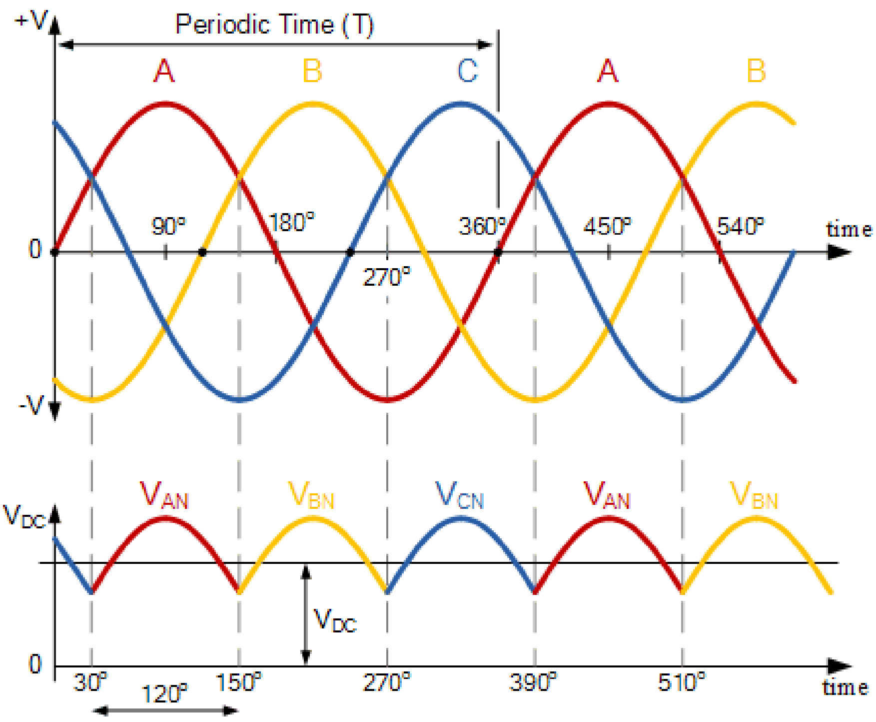

Fig.4. 3-phase rectifier waveform

2.3.2 Working principle of inverters

To understand how inverters work, we will start from the most basic circuit layout: the single-phase half-bridge VSI. The circuit layout is shown in Fig. 5. At the input of the circuit is a capacitive divider (implemented by two high value capacitors, namely C_+ and C_-), whose function is to create a neutral point (N). S+ and S- are semiconductor switches, which are switched on or off according to the control. It goes without saying that both switching elements cannot be on at the same time, as the supply voltage would be short-circuited. Accordingly, a dead time must be inserted between the switching operations (e.g., when S+ is switched off and S- is switched on). In the example, our load is resistive in nature, in the simplest case (this type of load is very rare in reality).

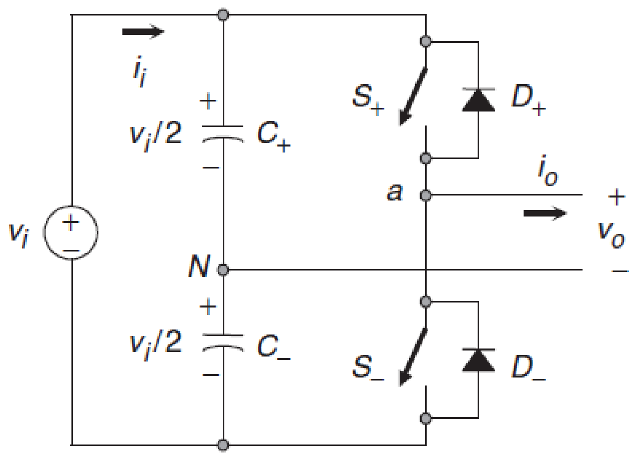

Fig.5. One phase, half-bridge inverter

The important waveforms of the half-bridge inverter are shown in Figure 6, which are: the voltage of the high side switch (S+), low side switch (S-), and output voltage (Vo).

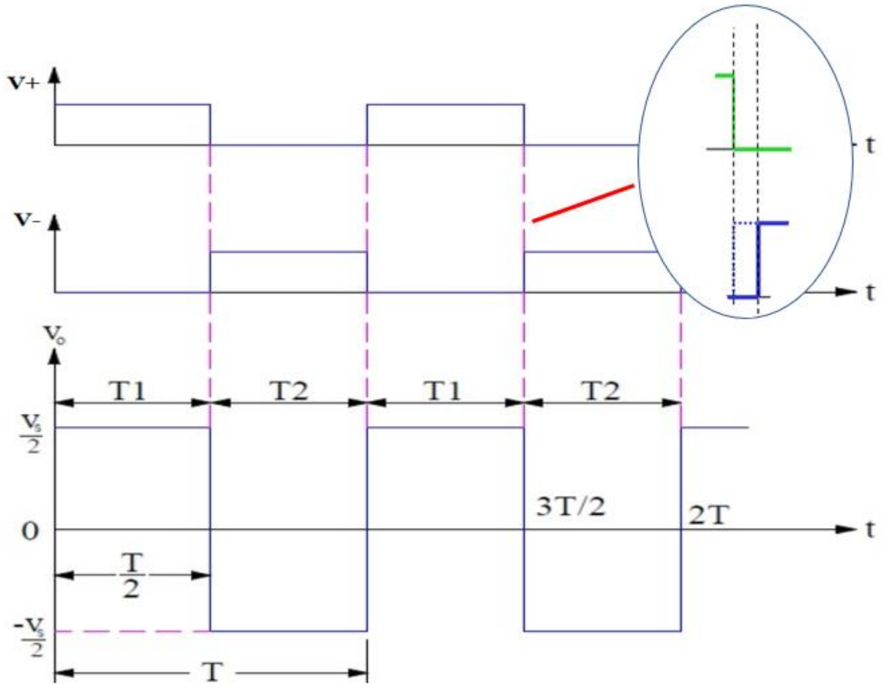

Fig. 6. Waveforms of one phase, half-bridge inverter

For example, in an electric vehicle, the power inverter switches the connection between the battery (or main) and the electric motor on and off. Each switching event is a pulse. The inverter changes the speed at which the motor rotates by adjusting the timing between pulses and the width of the pulses as shown in Fig. 7.

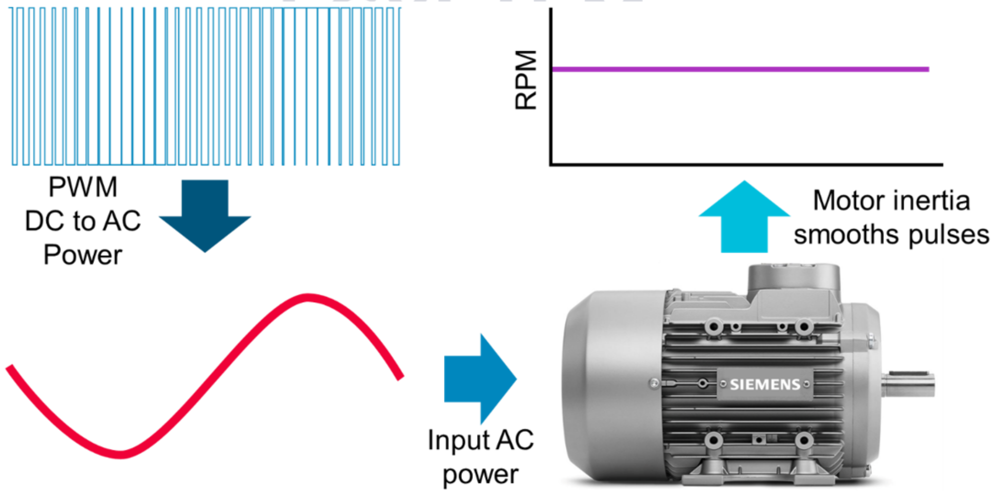

Fig. 7. VFD working

In most cases, a PWM signal is used to control the semiconductor switches. Last semester we used PWM signal to control MOSFET in buck converter. The working principle is shown in

Fig. 8. The principle is as follows: the outputs are high level (1) when the duty cycle is greater than the carrier counter value, or low level (0) otherwise. In this case, the duty cycle is fixed in every period.

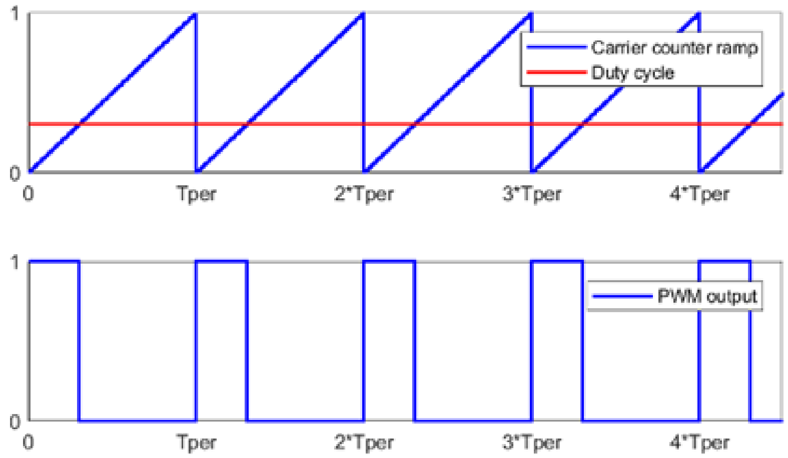

Fig. 8. PWM signal basics

In AC motor control the phase current is sinusoidal form. In the easiest case, the inverter has two two-level types: the semiconductor can carry the positive voltage or negative (or GND). The base idea of the creation of the sinusoidal phase current is shown in Fig. 9. This methodology shows the analog type of PWM generation. In practice, the generation of PWM is produced by a microcontroller (digitally).

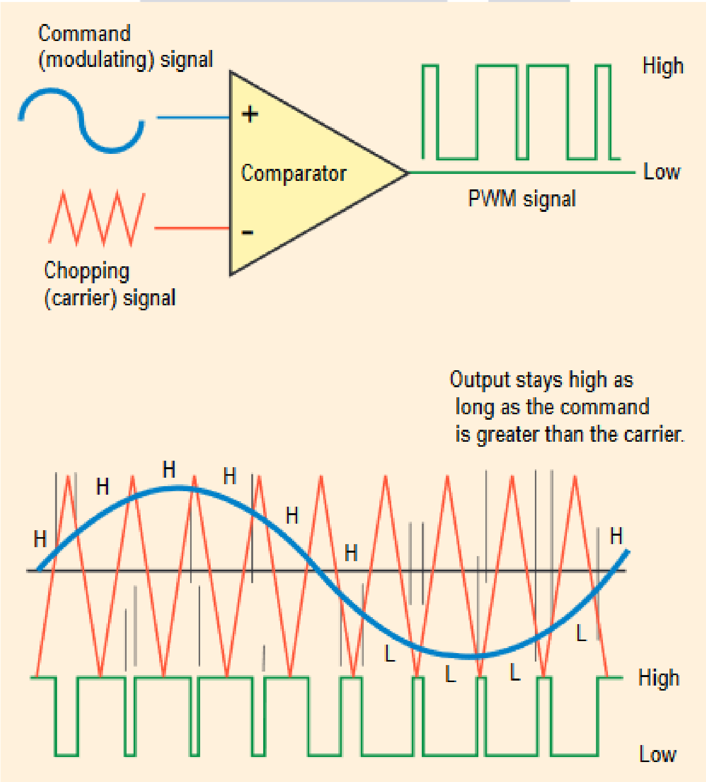

Fig. 9. How PWM works

In the analog case, we use a comparator (in electronics, a comparator is a device that compares two signal) which compare the carrier and the modulating signal. The output of the comparator can be low or high level, depending on

$$V_{out} = \begin{cases} 1\ (high), & if\ modulation\ is\ higher\ then\ carrier\ signal, \\ s0\ (low), & if\ modulation\ is\ lower\ then\ carrier\ signal. \end{cases}$$

The output of the comparator can be used for the switch of semiconductors.
Finally, let's look at what happens at the output of the inverter (Fig.): most electric motors (in Europe) operate at 50 Hz. With increasing or decreasing the operating frequency we can change the speed of the motor. This is the easier control of the AC motor.

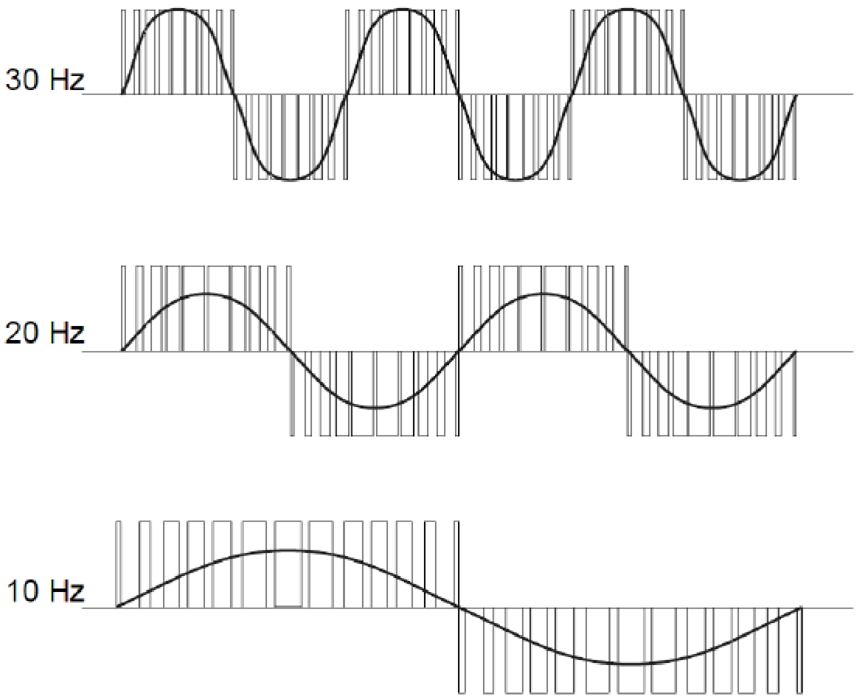

Fig. 10. PWM and sine wave of inverter output

2.3 3-phase plug

In three-phase systems, the connection to the mains must be standardized. IEC 60309 is a worldwide standard defined by the International Electrotechnical Commission for plugs, sockets, outlets, and couplers for industrial purposes. In catalogs of electrotechnical companies IEC 60309 material is categorized as CEE plugs and sockets. Reduced to 3-phase connectors, the plugs and sockets are categorized according to the maximum permissible currents. 16A types are rarely used for domestic purposes but are common in workshops and can be found at campings, marinas farms, etc. 32A, 63A, and 125A plugs and sockets are clear industrial devices. The 32A connector will be used in the laboratory, so its wiring is shown (see Fig. 11.).

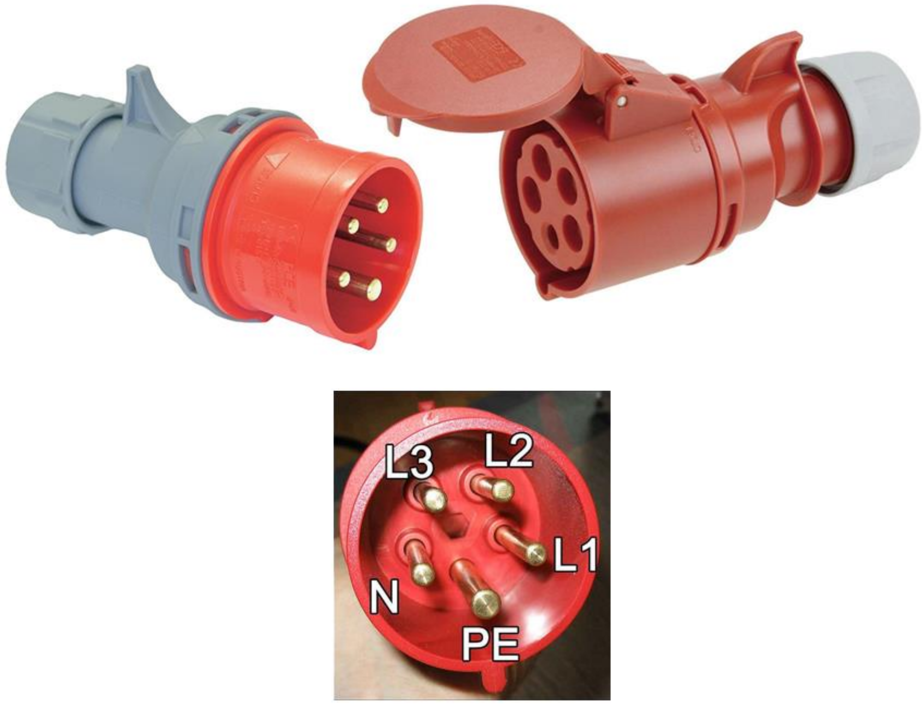

Fig.11. 3-phase connector and plug

2.4 Induction motor (nameplate)

The nameplate contains information about the construction characteristics and performance, electrical and mechanical parameters of the motor. Further data is usually available in the motor catalog. The motor's nameplate is located somewhere on the side or top of the motor. To understand the motor nameplate, let's look at an example (see Fig. 12.)

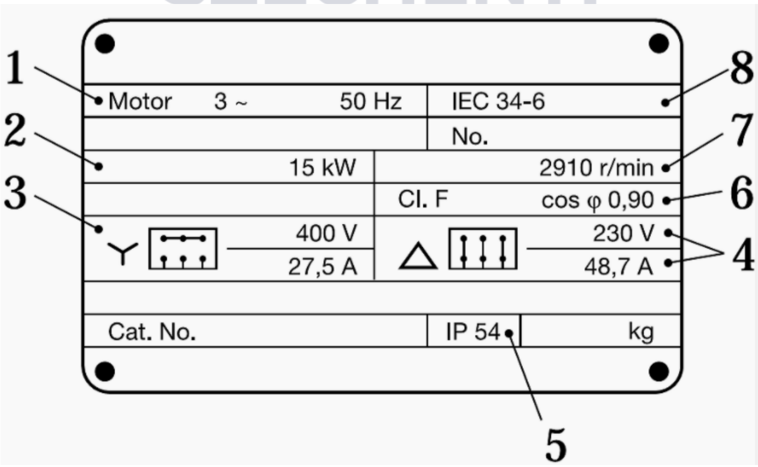

Fig.12. Typical motor nameplate -example-

Data marked with a number have the following meaning:

1. Motor phase number and frequency (f);
2. Power of the motor (P);
3. Motor voltage (U) and current (I) in star connection;
4. Motor voltage (U) and current (I) in delta connection;

5. Motor IP (ingress protection) classfication (IP number);
6. Power factor of motor (cos φ);
7. Motor speed;
8. Recommended cooling type.

2.4.1 Definitions

Motor IP (ingress protection): electric motor IP (ingress protection) classification is a measure of the capacity of the motor to resist ingress of dust and water. Objects, dust, or water may enter the motor providing they cannot have any detrimental effect upon its operation. Two numbers follow the letters IP. The first number defines resistance to dust and the second to water [2]. You can check the IP ratings guide in Fig 13!

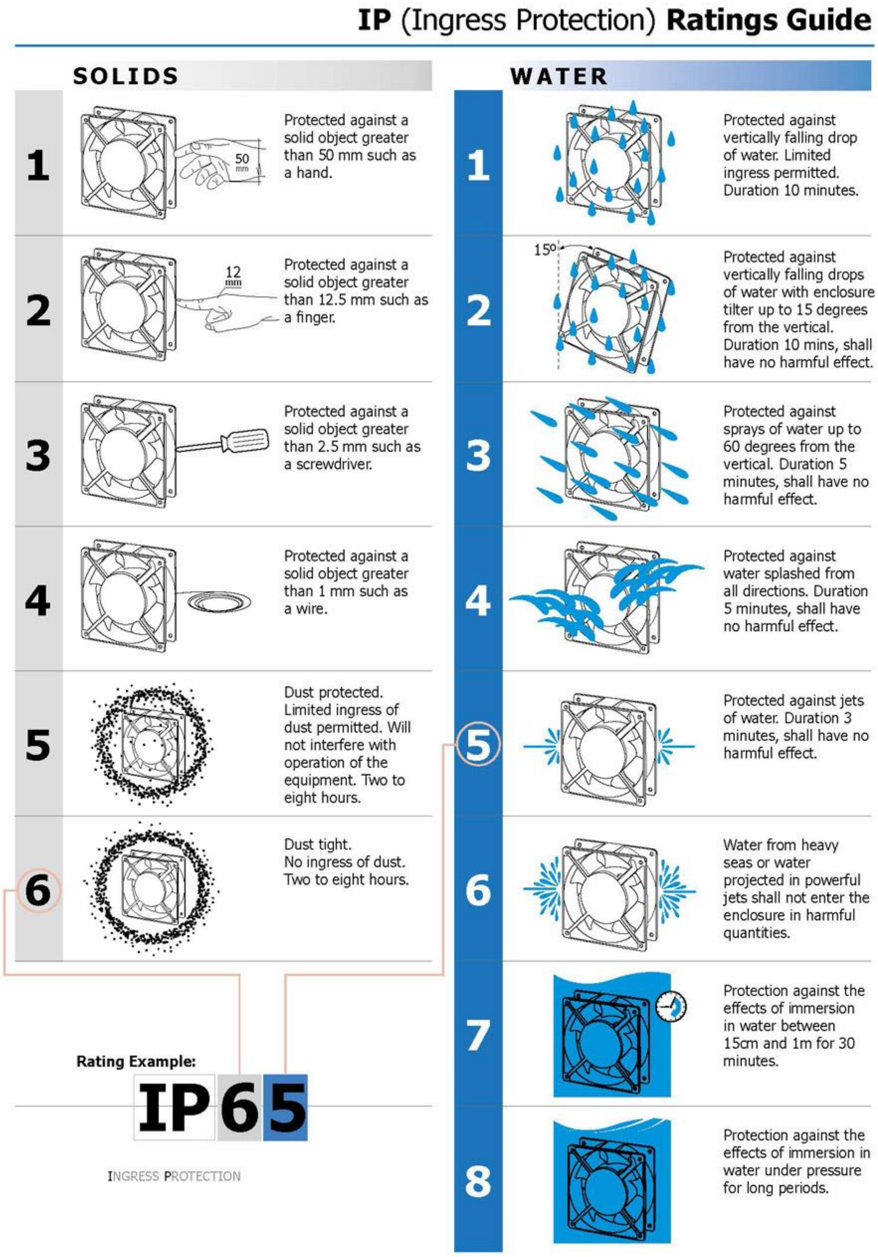

Fig.13. IP ratings guide [2]

Power factor: In single-phase systems, electrical power is the product of voltage and current, and is measured in watts, i.e.

$$P = UI\ [W]. \quad (1)$$

In three-phase systems, phase delays and phase shifts occur due to capacitance and inductance, so not only active ("wattage") power is generated, but also reactive power. The two together are called also apparent power. The relationship of the three elements of powers, i.e. active power (P), reactive power (Q), and apparent power (S) is shown in Fig. 14.

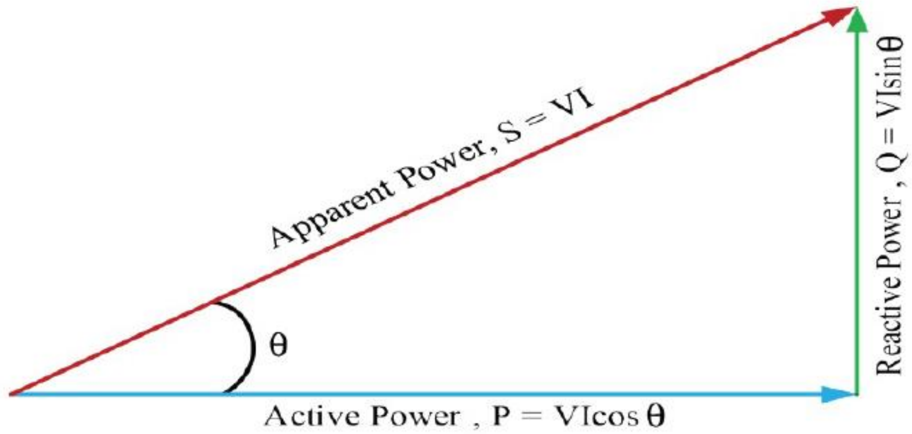

Fig.14. Power triangle, showing S, P, and Q powers [4]

A summary of the sign and unit of measure of each power:

- Apparent power, S [VA];
- Active power, P [W];
- Reactive power, Q [Var].

In Fig. 4. is shows a Θ angle between active and reactive power. This Θ angle can be calculated using the cos function, given the active and reactive powers. This quantity, "cos Θ" is also called the power factor. A motor's power factor represents the ratio of active or real power to the apparent power, which is the product of voltage and current. A low power factor indicates that the motor is drawing more reactive power and less active power, which can lead to voltage drops, overheating, and energy waste. Fig. 15. shows the practice meaning of the power factor.

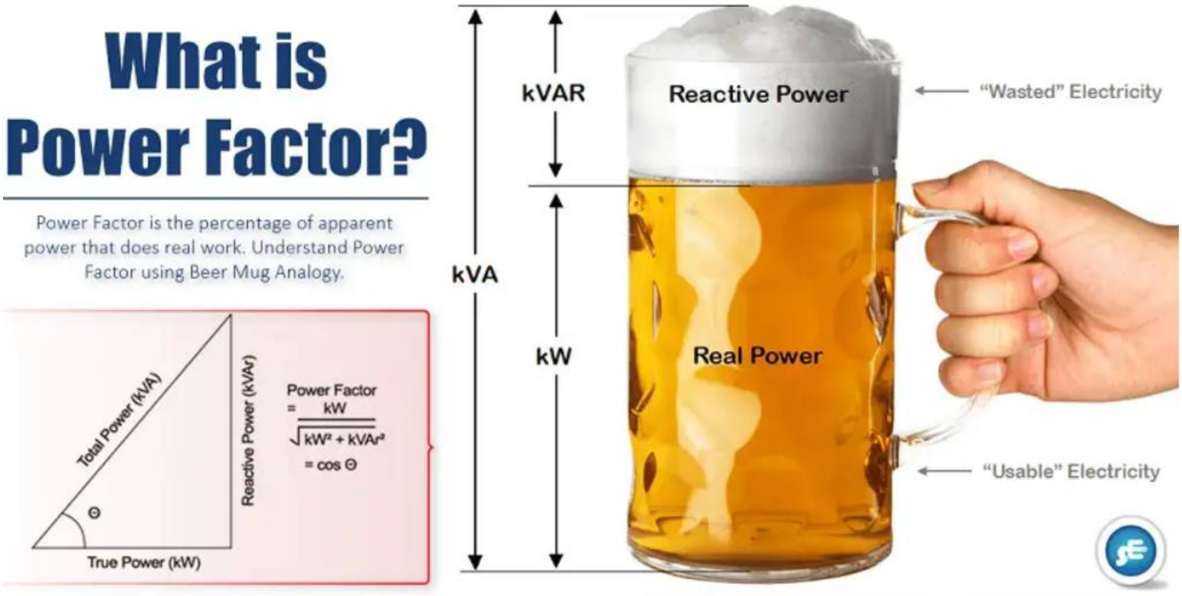

Fig.15. What is a power factor (in practice) [5]

3. Measurement exercises

3.1 Checking the three-phase plug by multimeter

In this practice, we are checking the three-phase plug and wire using a digital multimeter (see Fig. 16).

Fig.16. 3-phase connector with cable

The steps of measurement:

1. Set the digital multimeter to continuity test!
2. Check the correct connection of the connector! L1, L2, L3 etc.! If you measure both ends of the wire, you will hear a beeping sound! Use the second figure for the test!

3. Note which color belongs to which phase/connector!

3.2 Connecting the main and the motor to the inverter

1. You can access the terminal after removing the cover (see Fig. 17.).

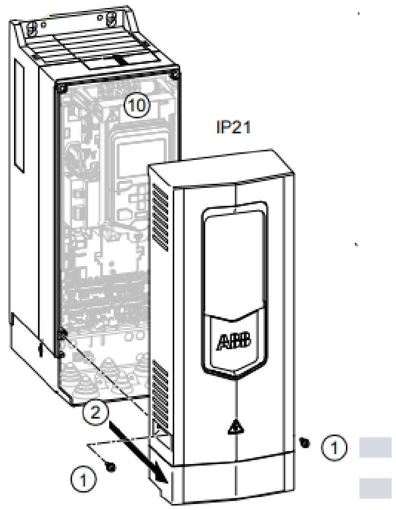

Fig.17. 3 Disassembling the cover of inverter

2. After removing the cover, connect the mains and motor cables as shown in Fig. 18. (green-yellow = earth, brown = phase 1, black = phase 2, grey = phase 3)

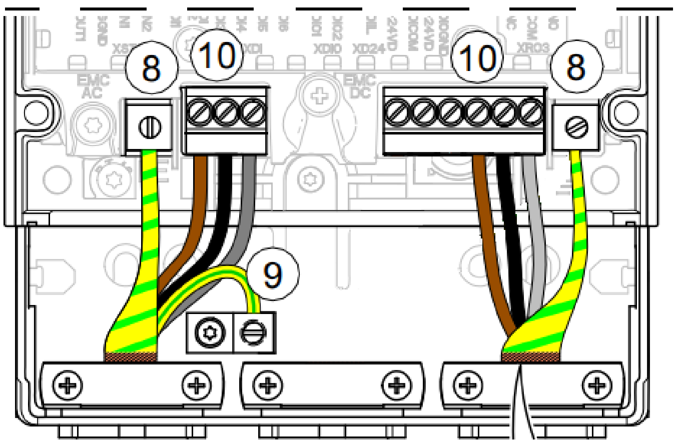

Fig.18. Wiring of an inverter (left is the input (main), right side is the output (motor))

Before connecting to the mains, the connection must be checked by the measuring supervisor!!

3.3 Setting up the inverter

1. Check and note the parameters from the motor's nameplate. If the torque parameter is not available, you can calculate it as follows:

$$P = \sqrt{3} \cdot U \cdot I \cdot cos\varphi \quad (2)$$

$$M = \frac{60 \cdot P}{2 \cdot \pi \cdot n} \quad (3)$$

2. The inverter will switch on automatically when it is connected to the mains. After loading, the main screen is displayed, showing the current values (see Fig. 19).
3.

Fig.19. Main menu and control panel of inverter

4. Use the right arrow to enter the settings, where you can start the configuration in the "Parameters" menu (Fig. 20.).

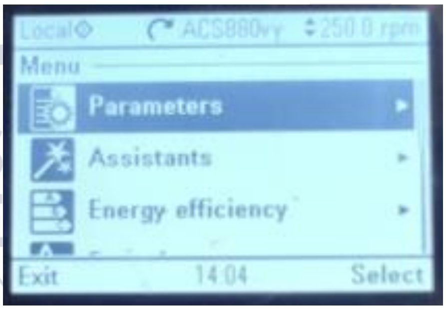

Fig.20. Parameters menü

5. Next, we move on to "Basic setup" where we start the configuration (see Fig. 21).

Fig.21. Basic setup

6. Next, you can set the language, localization, units of measurement and date/time (the option (marked III) option we don't used during the measurement) (see Fig. 22).

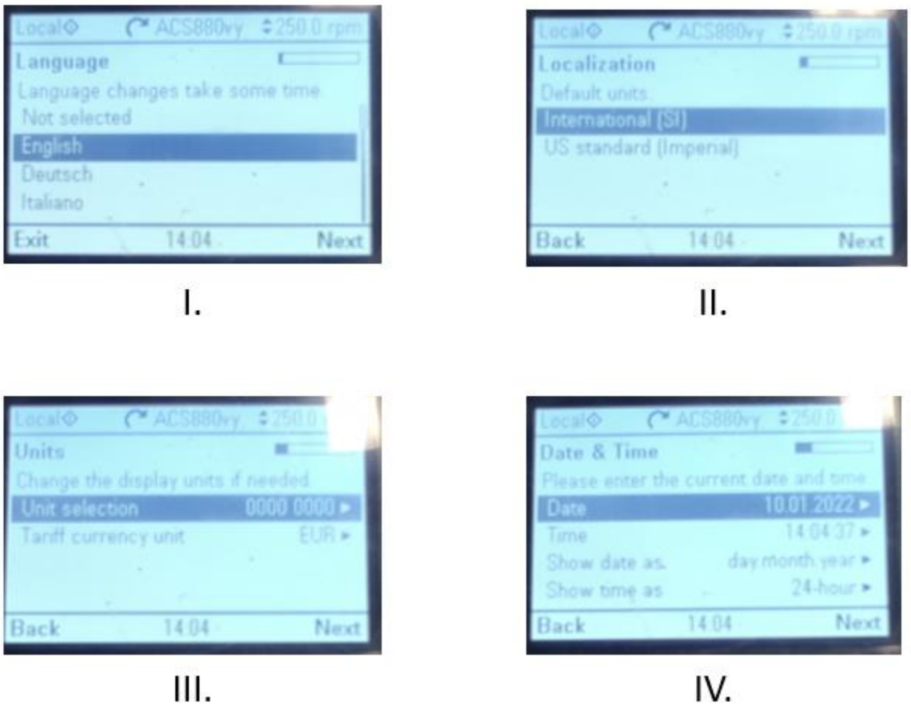

Fig.22. Basic settings

7. The next menu you can set the mains voltage (see Fig. 23).

Fig.23. Supply voltage setup

8. The motor data can be entered after the mains voltage. Motor parameters to be set (can be read from the motor nameplate):

   Motor type: asynchronous motor, permanent magnet motor or synchronous reluctance motor

   - Rated voltage [V];
   - Rated current [A];
   - Rated speed [rpm];
   - Rated power [kW];
   - Next page:
   - Power factor (cosφ);
   - Rated torque [Nm];
   - Control mode: usually we will need the direct torque control (DTC).

9. After entering the motor specifications (if one of the parameters is faulty, this menu will not let you through and will send an error message), you can enter the maximum and minimum speed and torque, and the maximum current (see Fig. 24).

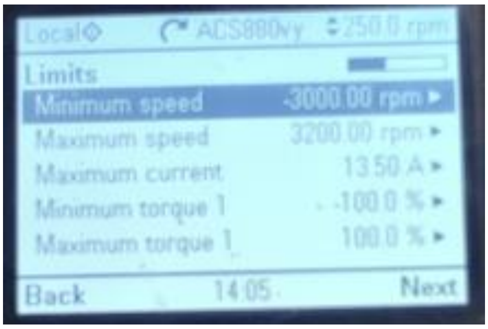

Fig.24. Limits setup

10. At the end of the configuration, test the motor operation with the Direction test ("Yes, test now"). When run, it will ask if the rotor started to rotate in the right direction, if not you can specify to change the rotation direction. After setting the rotation direction we can specify how detailed the instrument should self-adjust, for us "Reduced ID run" will be sufficient, this will take a few minutes, and if successful it will return to the main menu and is ready to use.

5. Conclusions

7. References

[1] https://new.abb.com/products/3AXD50000046386/acs880-01-14a3-7

[2] F. Bordry and D. Aguglia, *Definition of Power Converters*, Proceedings of the CAS-CERN Accelerator School, ERN, Geneva, 2015.

[3] https://www.electricaltechnology.org/2021/11/vfd-variable-frequency-drive.html

[4] https://www.electronics-tutorials.ws/power/three-phase-rectification.html

[5] https://community.sw.siemens.com/s/article/Simcenter-Testlab-Switching-Frequencies-and-Pulse-Width-Modulation-PWM-Signals

[6] https://mathworks.com

[7] https://studylib.net/doc/18034204/pulse-width-modulation

[8] https://www.brennenstuhl.com/en-DE/selection-of-themes/construction-renovation/differences-between-the-types-of-sockets

[9] https://www.plugsocketmuseum.nl/IEC60309_1.html

[10] Electrical Engineering for Technical Secondary Schools, Student's book, Form Three.

[11] https://studyelectrical.com/2016/07/what-is-power-factor.html

[12] D. Bányai, *Frekvenciaváltó*, measurement guide, 2022.

[13] https://www.axair-fans.co.uk/all-technical-information/ip-classification/