# Three Phase Induction Motor

# Motor cutaway

- Lets start by studying the cut away of  the induction motor. There are two main types based on the rotor circuit; the wound (slip rings) and the squirrel age induction motor.

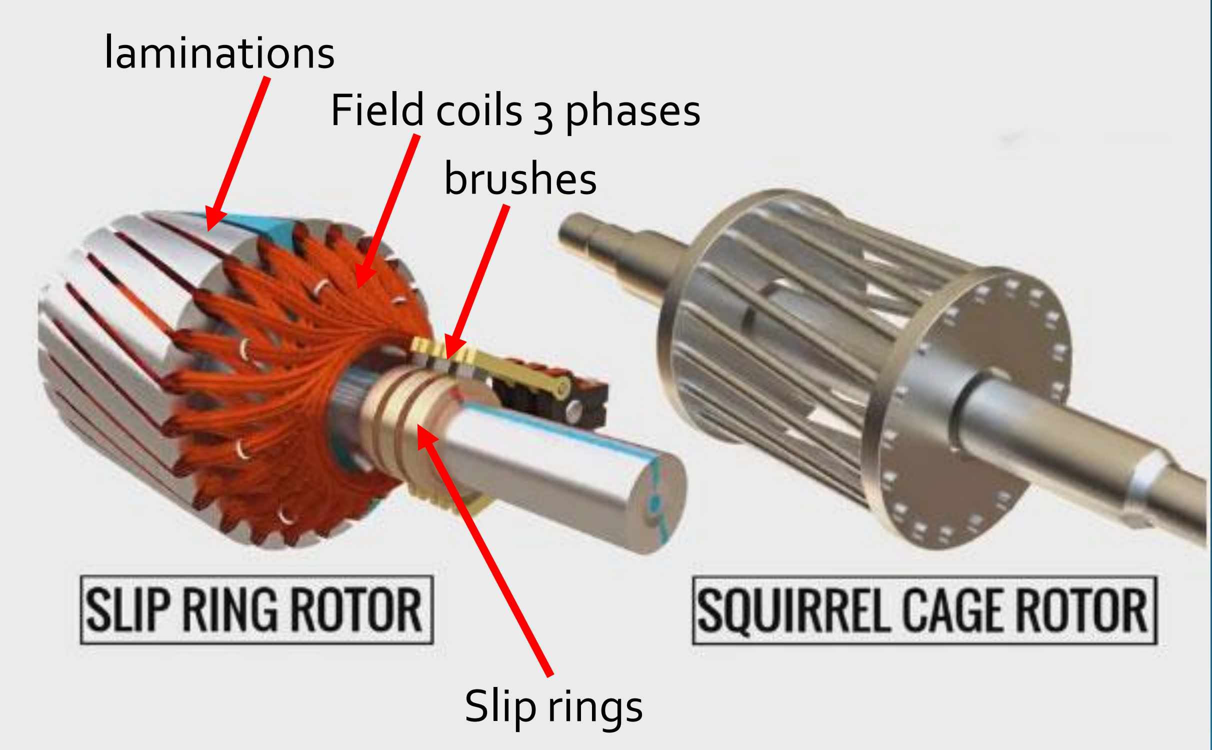
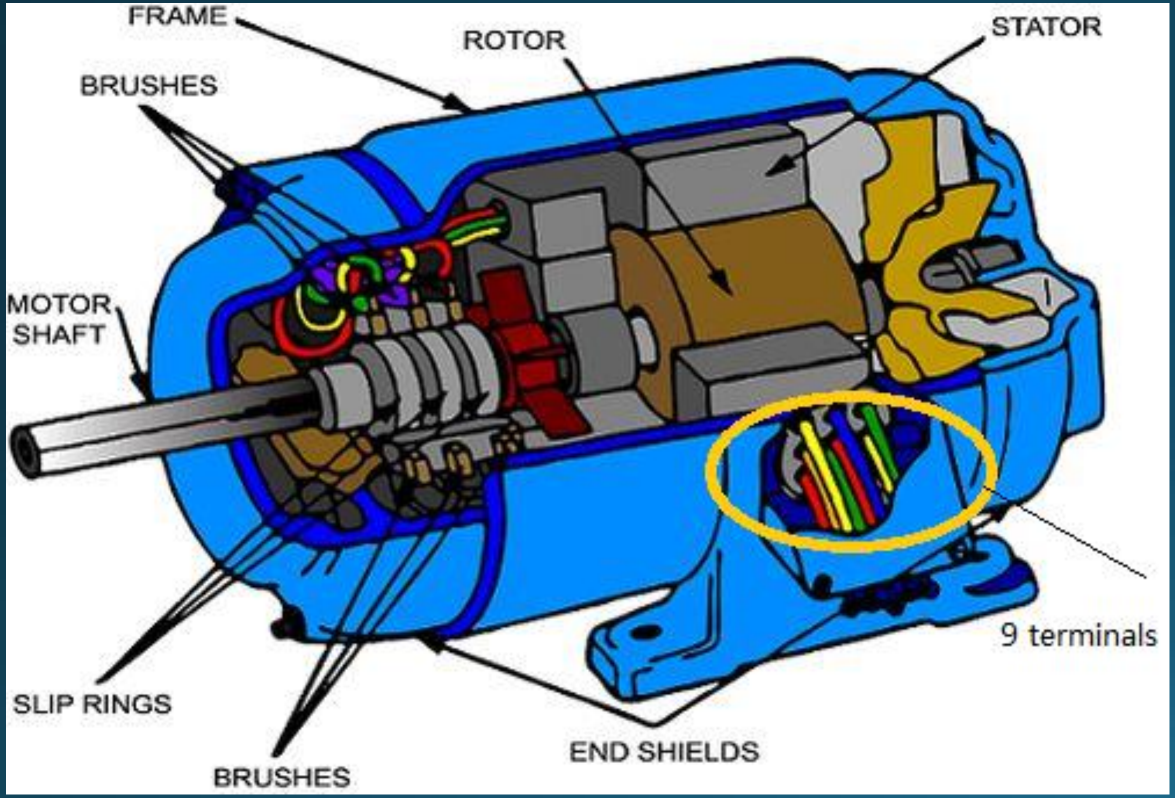



Figure 1

# Motor cutaway

- The parts are indicated on the figure. Note the difference in the number of terminals in each type. 6 in the squirrel cage versus 9 in the wound.



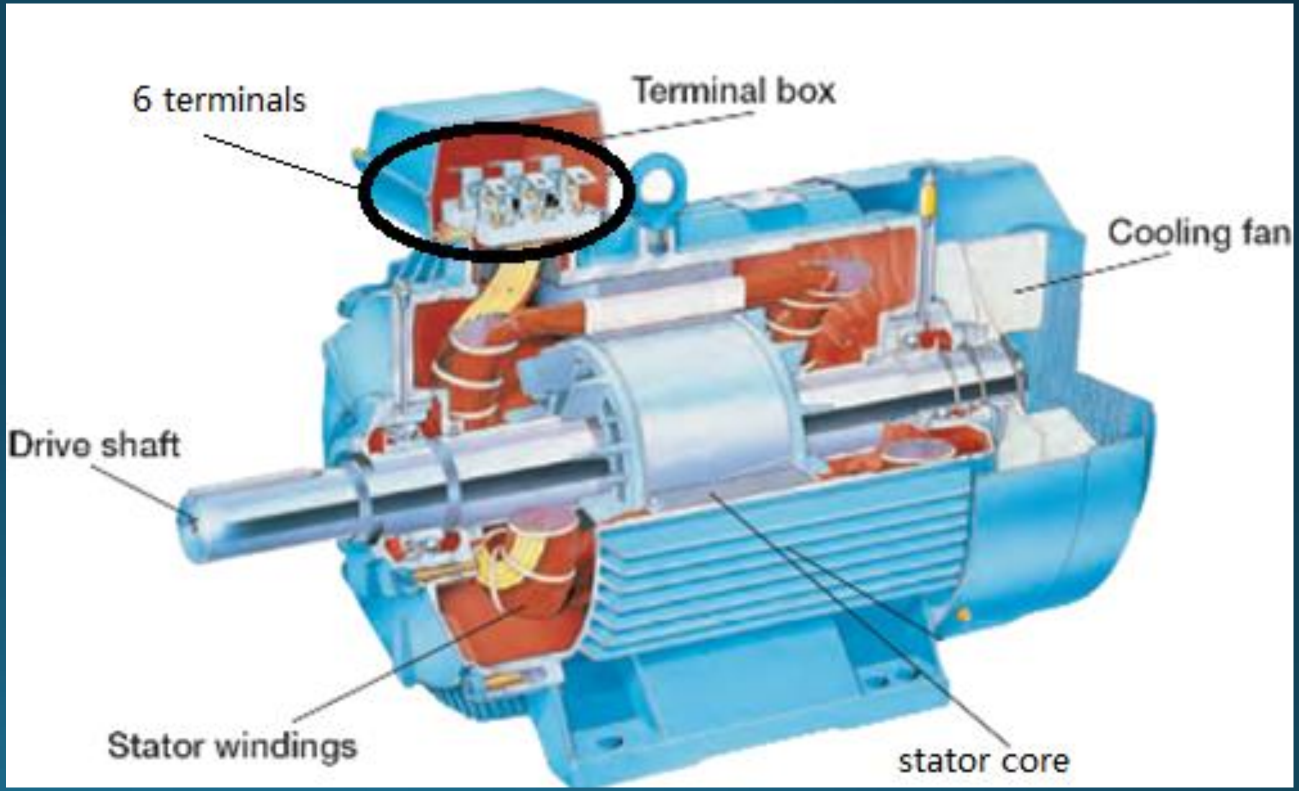




Figure 2

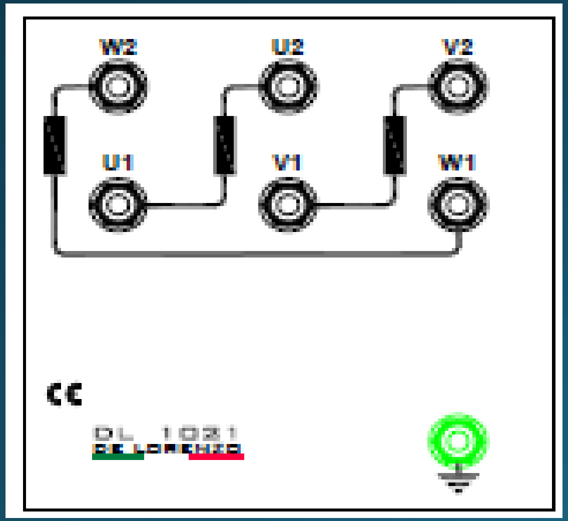
# Squirrel cage and wound rotor 3ϕIM

- The stator of each motor has 6 terminals to be connected as star or delta.
- The rotor of the squirrel cage motor has no rotor terminals because the rotor is a cage.(bars shorted by rings at their ends)
- The rotor circuit of the wound rotor motor is internally connected as star and has only three terminals in the terminal box that must be shorted.

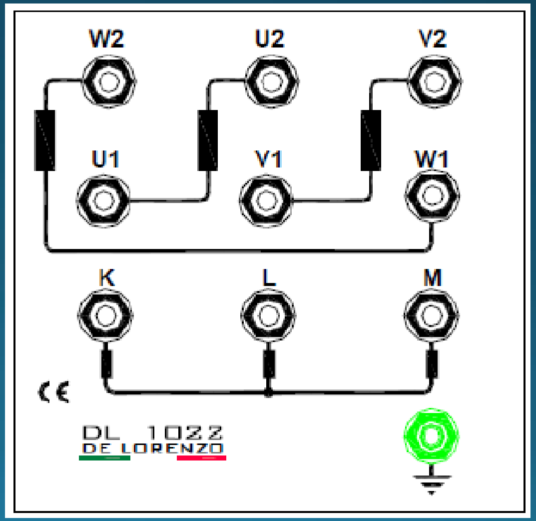
# Motor connection terminals

- For both types, between w1 and w2 there is a stator phase. Between v1 and v2 there is a second stator phase. Between u1 and u3 there is a third stator phase.
- In the slip ring motor, K,L and M are the rotor circuit terminals and must be shorted.

- Squirrel cage

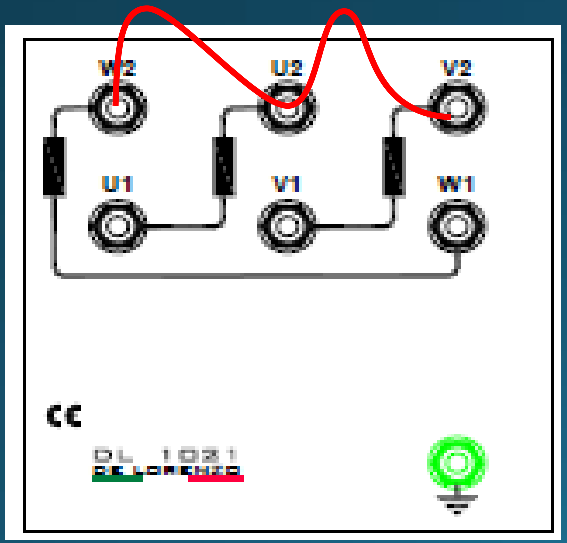


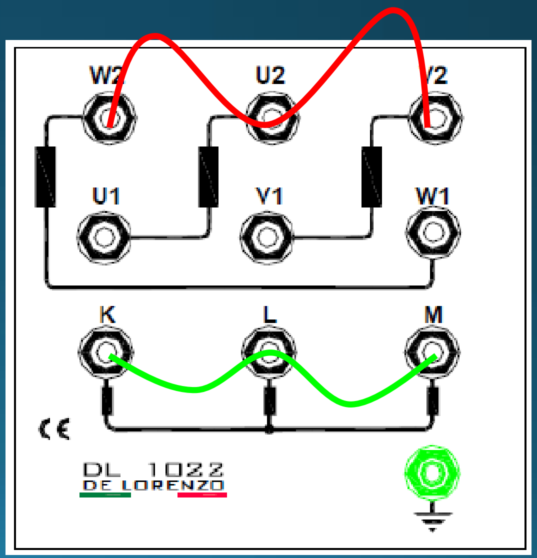

wound rotor (slip ring)



# Star connection

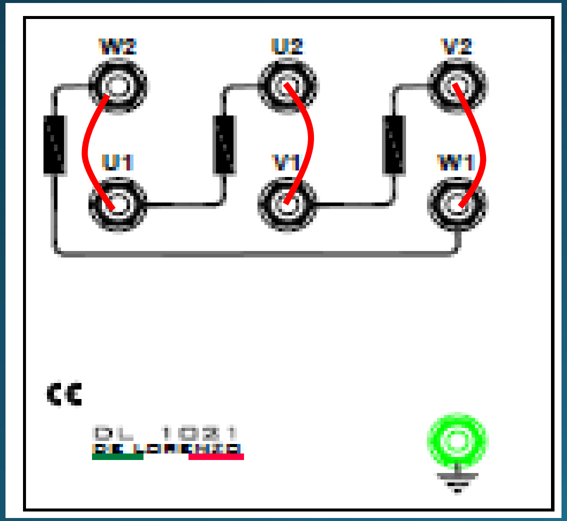
- You can short w2, v2 and u2. or w1, v1 and u1. the set that is not shorted is connected to L1, L2 and L3
- The rotor of the wound motor is always shorted regardless the connection of the stator

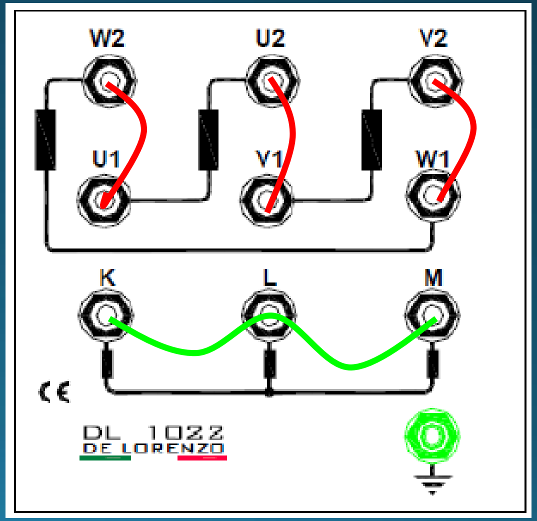


# Delta connection

- You can short the start of a phase with end of another phase but don't repeat couples. L1, L2 and L3 are connected to all the terminals with notation 1 or all terminals with notation 2.
- The rotor of the wound motor is always shorted regardless the connection of the stator



# 3 phase induction motor (3ϕIM) model

- The three phase induction motor (3ϕIM) is basically a rotating three phase transformer. So they share the same per-phase circuit. The only difference is that the secondary side of a transformer is open circuited to install an electrical load while the rotor circuit in a 3ϕIM is shorted since the load is mechanical.
- The rotor circuit in a 3ϕIM differs in construction between the squirrel cage and the wound types but still they have the same equivalent circuit.

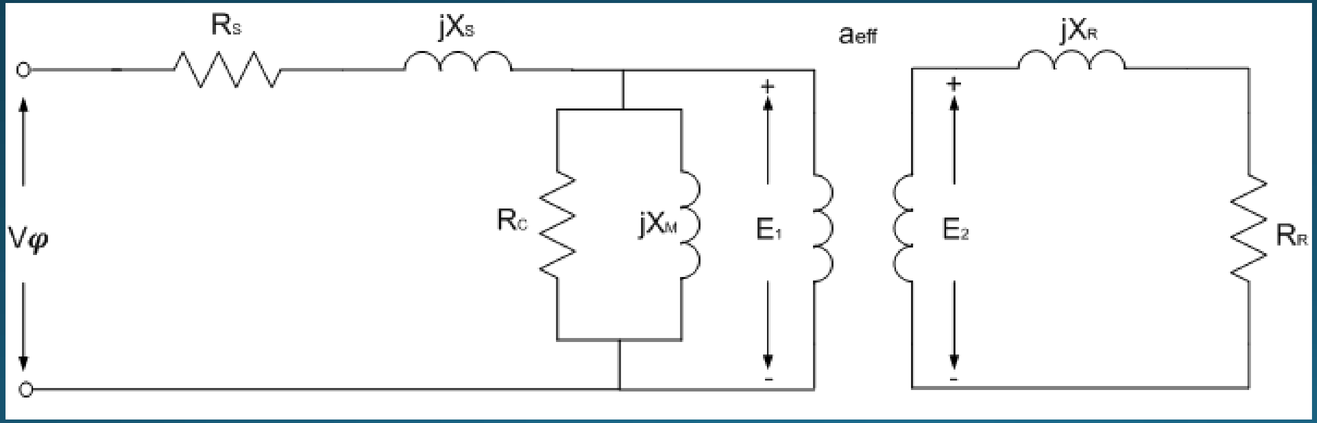



Figure 3

# 3 phase induction motor model parameters

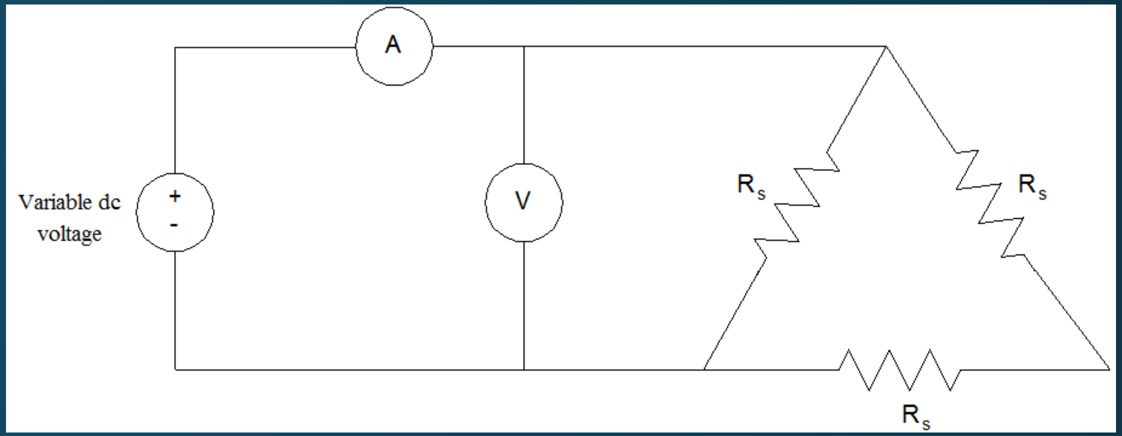
- To find the parameters of a 3ϕIM equivalent circuit, we must run some tests:
- Dc test
- No load test
- Locked rotor test

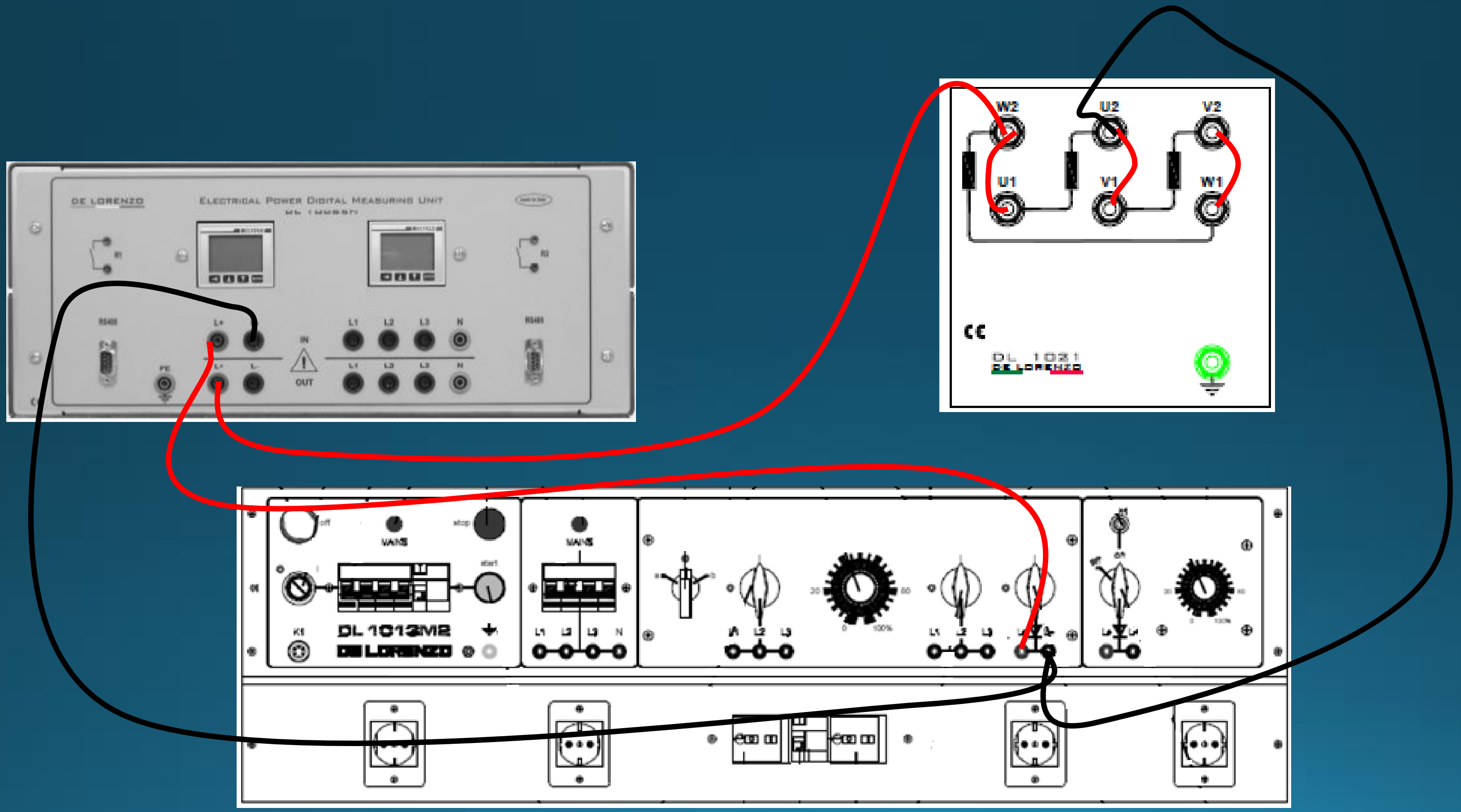
# DC test

- First, we must connect the stator as star or delta.
- The next step is to apply a dc voltage to the stator.
- Measure the dc current and dc voltage.
- Based on the connection, star or delta, apply the suitable equation and calculate the stator resistance.

# Dc test

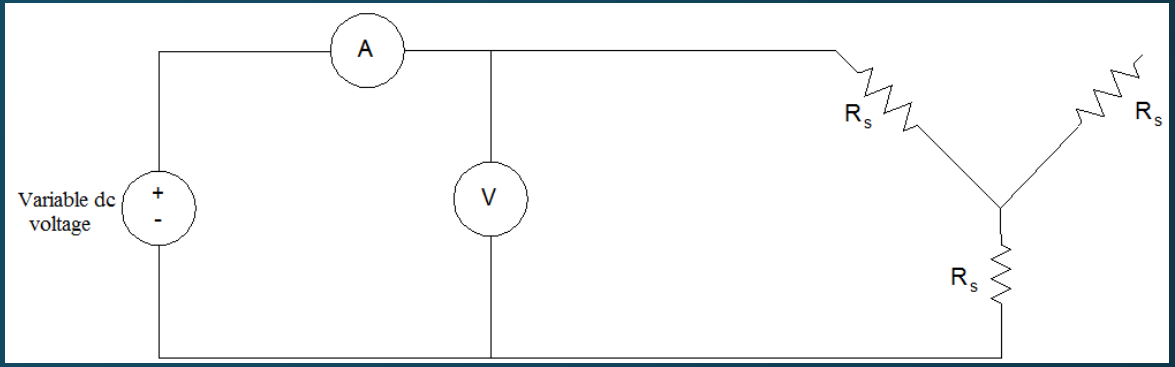
- Delta connection $R_S = \frac{3}{2} \times \frac{V_{DC}}{I_{DC}}$

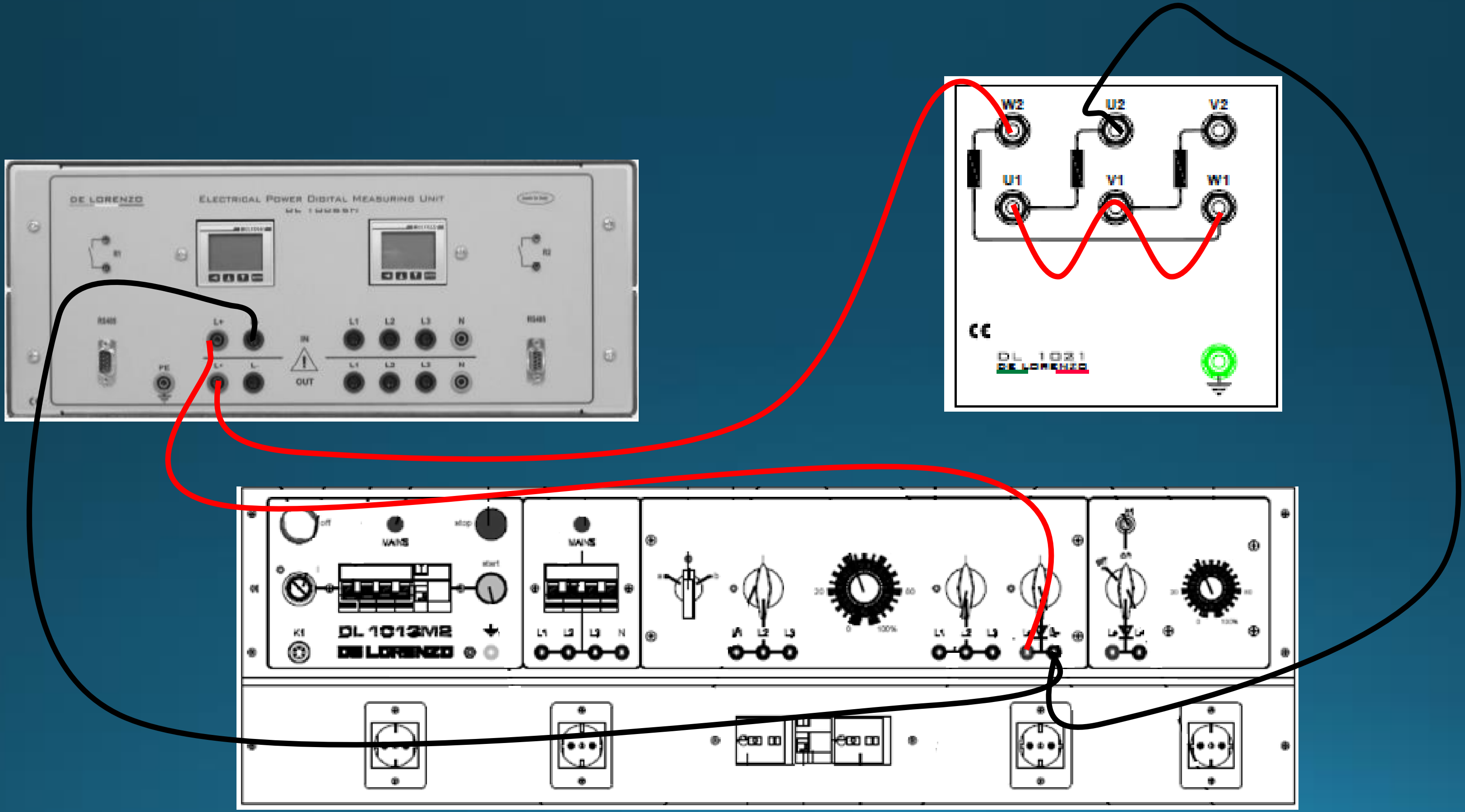


# Dc test

- Star connection $R_S = \frac{1}{2} \times \frac{V_{DC}}{I_{DC}}$



# No load test

- During this test the motor run freely (almost at its synchronous speed which means that the slip is almost zero), the load equals zero so is the rotor current. There are only the losses in the stator circuit (Rs found using the dc test) and rest are mechanical losses. These mechanical losses lumped together with core losses in Rc is considered constant through all times and are called the rotational losses.

1- connect the motor as delta (because the rated voltage in the delta case is less than that in the star case by a factor of √3.

2- increase the voltage until you reach the rated voltage specified by the motor name plate.

3- measure the voltage, current and power. From these values calculate the power factor.

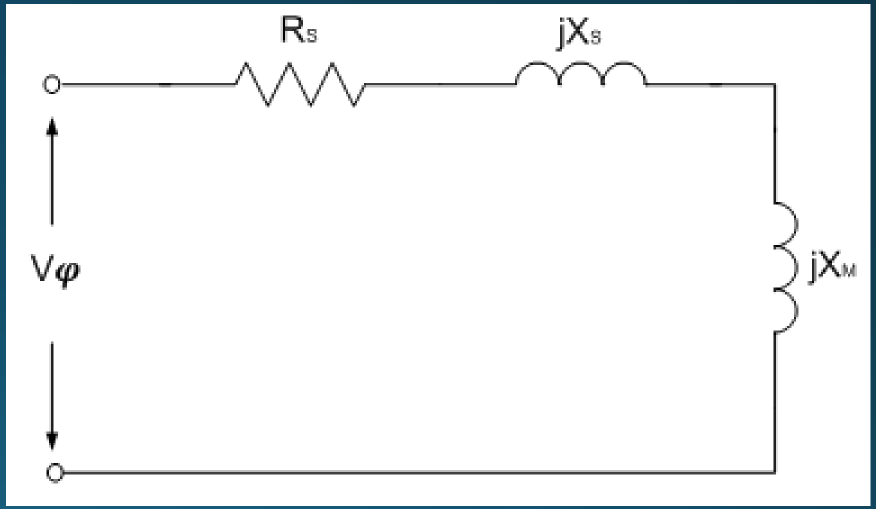
4- calculate the motor rotational losses. Where pin is the input power.

$$P_{rot.} = P_{in,NL} - P_{CU,S} = P_{in,NL} - 3I_{\phi}^{2}R_{S}$$

# No load test

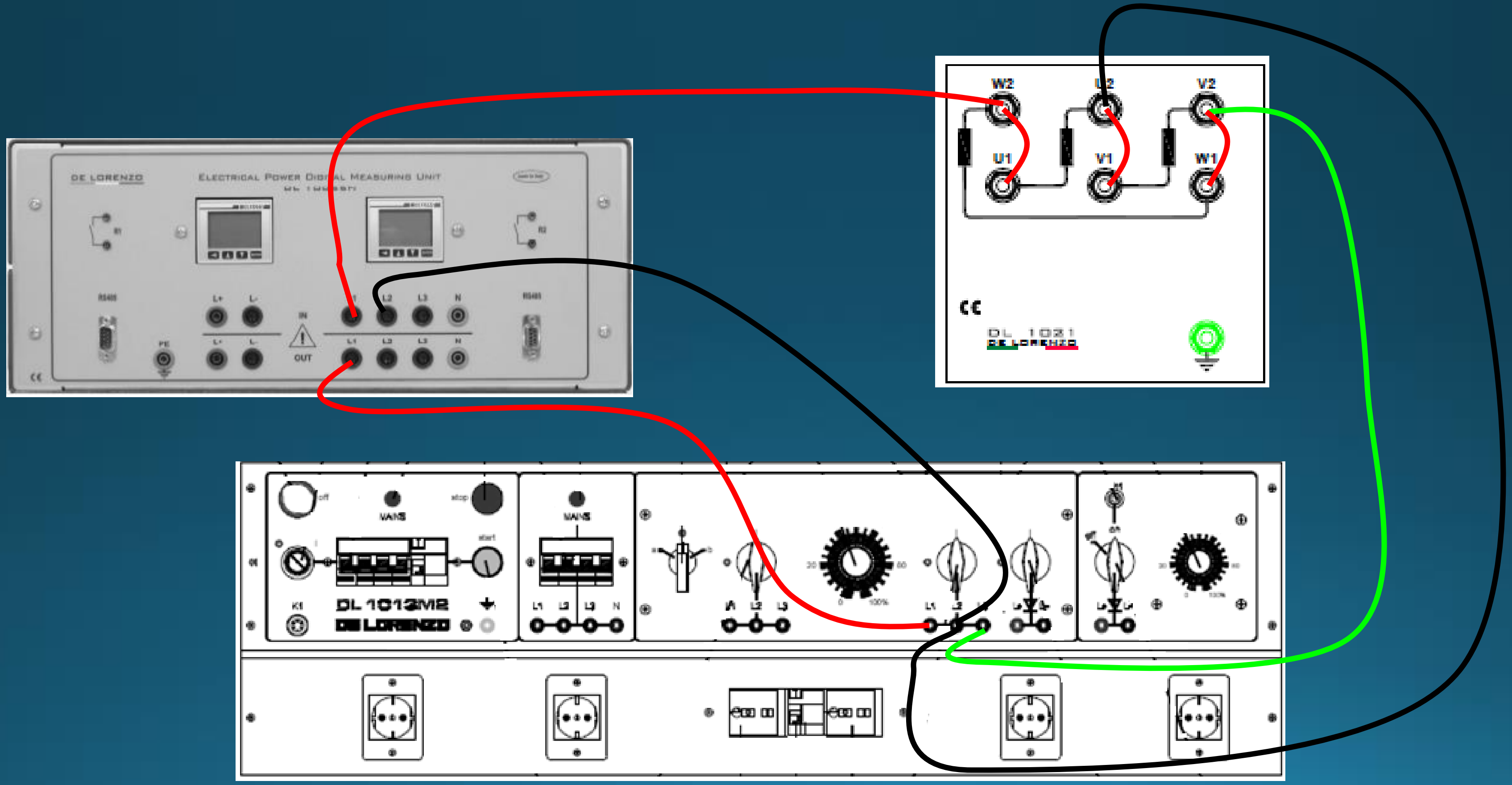
- The equivalent circuit of this test is shown below:

$$X_M = \frac{V_\phi}{I_\phi}\sin\theta - X_S$$



# No load test

- The mechanical load equals zero.



# Locked rotor test

- During this test the motor shaft is held still (locked) and cannot move (which means that the slip is 1), the rated current is drawn at these conditions at a very low voltage values.

1- connect the motor as star (because the rated current in the star case is less than that in the delta case by a factor of $\sqrt{3}$.

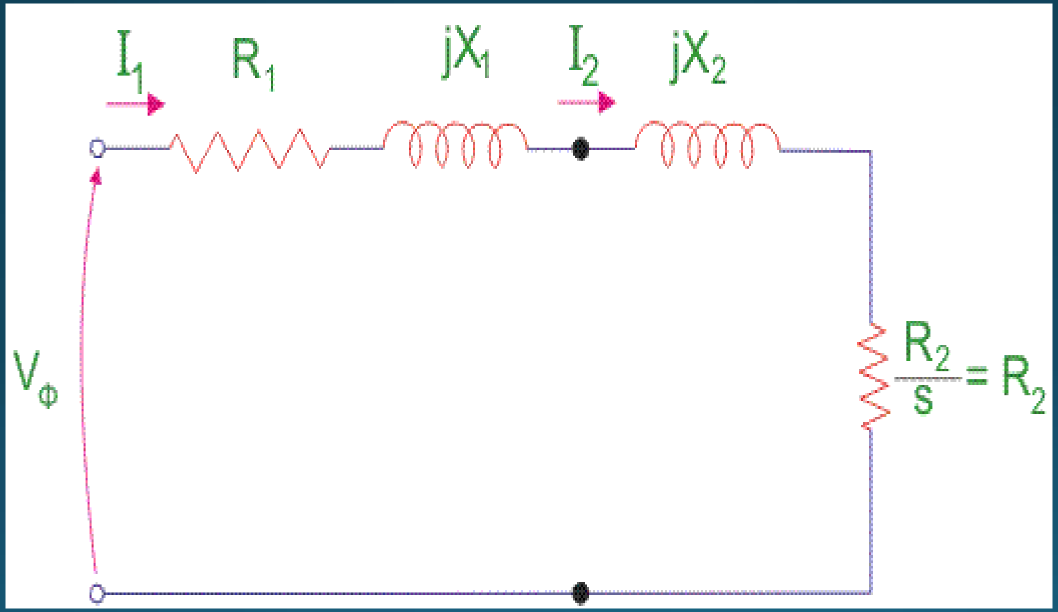
2- increase the voltage slowly until you reach the rated current specified by the motor name plate.

3- measure the voltage, current and power. From these values calculate the power factor.

4- calculate the impedance.

# Locked rotor test

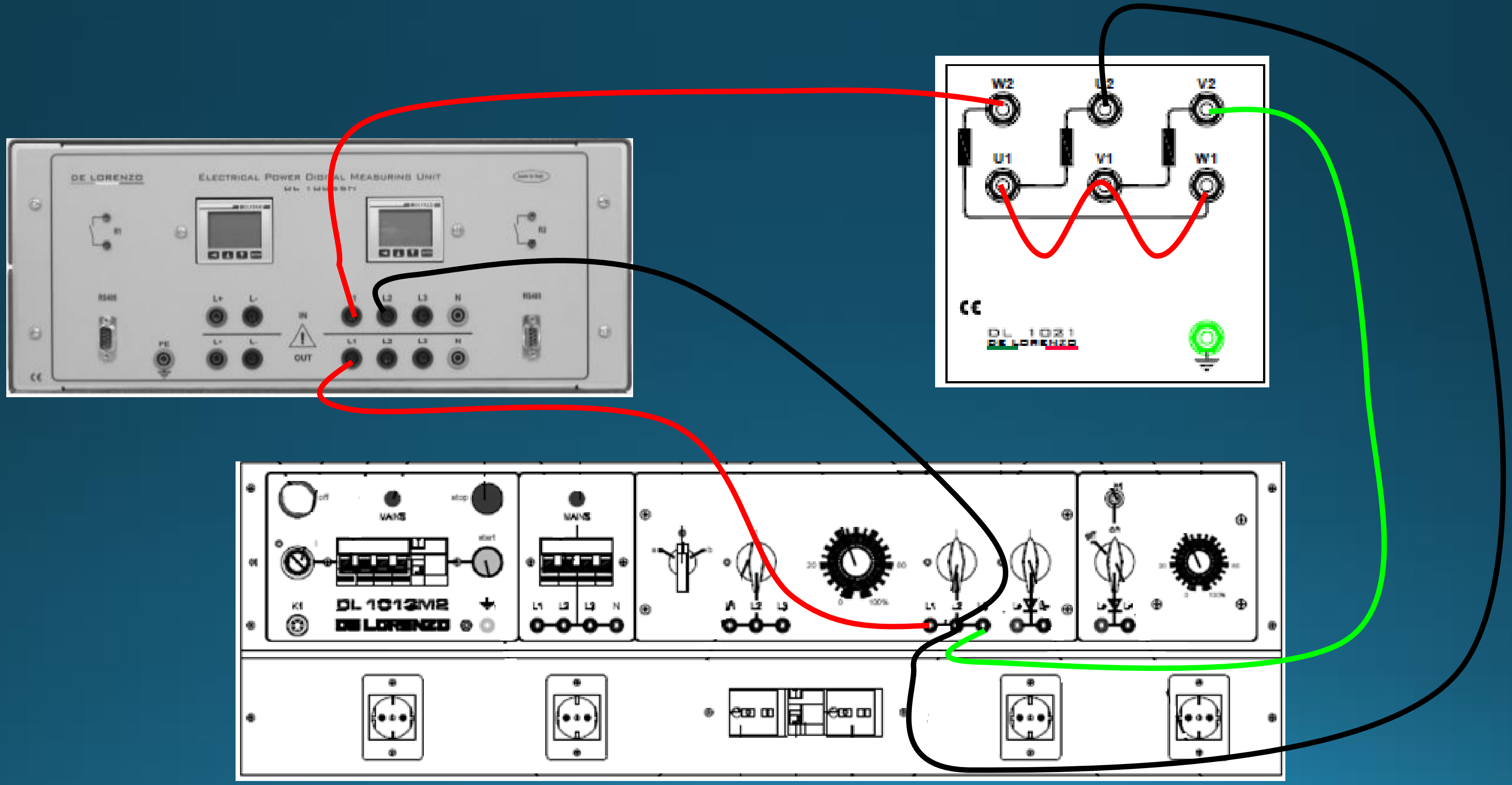
- The equivalent circuit of this test is shown below:




- Using this test the series impedance can be found.

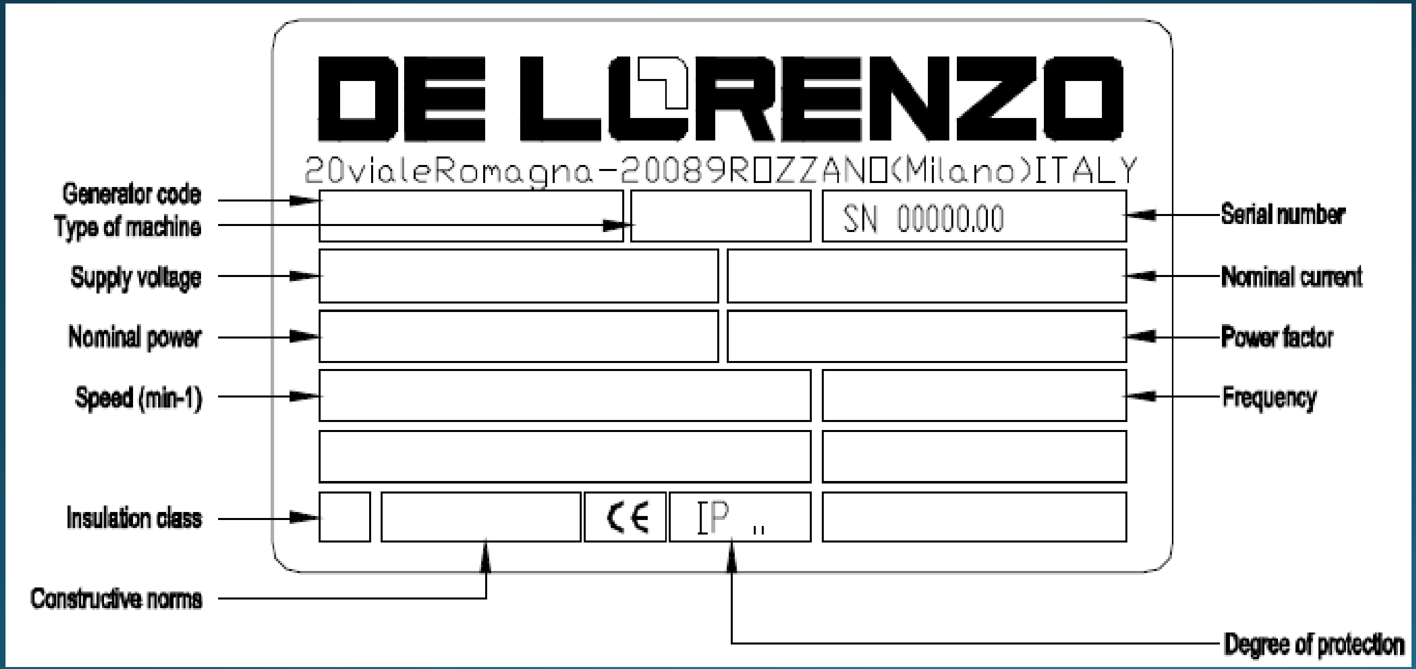
# Locked rotor test

- The load locks the motor shaft.



# 3ϕIM name plate

- There will be two supply voltage and nominal current values for both the star and delta cases. The nominal power is the mechanical output power. The speed is the base speed.




Figure

# Torque speed characteristics of 3ϕIM

- The torque speed characteristics is shown in the figure. And is given by the following relation ship:

$$\tau = KsE_2^2 \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}, K = \frac{3}{2\pi n_s}$$

- Note that the torque is proportional to the square of voltage.
- The curve has two regions: the stable region ( region of operation where torque and speed are inversely proportional.
- The unstable region, where the torque and speed are directly proportional which makes no sense. This region is only transient until the motor gains speed and move to the proper point on the stable region.

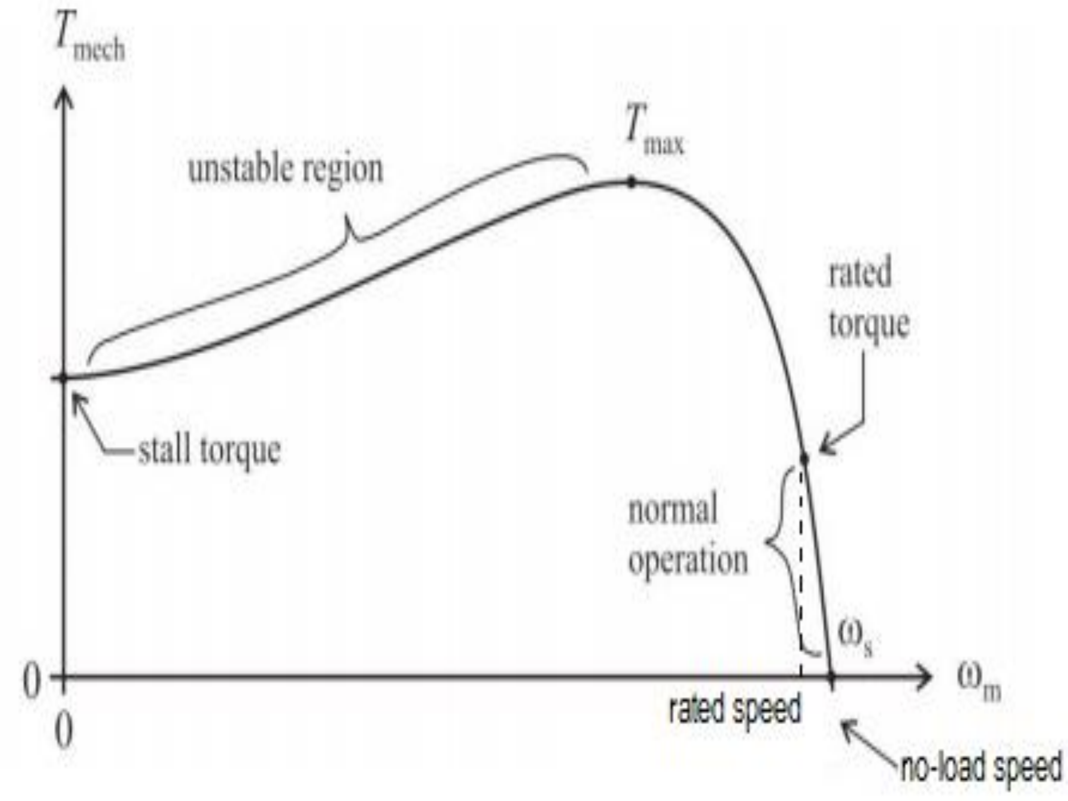



Figure 5

# Starting 3ϕIM

- We classify starting methods for squirrel cage induction motor into two types on the basis of voltage. The two types are

- Full voltage starting method.

- Reduced voltage methods.

# Full voltage method

- **Direct on Line Starting Method**
- This method is also known as the **DOL method**. In this method we directly switch the stator of the three phase squirrel cage induction motor on to the supply mains. Which means we plug the motor directly to the power supply and turn the power at its full value .

# Reduced voltage methods.

- Before we start discussing these methods, a concept must be understood. From the torque speed characteristics we noted that the torque is proportional to the square of the voltage applied to the stator. Another fact is that the torque is directly proportional to the drawn current.

$$\tau \propto I$$
$$\tau \propto V^2$$

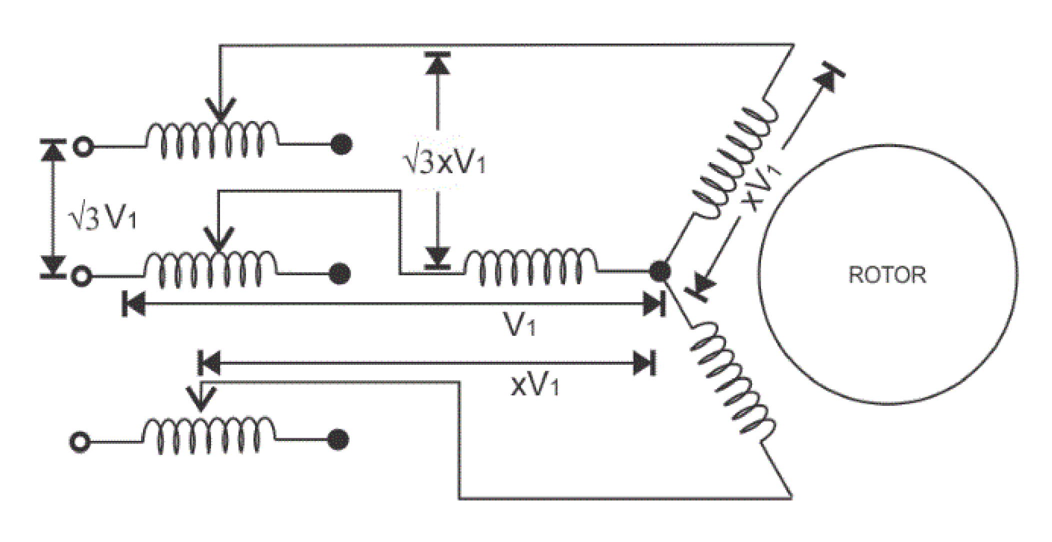
- This implies that reducing the voltage by a factor of 0.5 means reducing the torque by a factor of 0.25 and the current by the same factor 0.25

# Reduced voltage methods.

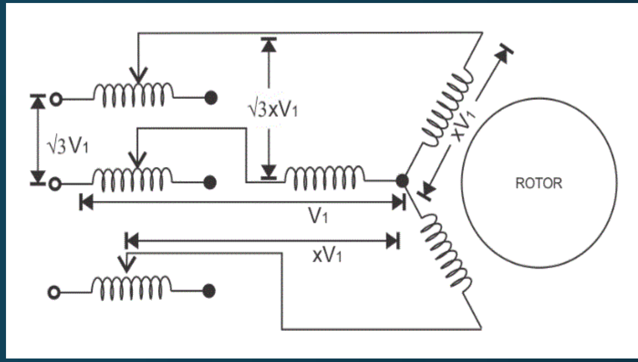
- **Stator Resistor Starting Method**
- **Auto Transformer Starting Method**
- **Star-Delta Starting Method**
- **Addition of External Resistances in Rotor Circuit** (only for the wound rotor motor)

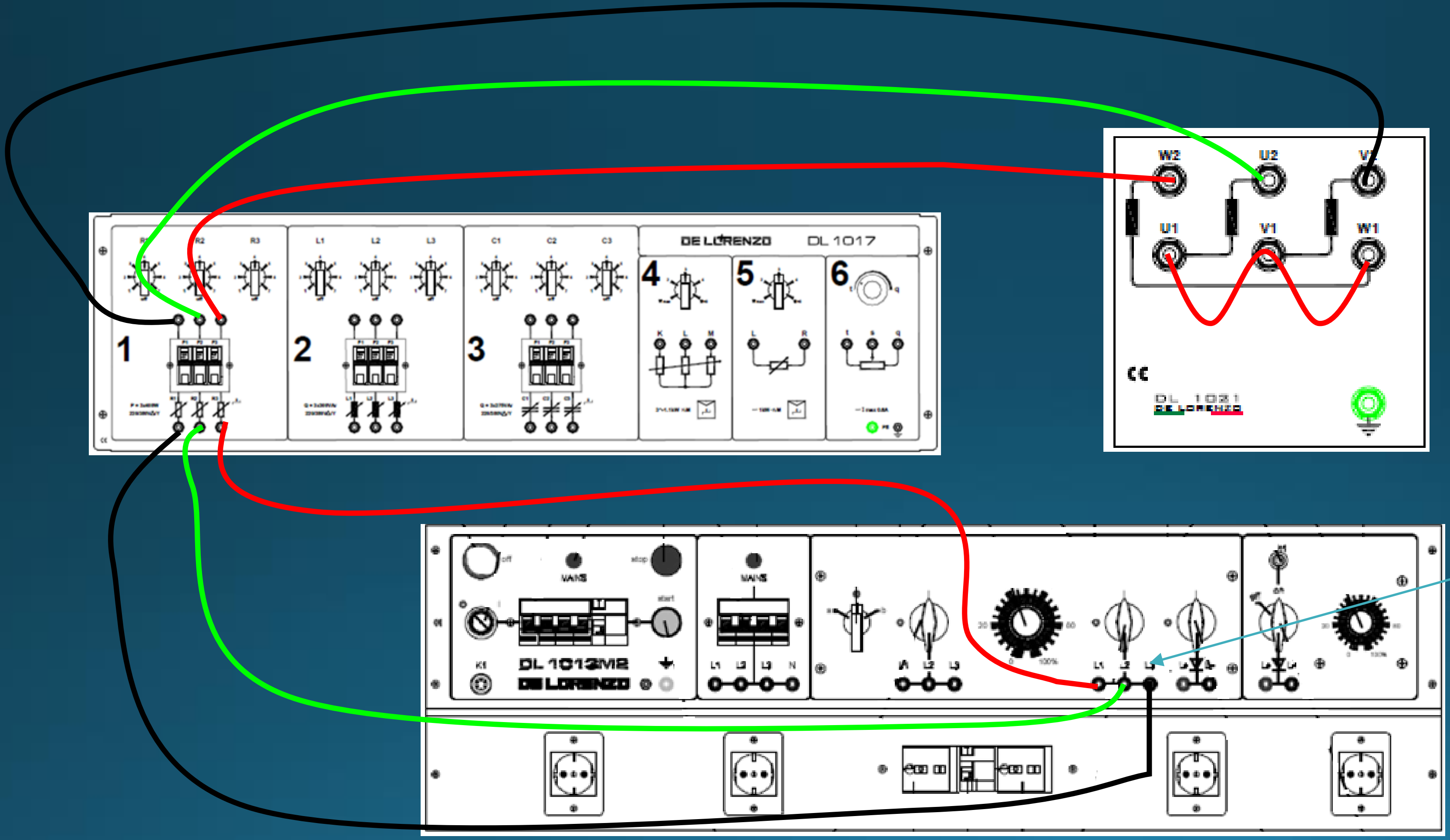
# Stator Resistor Starting Method

- Same as in dc motors, a resistor is added in series with each phase of the stator circuit of the motor. A voltage drop will occur at this resistor and reduce the voltage that reaches the stator circuit. Of course the supply is set to the rated voltage of the running conditions (in this figure the stator is connected as star and the rated voltage for star condition is 380V from the name plate).



# Stator Resistor Starting Method

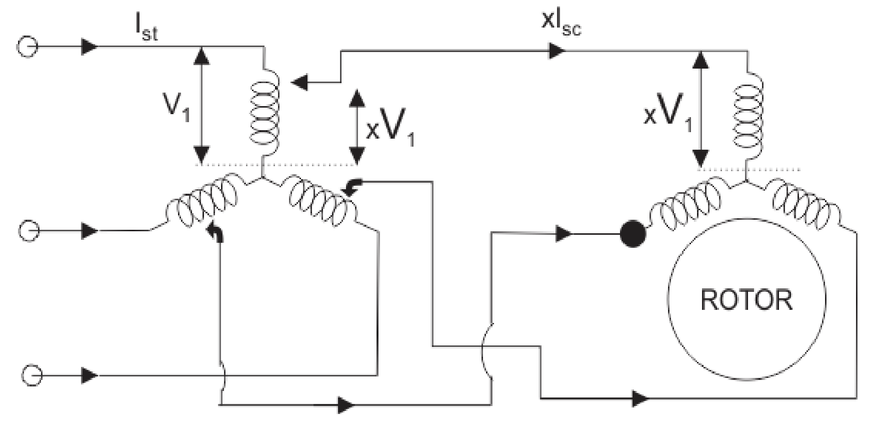



The supply is set to 380V

# Auto Transformer Starting Method

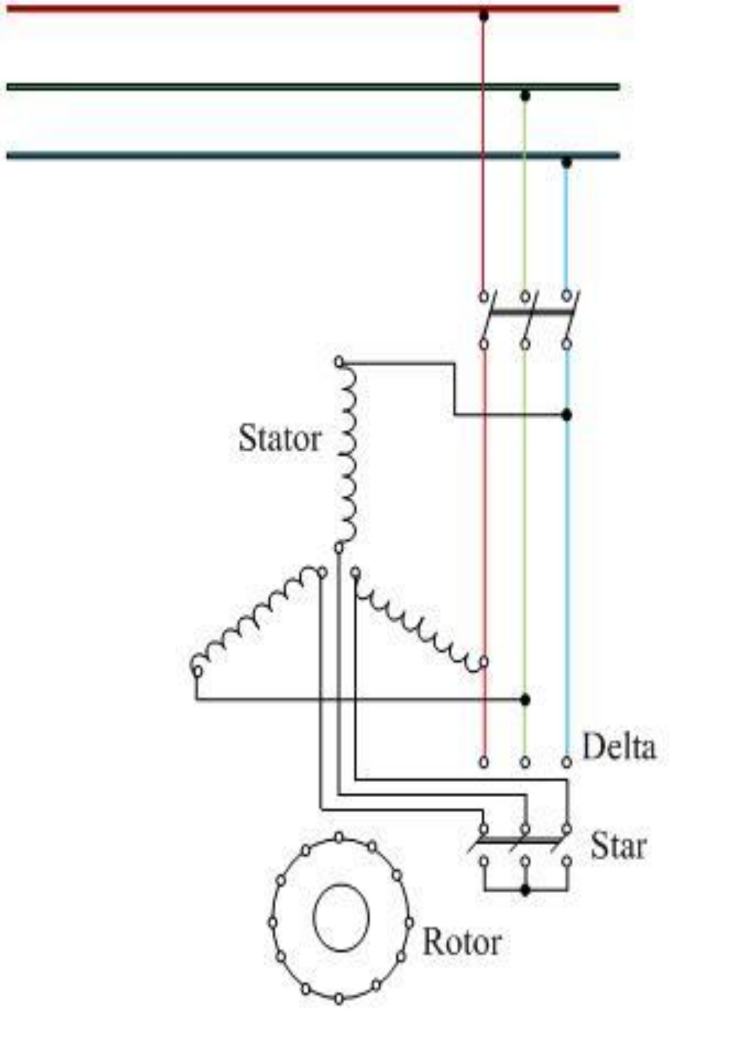
- In this method a step down autotransformer is used to reduce the voltage that reaches the stator. Of course the supply is set to the rated voltage of the running conditions (in this figure the stator is connected as star and the rated voltage for star condition is 380V from the name plate).




Pertaining to Auto-Transfer Starting

# Star-Delta Starting Method

- A special switch is used or a relay-contactor circuit is built. The method is used only when the motor must be connected as delta in the running conditions. From the beginning, the supply is set to rated voltage of the delta case which is 220 from the name plate of the motor in the lab and this voltage is not changed.
- At the start of the running, the switch is set to star which means the motor can sustain 380V but the supply if already set to 220V which is 1/√3 of the 380V. This means that the voltage is reduced by 1/√3 and the starting torque and current are reduced by 1/3.
- When the motor gains speed, the switch is changed to delta position. Now the 220V of the source are the same as the rated 220V of the stator.

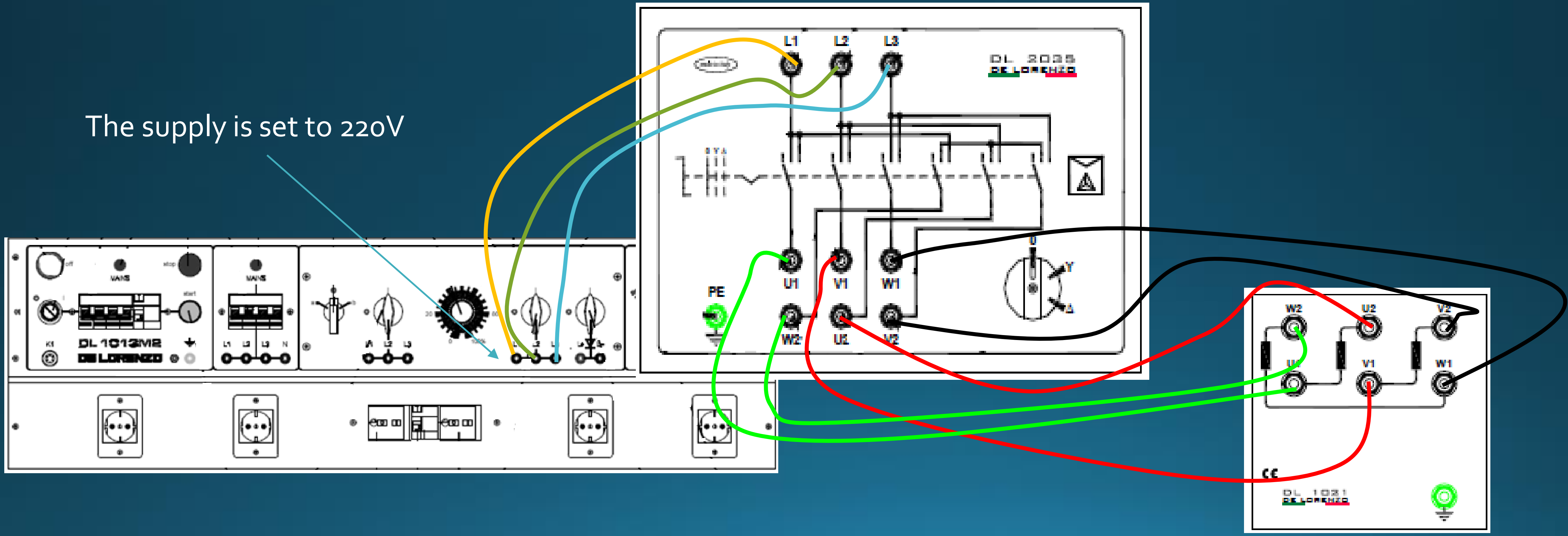


Star-Delta Starting

# Star-Delta Starting Method

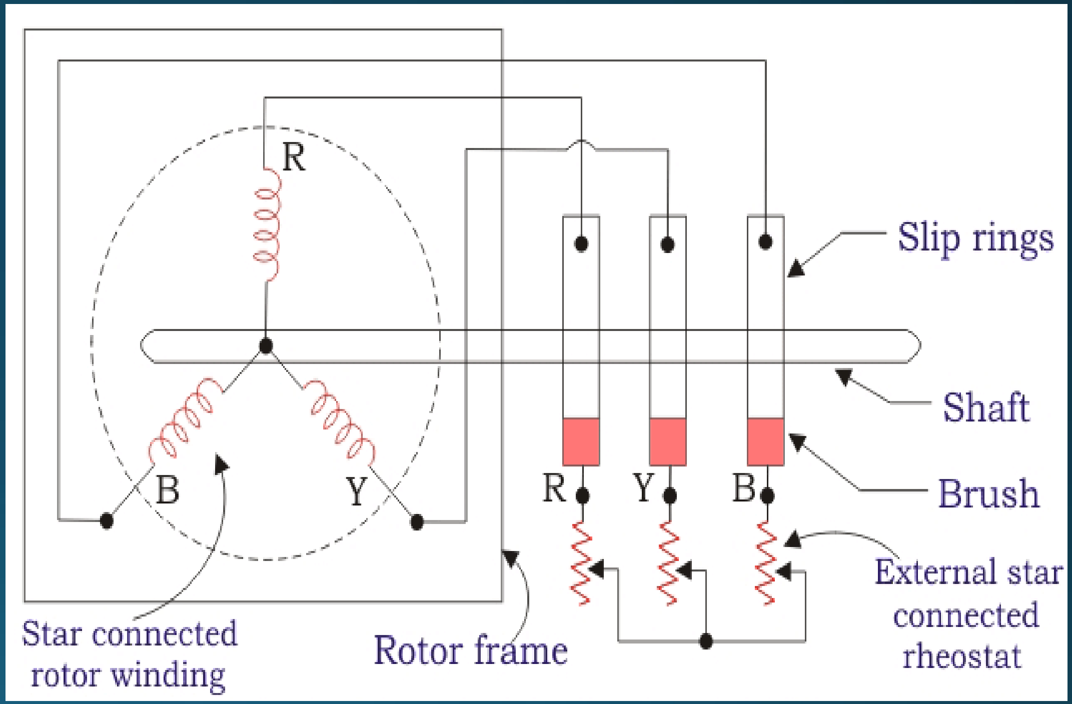
Simply follow the notation on the switch and motor. w1 of the switch with w1 of the motor, w2 of the switch with w2 of the motor and so on. Same holds for the lines and the switch L1 with L1 and so on.

The supply is set to 220V

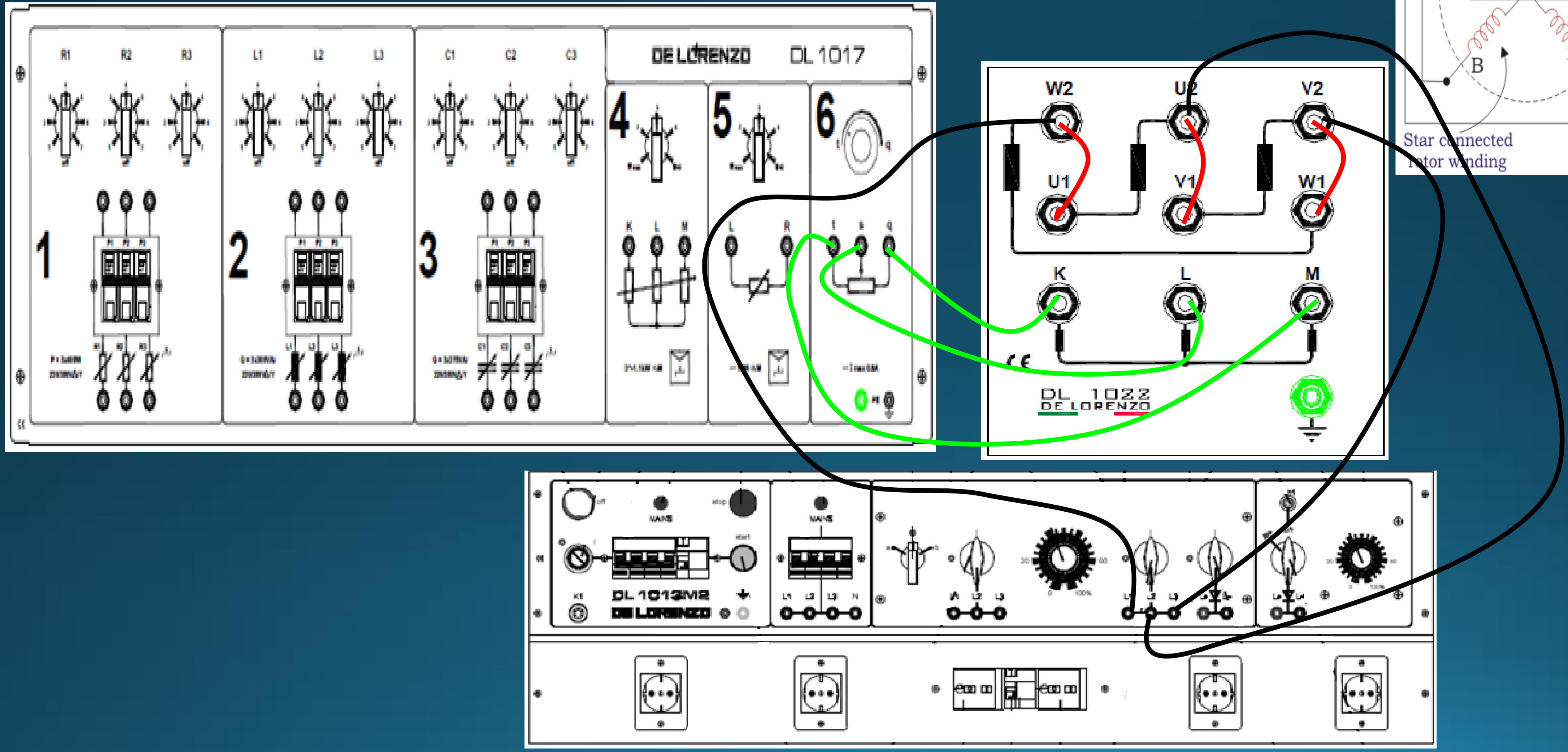


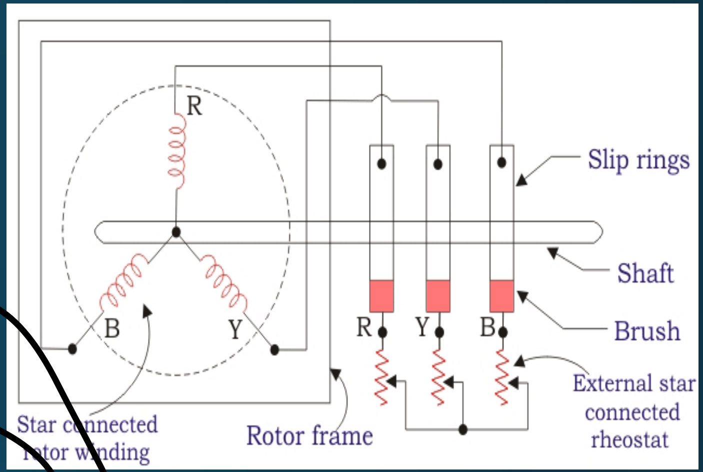
# Addition of External Resistances in Rotor Circuit

- All of the previous methods can be used with both slip ring and squirrel cage types. This method can only be is used with the wound type because the rotor circuit is not accessible in the squirrel cage type.
- But it is not as simple as adding a resistor to the stator circuit. Because as we mentioned previously, the rotor circuit is already connected as star and must be shorted from the outside. This requires a special resistor which is resistor “6” in the load box. The rotor is not shorted directly. It is shorted via this resistor and when the motor gains speed it is taken out of the circuit.
- The stator is connected as star or delta.



# Rotor Resistor Starting Method



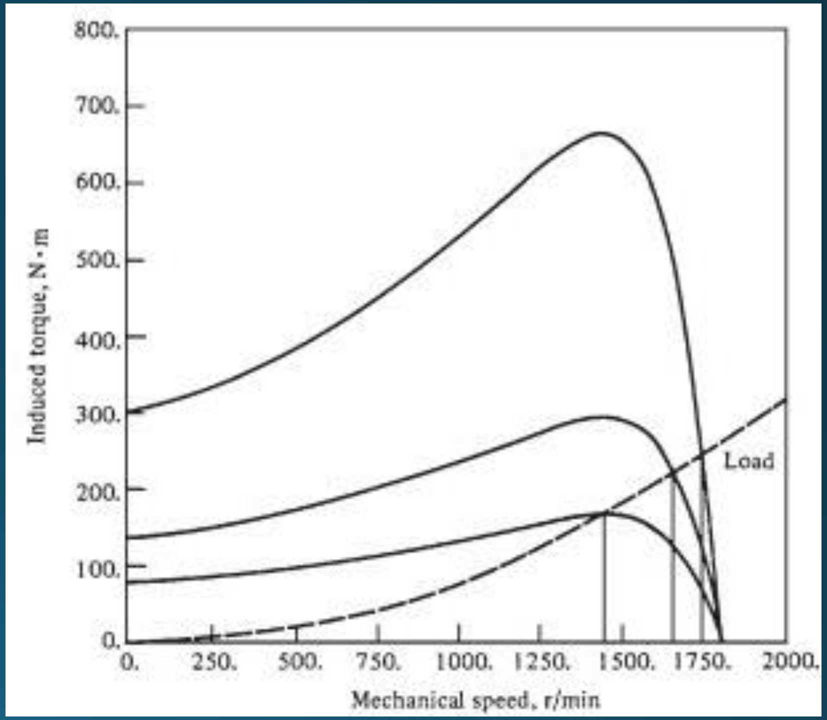



# Speed control of 3ϕIM

- By changing the applied voltage
- By changing the applied frequency
- Changing the number of stator poles
- Adding external resistance on rotor side

# Changing the applied voltage

- The voltage and speed are directly proportional. Decreasing the applied voltage will decrease the speed but this will come at the cost of less starting and pullout torques. Note that the no-load (synchronous speed is not affected)
- This can be done using the voltage supply.
- It controls speed below the base speed. Because the maximum voltage that can be applied is the rated voltage.



# Changing the applied frequency

- Lets start by studying the synchronous speed equation:

$$N_s = \frac{120\,f}{P} \quad \text{(RPM)}$$

- It is clear that the speed is directly proportional to frequency. But there is an important not here.

1- the voltage is fixed at its rated value while we study frequency effect

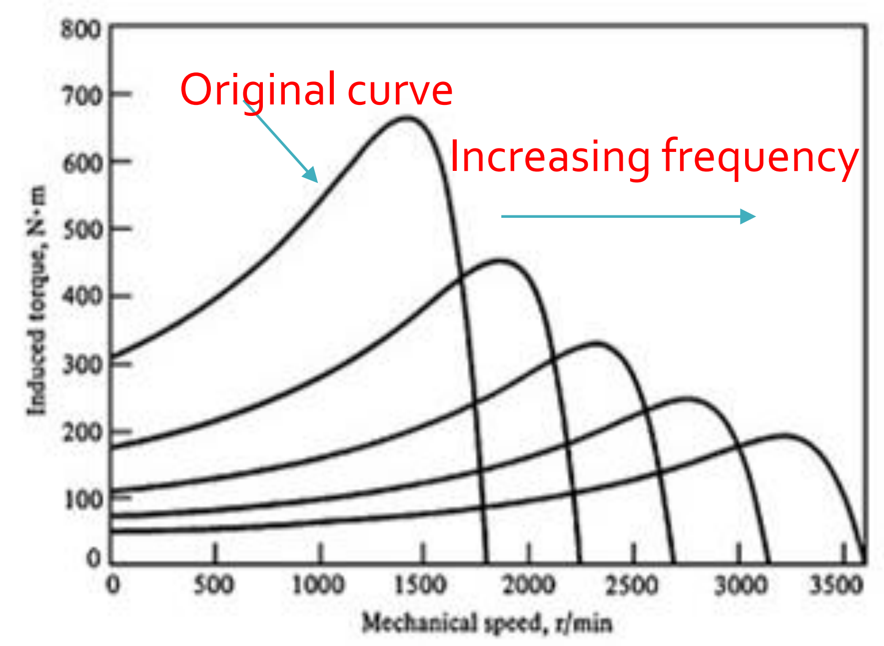
2- The frequency can be increased above the base frequency but cant be decreased below it unless voltage is decreased by the same factor. Why?

- It is known that,

$$e_{in} = \frac{d\emptyset}{dt} or \frac{\emptyset}{t} = \emptyset * f$$

- Then,

$$\emptyset = \frac{e_{in}}{f}$$




- If we keep the voltage at its rated value but decrease the frequency below its rated value, the flux must increase above its rated value and this is impossible because the core saturates.
- That's why we can only increase the frequency and have speeds above the base speed
- Changing the frequency requires an inverter.

# Changing the number of stator poles

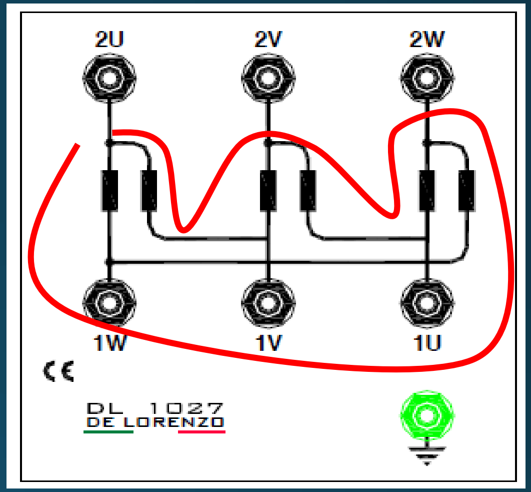
Again back to this equation

$$N_s = \frac{120\,f}{P} \quad \text{(RPM)}$$

- The synchronous speed depends on the number of poles. But changing the number of poles is not an easy matter. To do this, there are specially designed squirrel cage motors that come with two built in speeds: the high speed and the low speed.
- These motors are called double speed motors or dahlender motors. The double speed motor we have in the lab is a delta/double star motor.

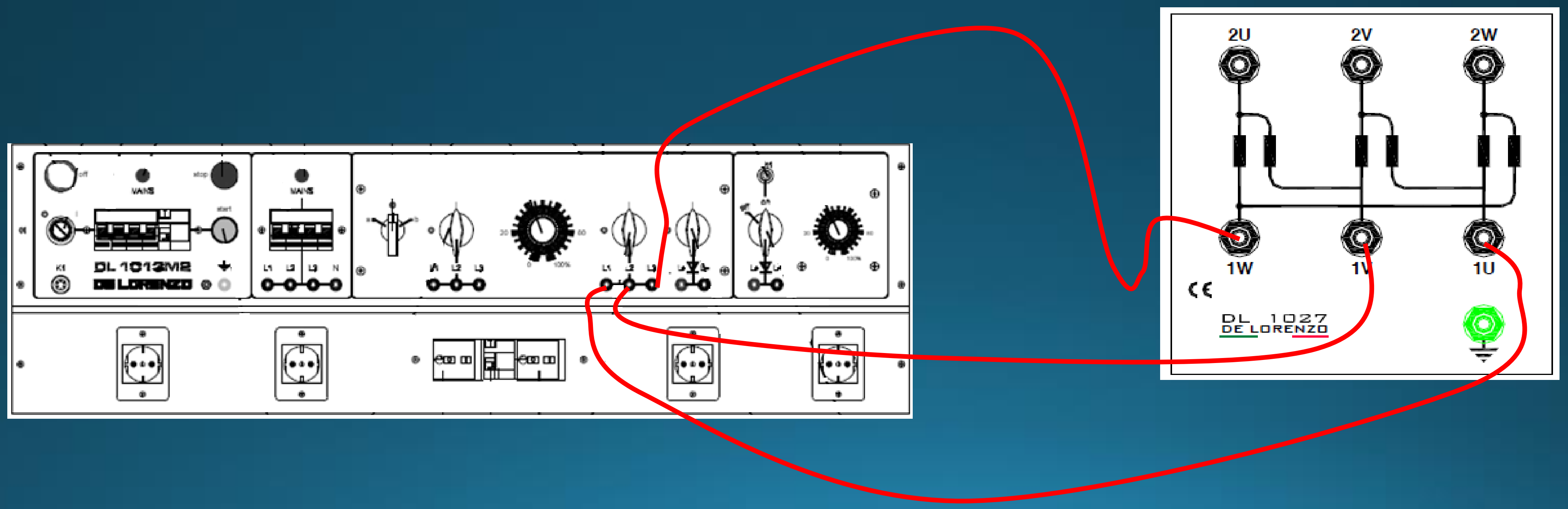
# Dahlender delta/double star Δ/YY

- As we mentioned it is a specially designed squirrel cage motor. By default it is internally connected as delta Δ and has the lower speed (half the speed). If the proper connection is made it become double star YY and has the higher speed. The motor in the lab has 1400rpm speed when Δ connected and has 2800rpm when YY connected.
- If you follow the red loop drawn you will see that the phases are internally connected as delta. From the data sheet you must short all the phases with the notation "1" to make the connection double star YY.



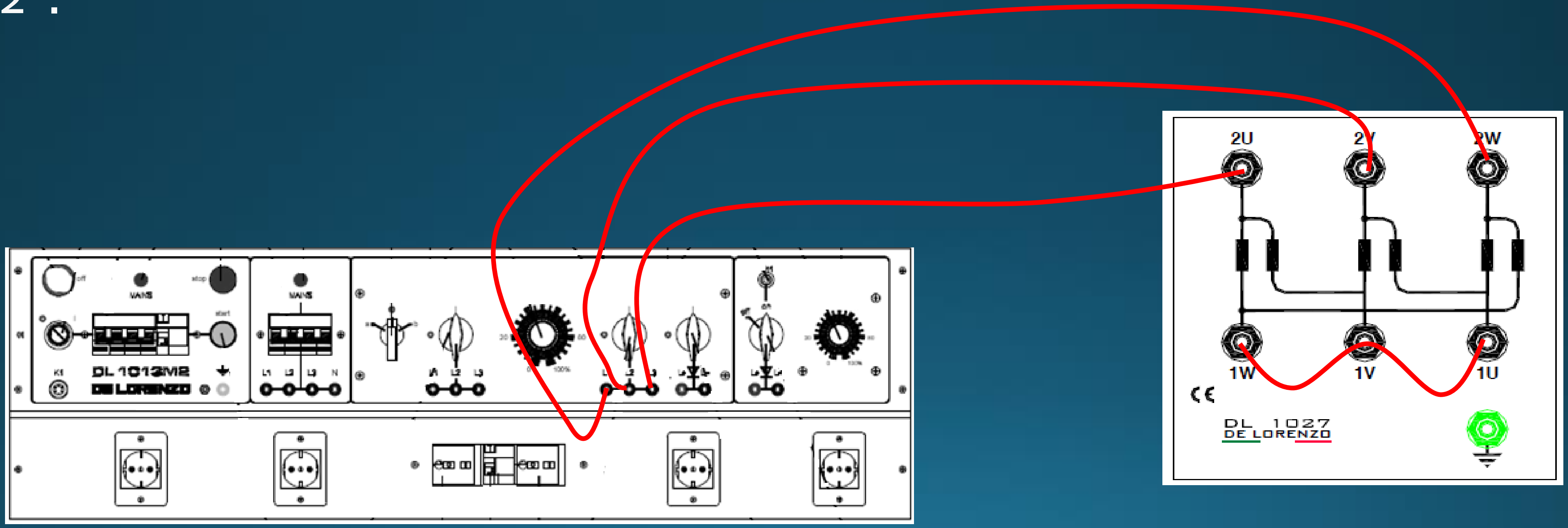
# Dahlender delta Δ connection

- As we explained, the motor phases is already internally connected as delta. So make nothing on the terminals just connect the lines to the terminals with notation “1”..



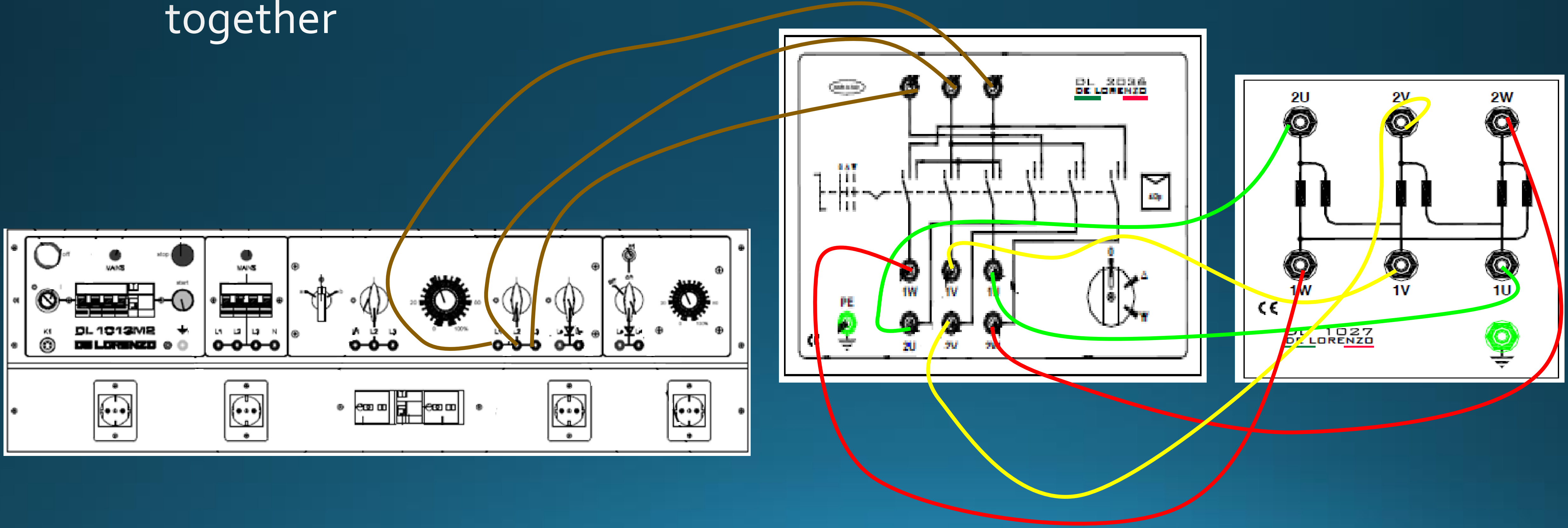
# Dahlender double star YY connection

- To connect the motor as double star, just short the terminals with notation “1” and connect the lines to the terminals with notation “2”.



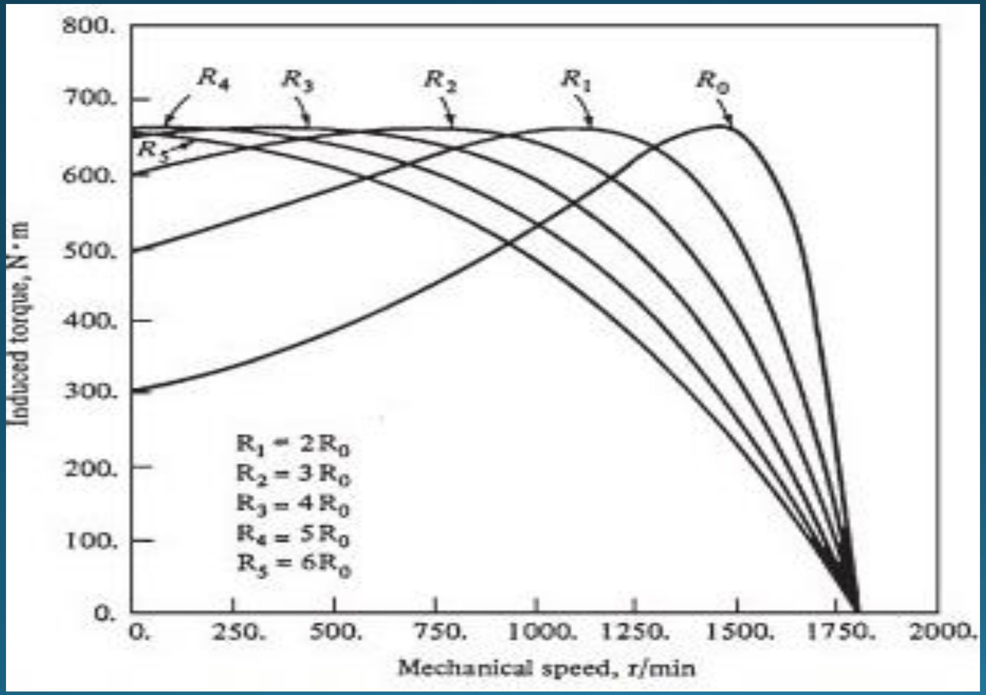
# Switching between delta and double star at running conditions

- If it is required to change the motor speed while it is running, a special switch is used. Just connect the matching notations together

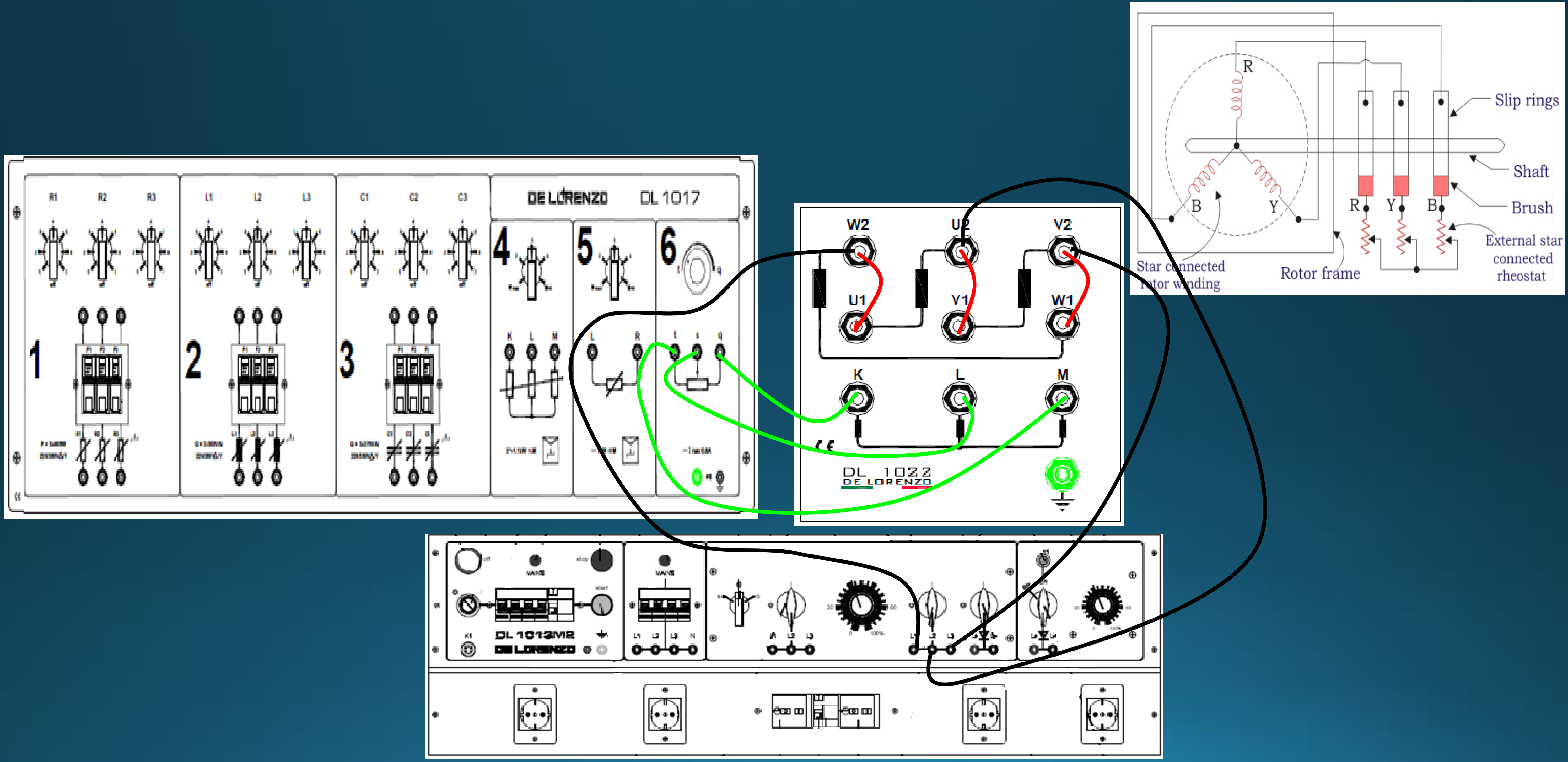


# Adding external resistance on rotor side

This speed control method is only applicable to the wound rotor induction motor. The same special purpose resistance "6" in the load box will be used to short the rotor circuit.

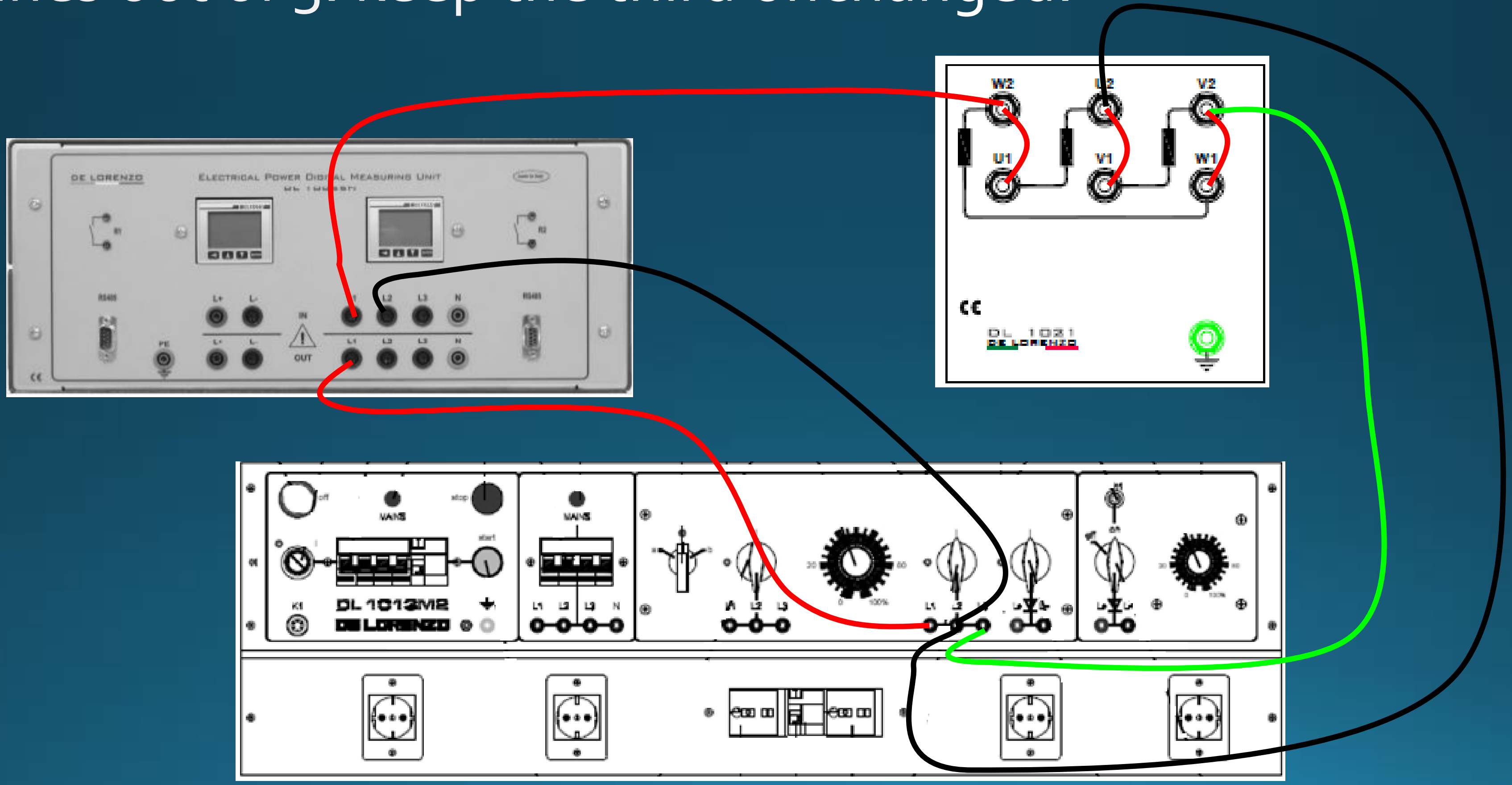


# Adding external resistance on rotor side



# Reversal of direction of rotation of 3ϕIM

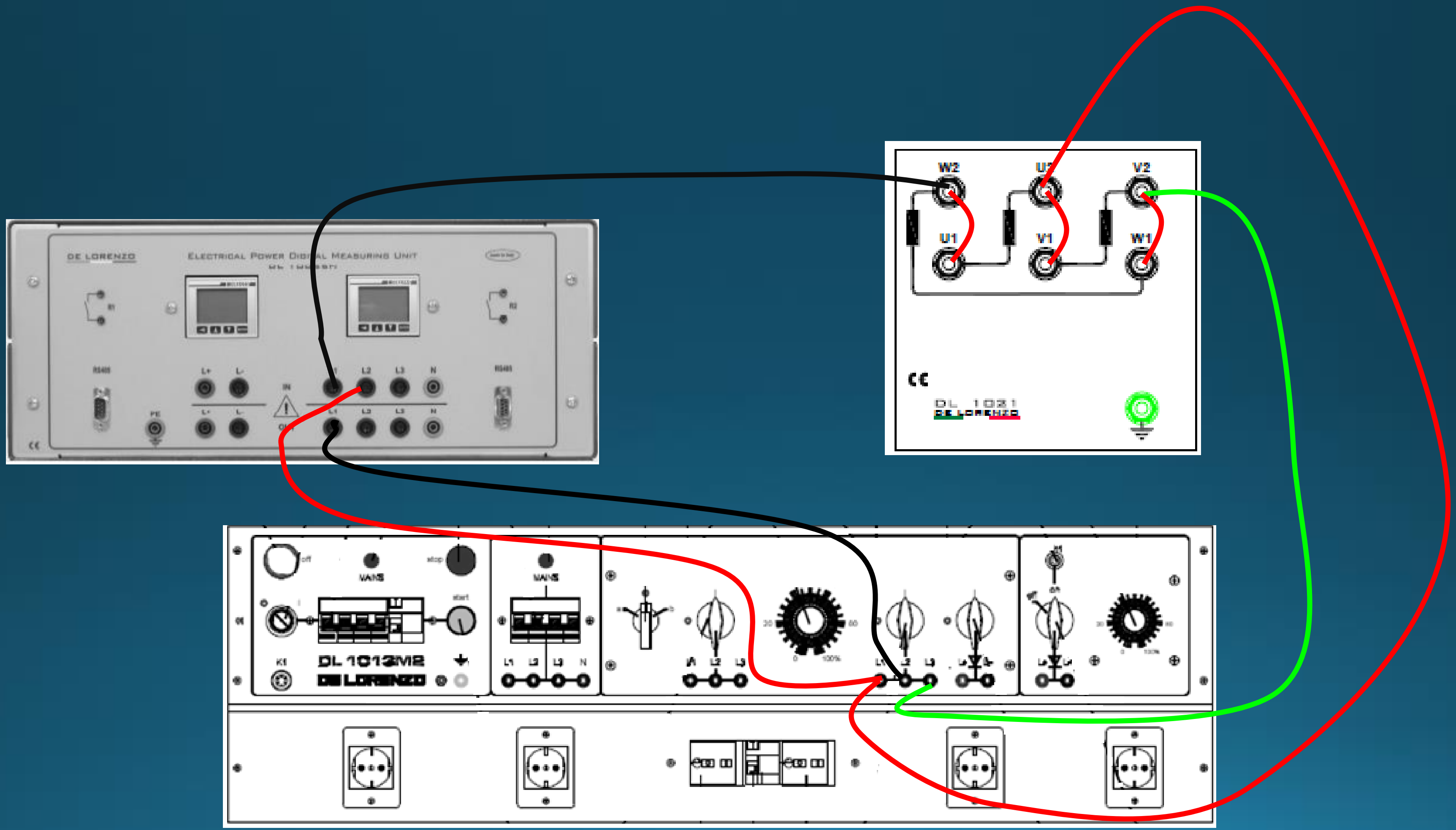
- You can reverse the direction of rotation of a 3ϕIM by reversing any two lines out of 3. keep the third unchanged.




original

# Reversal of direction of rotation of 3ϕIM

reversed



# Experimental setup



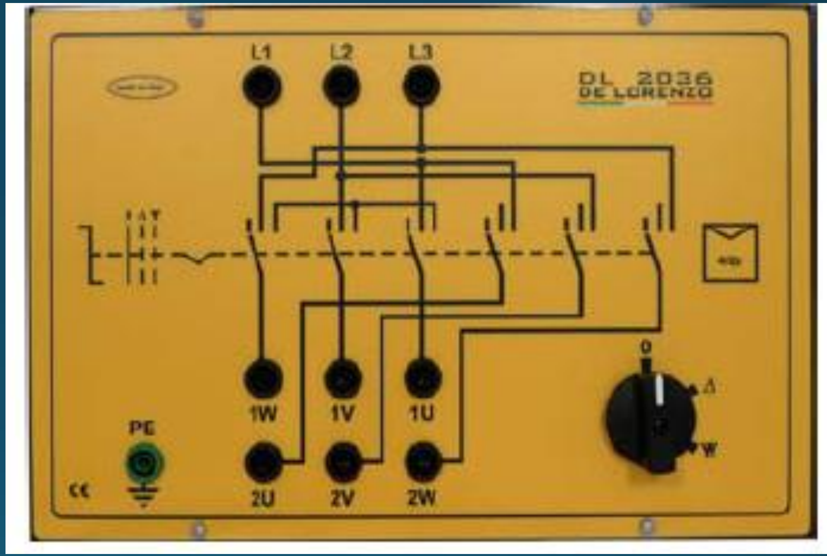

Squirrel cage

wound rotor

double speed

# Experimental setup


Star delta switch




delta double star switch

# Experimental setup



This resistor can be used with the stator circuit

this resistor is the same as “6” and can be used to short the rotor of the wound motor

# Power supply

- The ac induction motor requires a 3 phase ac power supply to operate it. As you know well by now, we have two variable ac power supplies in the lab;

- The one circled by blue and has Vmax=430V, Imax=5A.
- The one circled by yellow and has Vmax=240V, Imax=8A.

- The motor current = 4.2A in case of delta and 2.3 in case of star (from the name plate)
- The motor voltage =220 in case of delta and 380 in case of star.
- Clearly, both supplies (yellow and blue) can provide the current needed for either connection. On the other hand, the blue source can provide the voltage required for the star case while the yellow source cant.
- Both sources can operate a delta connected motor.

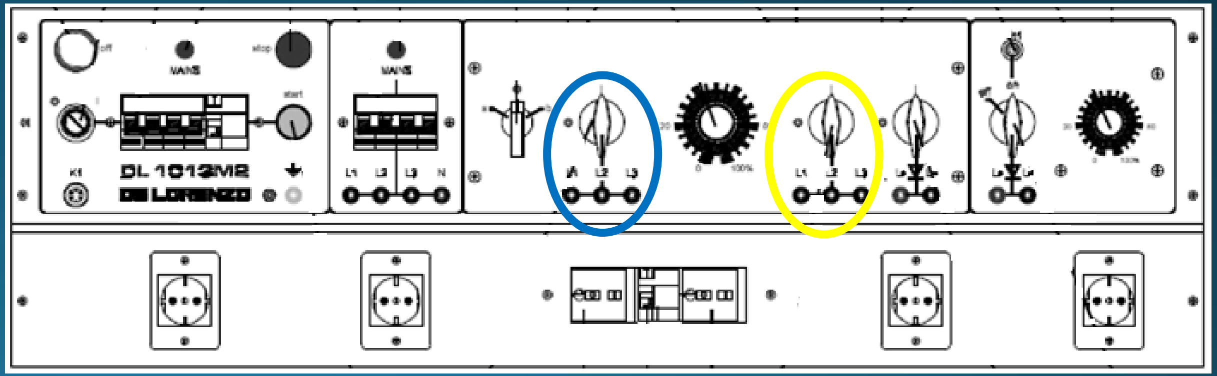
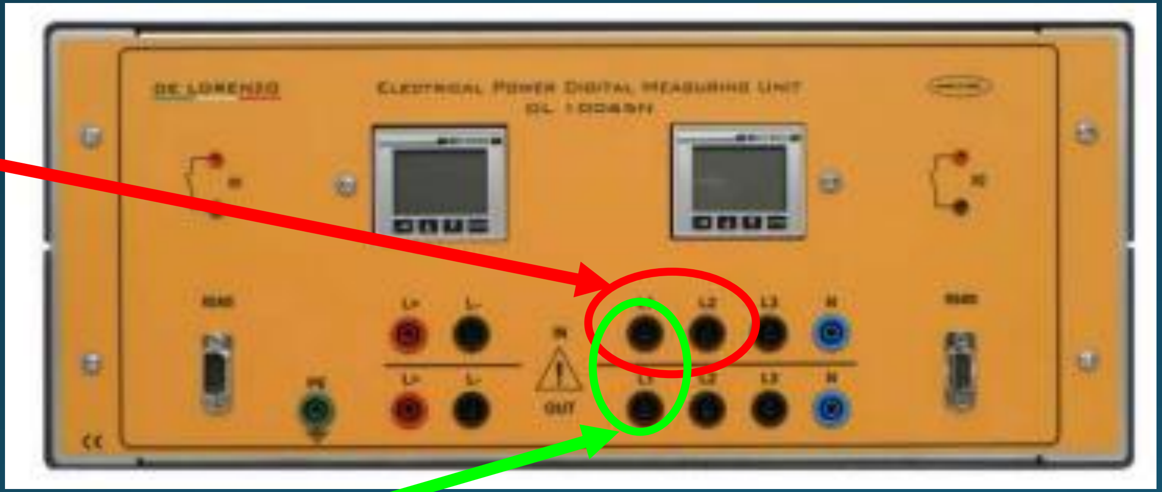



Figure 12

# Digital multimeter

ac voltmeter
(horizontally)

Don’t forget about
the common node




ac ammeter
(vertically)

Using this unit you can measure one voltage and one current as long as there is a common point

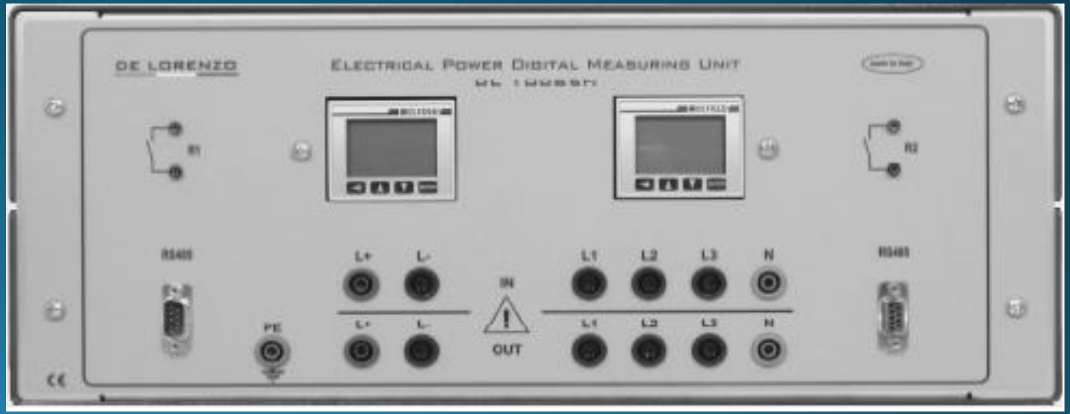



Figure 13

Good luck everyone
Stay home .. Stay safe

Prepared by:
Eng.Shatha Al-Qadomi