# ELEC-E8407

# Electromechanics

# Laboratory Report 02:

# Induction machine

Muhammad Dayyan Hussain Khan (101423382)

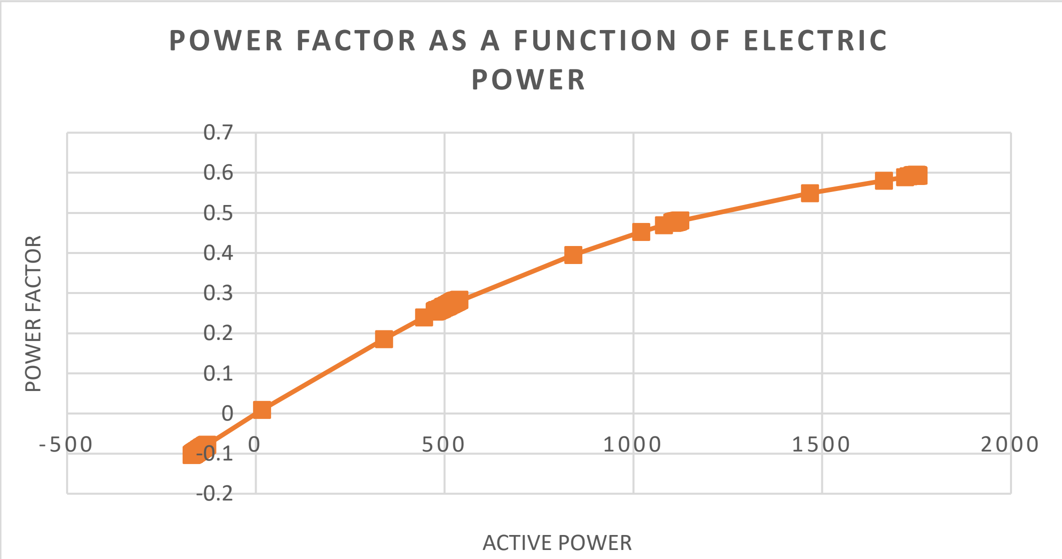
Antti Laitinen (708218)

Tuomas Luotamo (792334)

Jaakko Halonen (792062)

# FINAL REPORT

1. **Draw the efficiency and the power factor as functions of the electric power (I = I0...1,2 IN) of the induction generator connected to an infinite bus. Comment!**



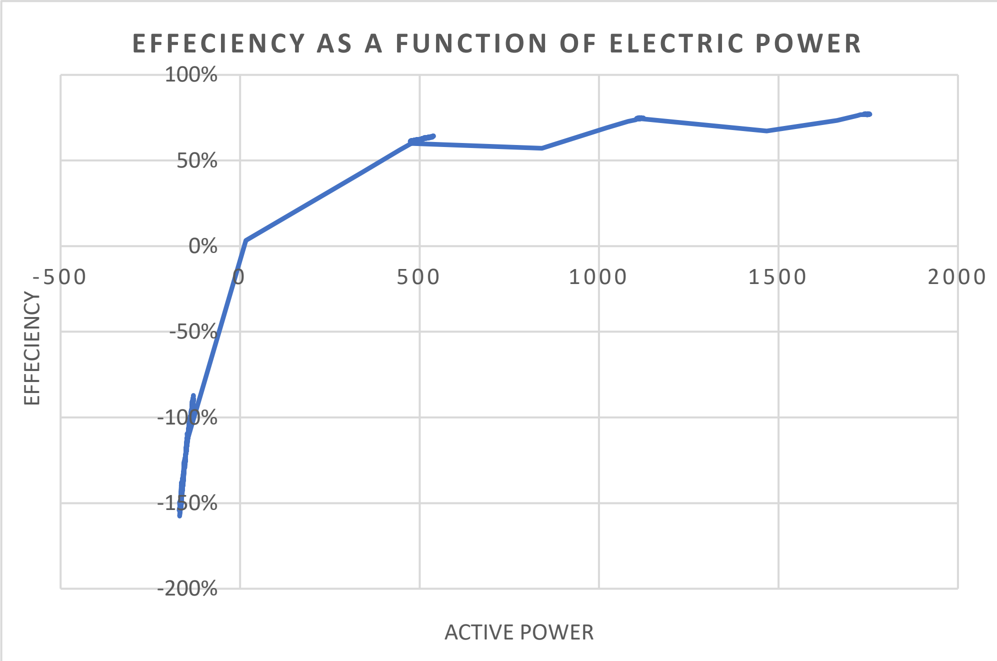

The power factor (PF) of an induction generator is a measure of how effectively it converts electrical power into useful work. It is the cosine of the angle between the voltage and current waveforms. Power factor is given by the formula:

Power Factor (PF) = cos ø

Where ø is the angle between the voltage and current waveforms.

The power factor can vary with the electric active power output. At full load, it is desirable to have a power factor close to 1 (unity power factor). As the load decreases or increases, the power factor may deviate from unity. Leading power factor (capacitive) or lagging power factor (inductive) can occur based on the reactive power requirements of the load and generator. Power factor correction equipment may be used to maintain a desired power factor within an acceptable range.

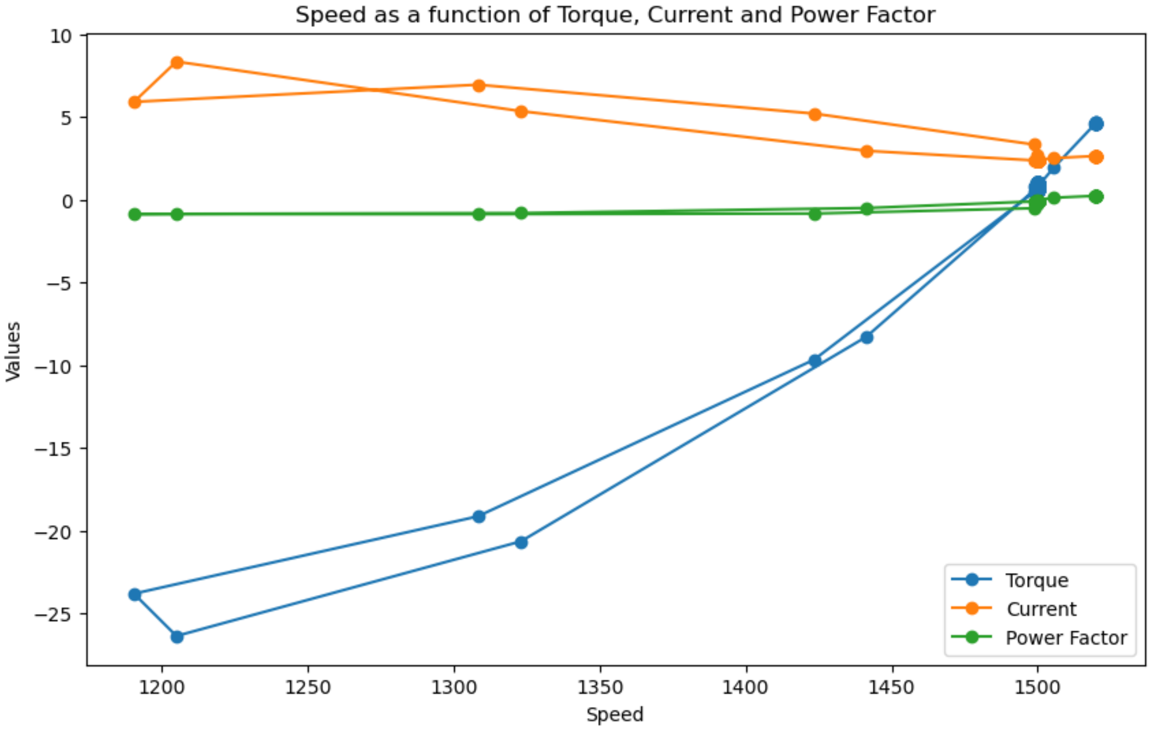
Here in the case of an Induction Generator as the Electrical Ouput Power is increased the power factor tends to be moving towards unity which means that more electrical power is being converted into useful work. As a result, the angle between the voltage and current waveforms tends to decrease, approaching zero.




The efficiency of an induction generator is the ratio of useful electrical power output to mechanical power input. As the electric active power output of the induction generator varies ($I = I_0 ... 1.2I_N$), the efficiency curve will show how well the generator converts mechanical power into electrical power at different operating points. In an ideal scenario, efficiency is maximized at the rated power output, but it may vary across the operating range. There might be a peak efficiency point, and efficiency could drop at lower or higher power outputs. The efficiency curve can be influenced by factors such as losses in the generator, core losses, copper losses, and friction losses. At lower power levels, the efficiency might be lower due to fixed losses that don't decrease proportionally with reduced power output.

The choice of operating point (electric power output) depends on the specific requirements of the application and the balance between efficiency and power factors. Some applications may prioritize a high-power factor, especially if there are penalties for poor power factor in the utility billing structure. Others may prioritize efficiency.

2. **Draw the torque, current, and power factor curves of the induction motor as function of the speed. Compare with the theoretical curves.**




1. <u>**Torque vs. Speed:**</u>
   The torque-speed curve of an induction motor generally shows a decreasing trend as speed increases. It typically exhibits a peak torque, often referred to as the breakdown torque, at a specific speed. Beyond this point, the torque decreases, and the motor operates in the region of constant power. The theoretical torque-speed curve is often derived from the motor's electrical and mechanical characteristics. It helps in understanding the motor's performance under different operating conditions. Initially, as the speed increases from 0 to the nominal speed, the torque increases, reaching a peak known as the pull-out torque. This is the maximum torque the induction generator can produce at nominal speed. As the speed continues to increase beyond the nominal speed, the torque starts to decrease. This is characteristic of the field weakening region, where the weakening of the magnetic field reduces the torque capability of the induction generator.

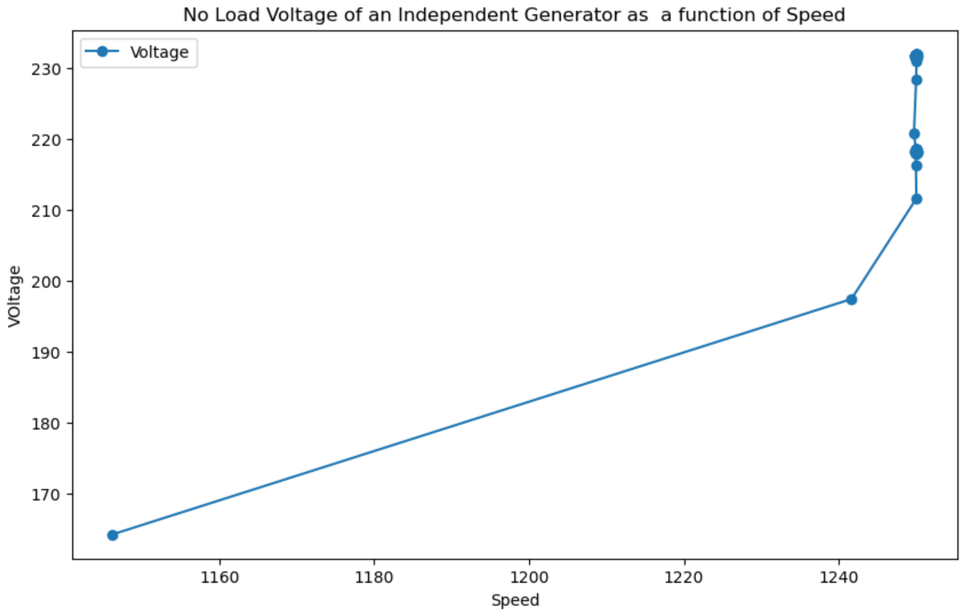
2. <u>**Current vs. Speed:**</u>
   The current drawn by an induction motor tends to increase with an increase in load (torque) and decreases with increasing speed. At low speeds, the current is relatively high as the induction generator requires more current to produce the necessary magnetic field for torque production. As the speed increases beyond the nominal speed, the back electromotive force (EMF) increases, leading to a reduction in current. However, in the field weakening region, the current may still increase due to the need for more excitation to maintain the required magnetic field. Theoretical calculations,

such as those derived from the equivalent circuit of the motor, can provide an expected relationship between current and speed. However, real-world factors like losses and non-idealities can lead to deviations.

3. **Power Factor vs. Speed:**
   The power factor of an induction motor is influenced by the balance between active (real) power and reactive power. At light loads or low speeds, the power factor tends to be lower due to the presence of significant reactive power. The power factor at low speeds is often low due to the high reactive power component associated with magnetizing the induction generator. The power factor gradually improves as the speed increases toward the nominal speed. In the field weakening region, the power factor tends to decrease. This is because the reduction in excitation at higher speeds can lead to an increase in reactive power demand, impacting the power factor adversely. Theoretical calculations based on the motor's electrical characteristics can provide insights into the expected power factor behavior. Power factor correction mechanisms may be employed to improve power factor under various operating conditions.

The actual performance of an induction motor may deviate from the theoretical curve due to practical considerations such as losses, saturation effects, and variations in manufacturing tolerances.

3. **Draw the no-load voltage of the independent generator as a function of the speed (with a few capacitors). Your notes on the excitation frequency?**




The no-load voltage of an independent generator is influenced by its excitation frequency. However, it's important to note that the excitation frequency of a generator is typically fixed and determined by the speed of the prime mover (such as a turbine or an engine) and the number of poles in the generator. The excitation frequency ($f_{excitation}$) is related to the generator speed ($N$) and the number of poles ($P$) by the formula:

$$f = \frac{N * P}{120}$$

Now, let's consider the relationship between the no-load voltage and the generator speed, assuming a fixed excitation frequency.

1. **<u>No-Load Voltage vs. Generator Speed:</u>**
   At no load, the voltage of an independent generator tends to increase with the speed. This is because the induced electromotive force (EMF) in the generator is proportional to the product of the magnetic flux and the rotational speed. The relationship can be expressed by the formula:

   $$E_{No\ Load} \propto N . \emptyset$$

   As the speed increases, the no-load voltage increases linearly if the excitation (magnetic flux) is kept constant.

2. **<u>Effect of Capacitors:</u>**
   Capacitors in a generator system are often used for power factor correction or to improve the stability of the voltage. They can affect the voltage regulation characteristics, especially at no-load._Adding or removing capacitors can change the

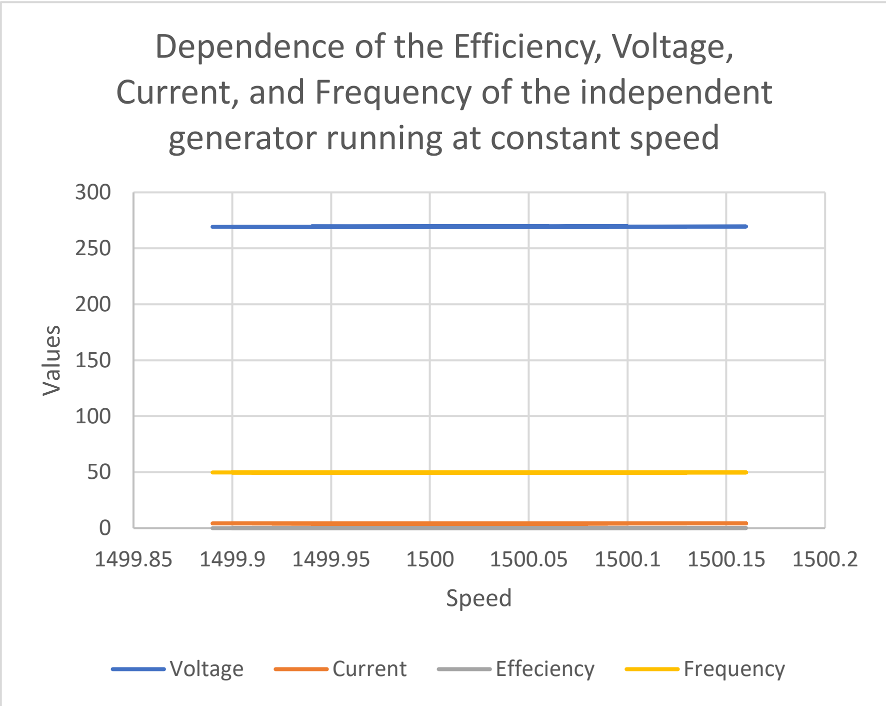
power factor of the generator, influencing the reactive power and, consequently, the voltage. The specific impact of capacitors on the no-load voltage would depend on the generator's design, the connected load, and the power factor requirements.

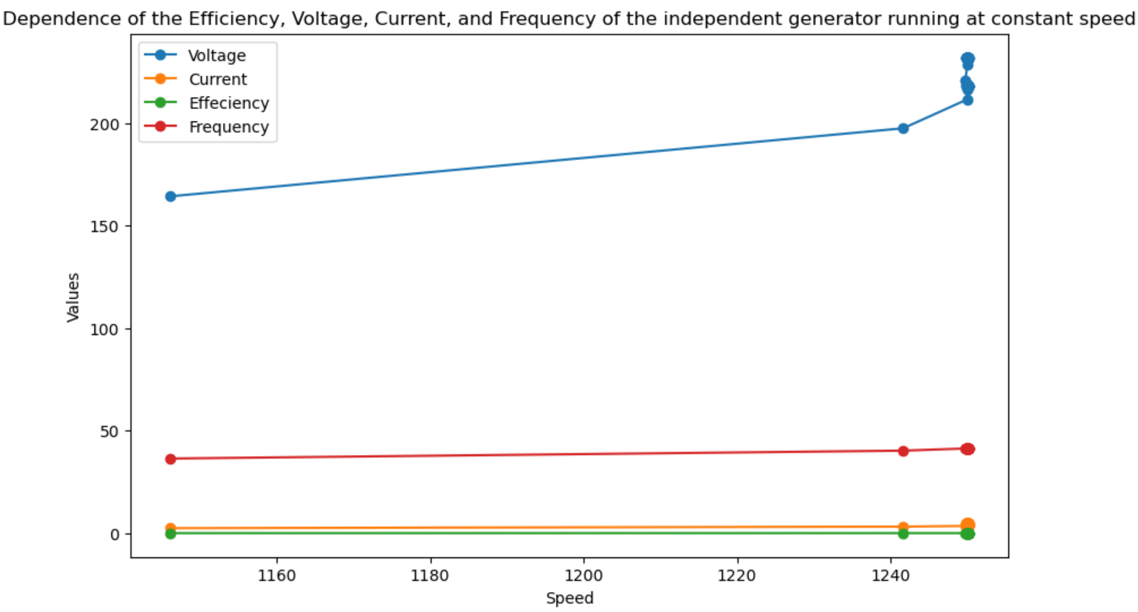
3. **Excitation Frequency:**
The excitation frequency, as determined by the generator speed and the number of poles, is crucial for maintaining the synchronous operation of the generator. Deviations in the excitation frequency from the rated value can lead to instability and improper functioning of the generator. The excitation system of the generator is responsible for maintaining the proper field current to ensure the desired magnetic flux, and hence, the no-load voltage. Monitoring and controlling the excitation frequency is a critical aspect of generator control systems to ensure stable and reliable power generation.

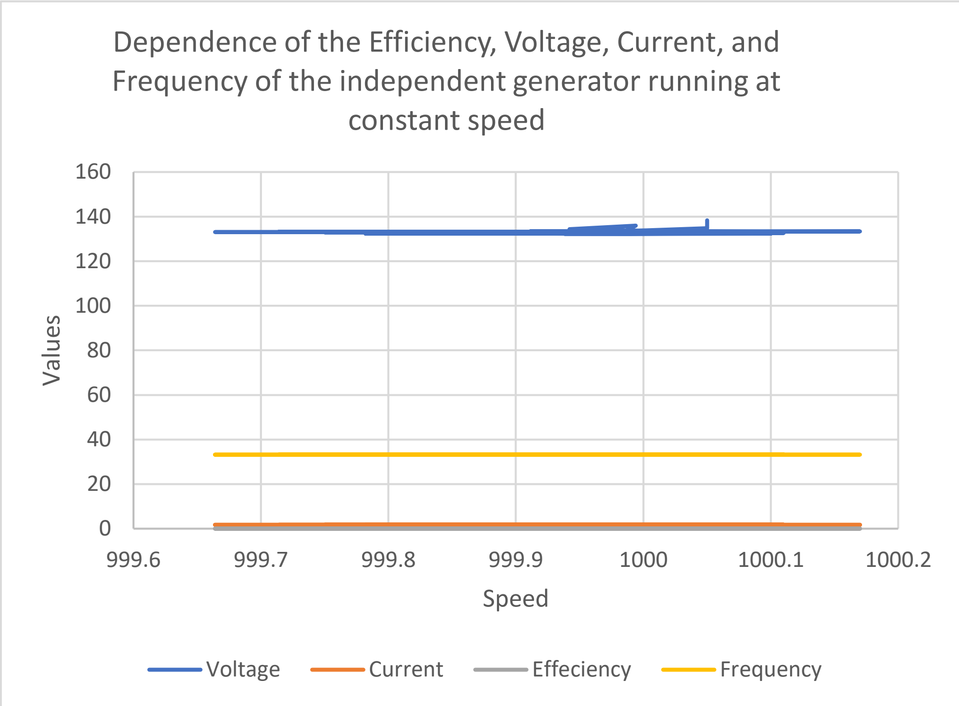
In summary, the no-load voltage of an independent generator is influenced by its speed, and the excitation frequency is a crucial factor in maintaining proper generator operation. The inclusion of capacitors in the system can affect the voltage regulation characteristics, especially under no-load conditions. The specific details would depend on the generator's design and the control system in place.

**4. Draw the dependence of the efficiency, voltage, current, and frequency of the independent generator running at constant speed on the load (cos = 1). Your comments!**

In this measurement we added the capacitor banks to the system and ran the generator in independent mode. This has a profound effect on the excitation current. Here we have plotted the frequency, voltage, current and efficiency at a function of time at different constant speed during the measurements.






1. **Efficiency:**
   The efficiency of a generator is the ratio of its output power to its input power. At a constant speed with a constant load of power factor unity, the efficiency is generally high and remains relatively stable. This is because power losses are minimized under these conditions.

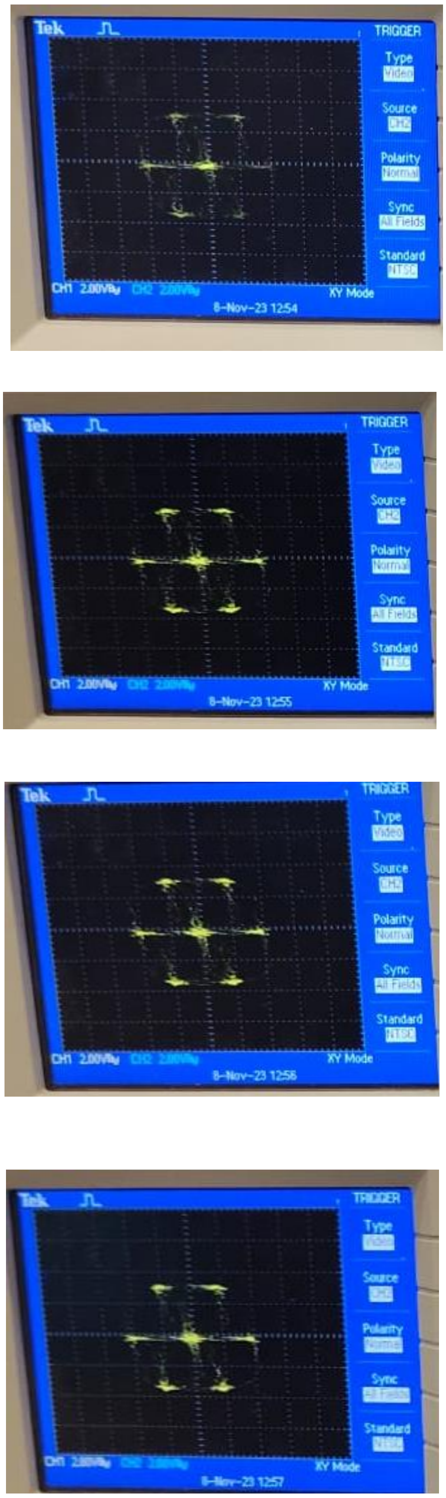
2. **Voltage:**
   The generator voltage tends to remain stable at a constant value when the speed and load are constant. In an ideal scenario with a constant load of power factor unity, the voltage regulation is good, and the generator maintains a steady-state voltage.

3. **Current:**
   The current in the generator is determined by the load connected to it. With a constant load of power factor unity, the current is constant as well. In an ideal scenario, the current remains steady, and variations are minimal.

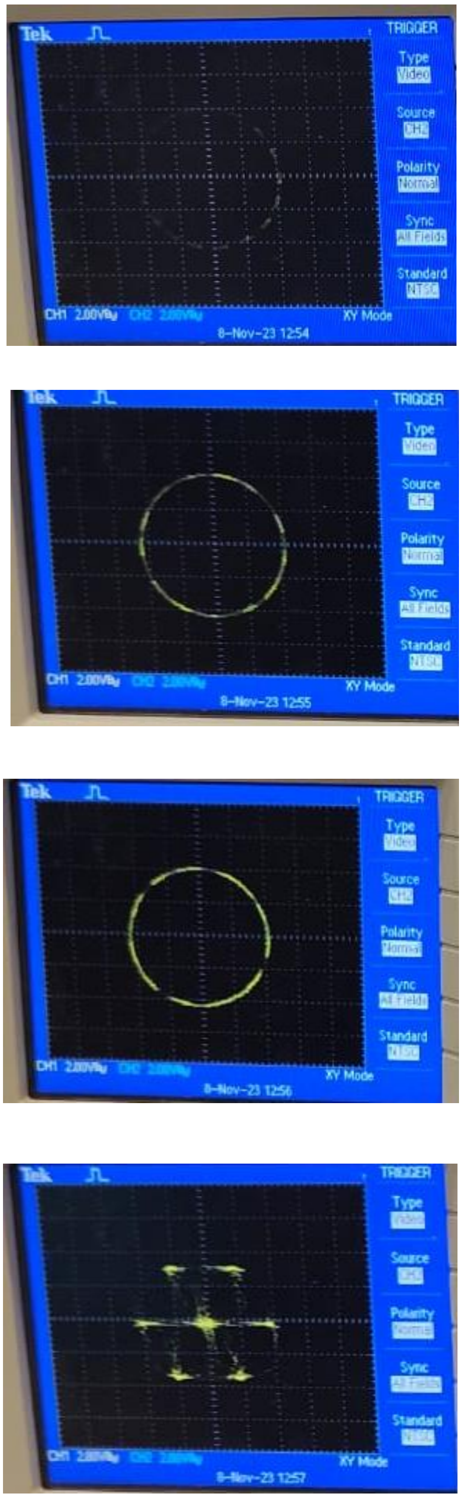
4. **Frequency:**
   The frequency of the generator output is directly tied to its rotational speed. In a generator running at a constant speed, the frequency remains stable as long as the mechanical speed is constant.

It's important to note that these idealized conditions may not always be achieved in real-world scenarios due to factors such as variations in load, changes in the prime mover's speed, and the presence of non-idealities in the generator and the connected system. Advanced control systems and power factor correction mechanisms may be employed to optimize the performance of the generator under various operating conditions.

5. **How do the stator voltage, current and flux vectors differ from each other in grid and frequency converter operation?**




**Stator Voltage Vectors**




**Stator Flux Vectors**

In the context of an induction motor or generator, the stator voltage, current, and flux vectors can behave differently in grid operation compared to frequency converter (also known as variable frequency drive, VFD) operation.

**Grid Operation:**

1. **Stator Voltage Vector:**
In grid operation, the stator voltage is sinusoidal and is synchronized with the grid frequency (50 or 60 Hz in most cases). The voltage vector follows the sinusoidal waveform of the grid, and its magnitude and frequency are determined by the grid characteristics.

2. **Stator Current Vector:**
The stator current vector in grid operation ideally lags the voltage vector by the power factor angle (cosine of the phase angle between voltage and current). The current waveform is sinusoidal and in phase with the grid voltage in the case of a purely resistive load.

3. **Stator Flux Vector:**
The flux vector in grid operation is sinusoidal and lags the stator voltage vector by the magnetizing angle. This angle is determined by the characteristics of the motor and is typically a small angle.

**Frequency Converter (VFD) Operation:**

1. **Stator Voltage Vector:**
In frequency converter operation, the stator voltage vector is not constrained by the grid frequency. It can have various waveforms depending on the control strategy used. It might be a modified sine wave, a square wave, or a pulse-width modulated (PWM) waveform. The frequency and magnitude of the stator voltage can be adjusted independently of the grid.

2. **Stator Current Vector:**
The stator current vector in frequency converter operation can have different characteristics based on the control strategy. It may not necessarily follow a sinusoidal waveform and could have harmonics depending on the inverter design and modulation technique. The current can also lead or lag the voltage based on the inverter control strategy and the load characteristics.

3. **Stator Flux Vector:**
The flux vector in frequency converter operation can be controlled independently of the grid. The control system of the frequency converter adjusts the voltage and frequency to achieve the desired magnetic flux in the motor. This allows for precise control of motor performance, including speed and torque.

Thus, it was also observed during the Lab Operation that these Vectors were prominent when the frequency was increased and can be seen in the pictures above as well.