

MIDDLE EAST TECHNICAL UNIVERSITY

Electrical & Electronics Engineering

Simulation Project

EE 462 – Utilization of Electric Energy

EE-464 – Static Power Conversion II

Instructor:

Dr. Emine BOSTANCI

Dr. Ozan KEYSAN

Students:

Ali Aydın - 2093326



**INTRODUCTION**

We need to make a simulation project for EE462 and EE464 courses. The aim of this project is designing a motor drive by using sinusoidal PWM for surface mount permanent magnet synchronous machine. For controlling motor, we implemented a current and speed controller by using id-iq parameters. We cannot use Simulink blocks. Therefore, we need to create our own blocks. For part B, we should use sinusoidal PWM technique. Also, in part D, we select the ideal component for project.

**PART A: PRE-DESIGN STAGE**

1-) We know a relation between torque and power. By using that equation, we can find the rated speed.

wmech = 266.67 rad/sec

Trated=300 N.m

The rated torque is given the specification.

2-) Maximum speed is given the specification. By using that, we can find maximum applied frequency.

fmaximum is 467 Hz. For switching frequency, we should take it at least 21 times of fmaximum. We can choose the switching frequency as 10 kHz.

3-) The ripple value of input voltage is not specified but we want almost DC voltage and we can choose the ripple value as %2. We can use below equation

Where I=250A (maximum motor current), f=300 Hz (since three phase rectifier output)

When we calculate by using that equation, we find DC link capacitor value as 83 mF.

In order to test DC capacitor, we need to calculate resistance value. We know voltage value (565 V) and rated current (120A). Then, we calculate resistance as 2.16 ohm.

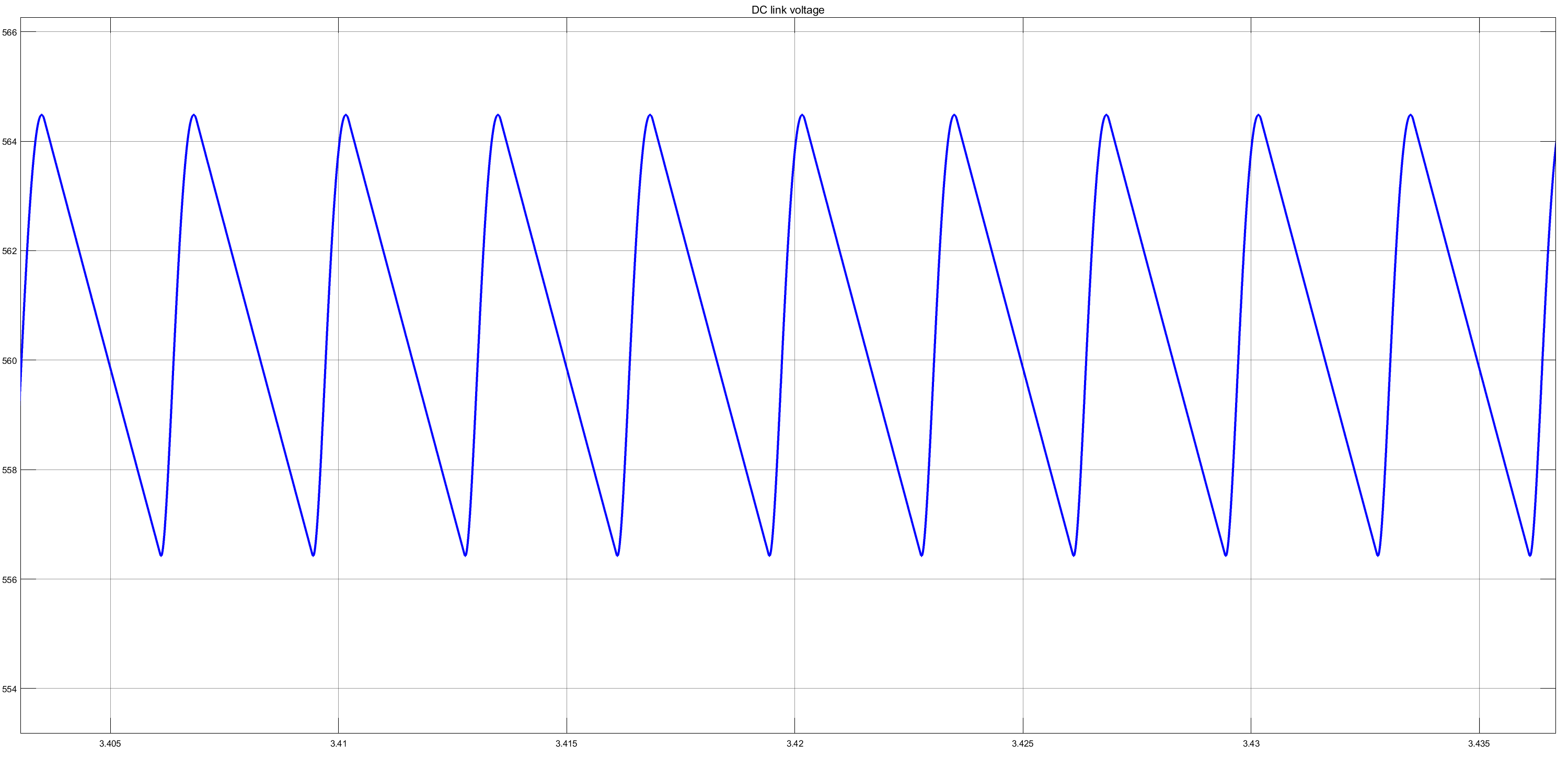


Figure : Output waveform of DC link voltage

Therefore, we established the circuit and tested it. We can see the voltage waveform in the figure 1. And, ripple value is %1.5.

**PART B: SINUSOIDAL PWM**

We can see the whole block diagram of our system in the figure 2.

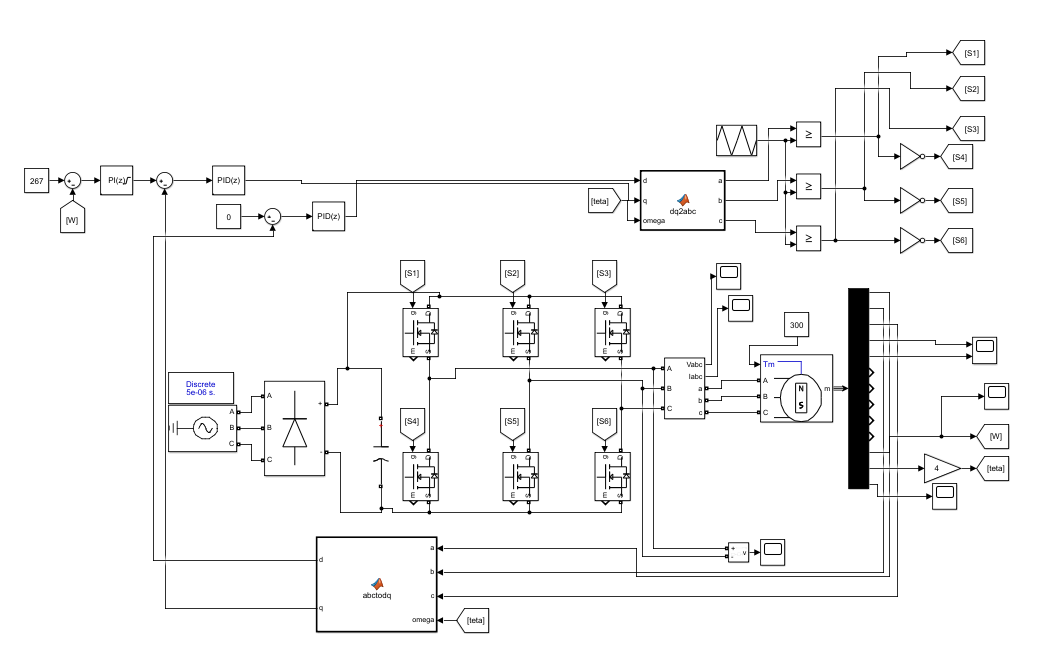


Figure : Whole block diagram of motor drive

1. In this part, we should 60 Nm constant torque load to motor input torque parameter. However, firstly, we need to give %90 of rated speed. Then, after reaching steady state, we need to give rated speed as speed reference.

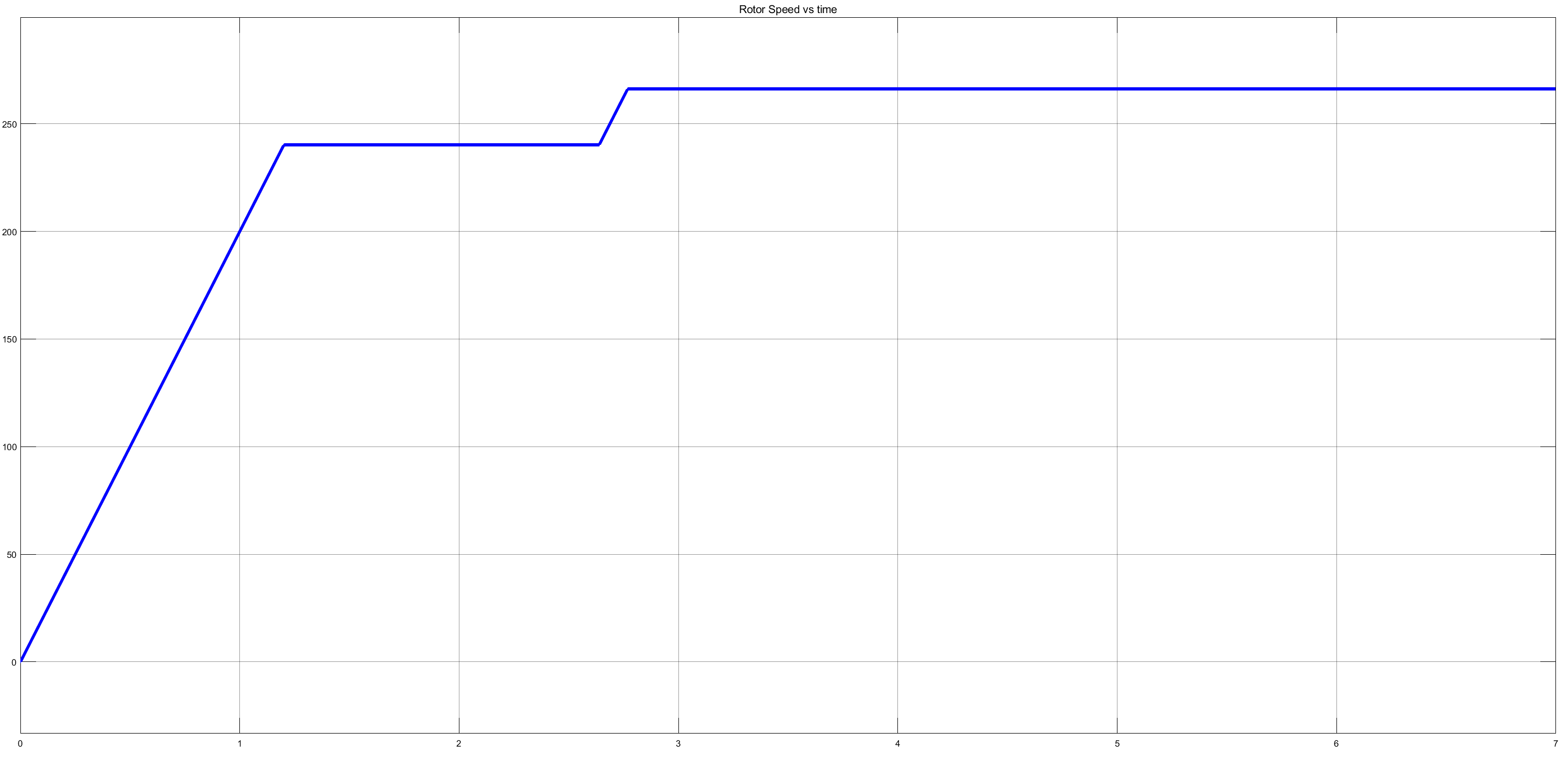


Figure 3: Rotor Speed(rad/sec) vs time(sec) characteristic

When we change the speed reference, as seen in the figure 3, motor reaches the steady state in short amount of time.

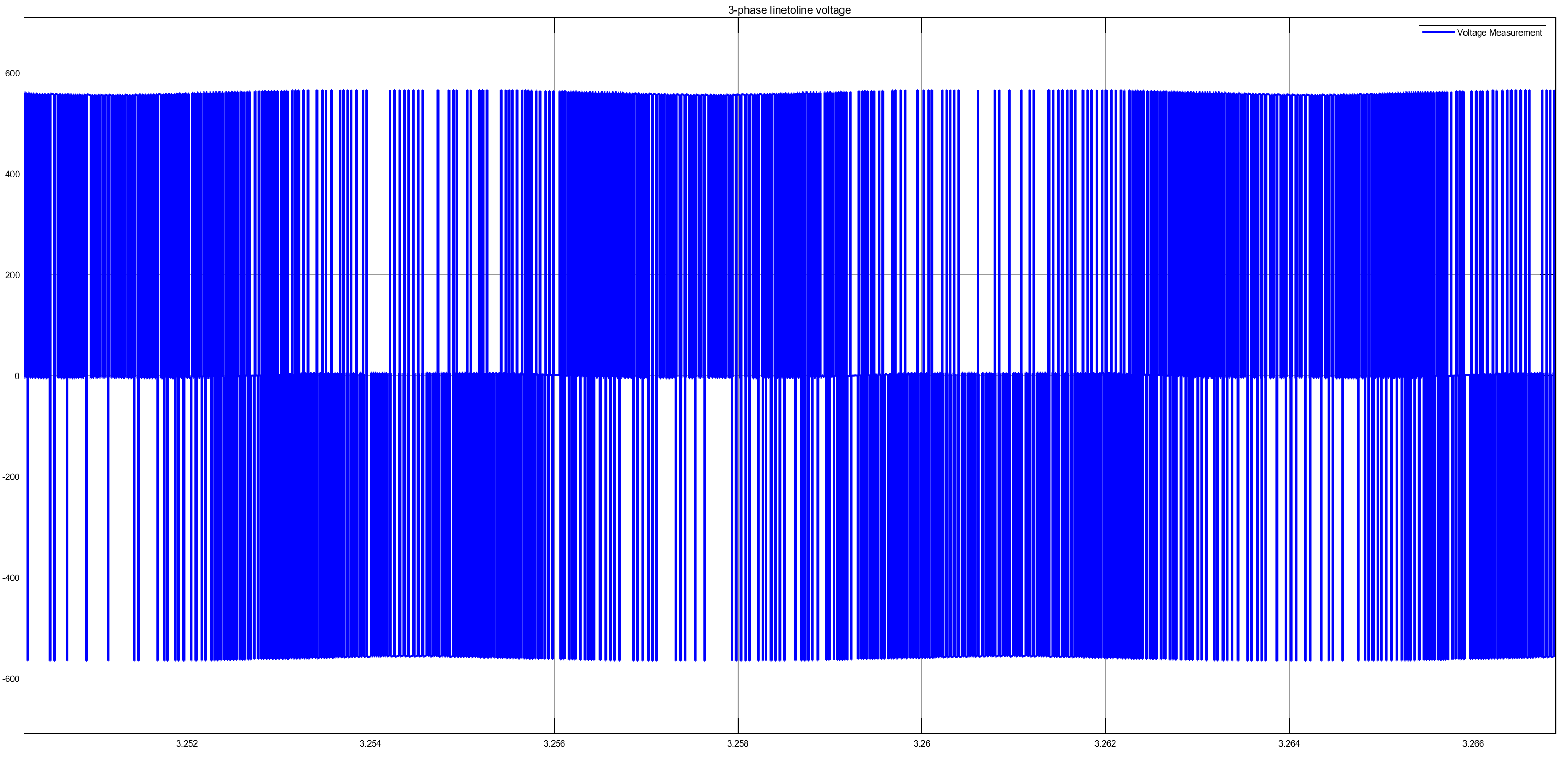


Figure 4: VAB linetoline voltage from a distance

In the figure 4, we see the VAB line-to-line voltage. However, in the real sinusoidal pwm technique, we should not see like this waveform. We should see like in the figure 5. The reason is that frequency and magnitude of references are changing continuously. Due to that, we do not see proper waveforms.

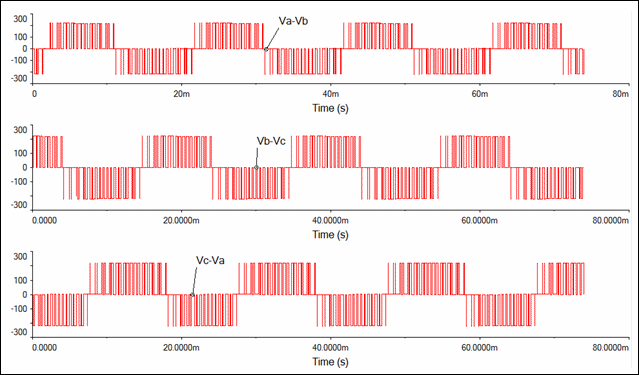


Figure : Sinusoidal pwm output waveforms

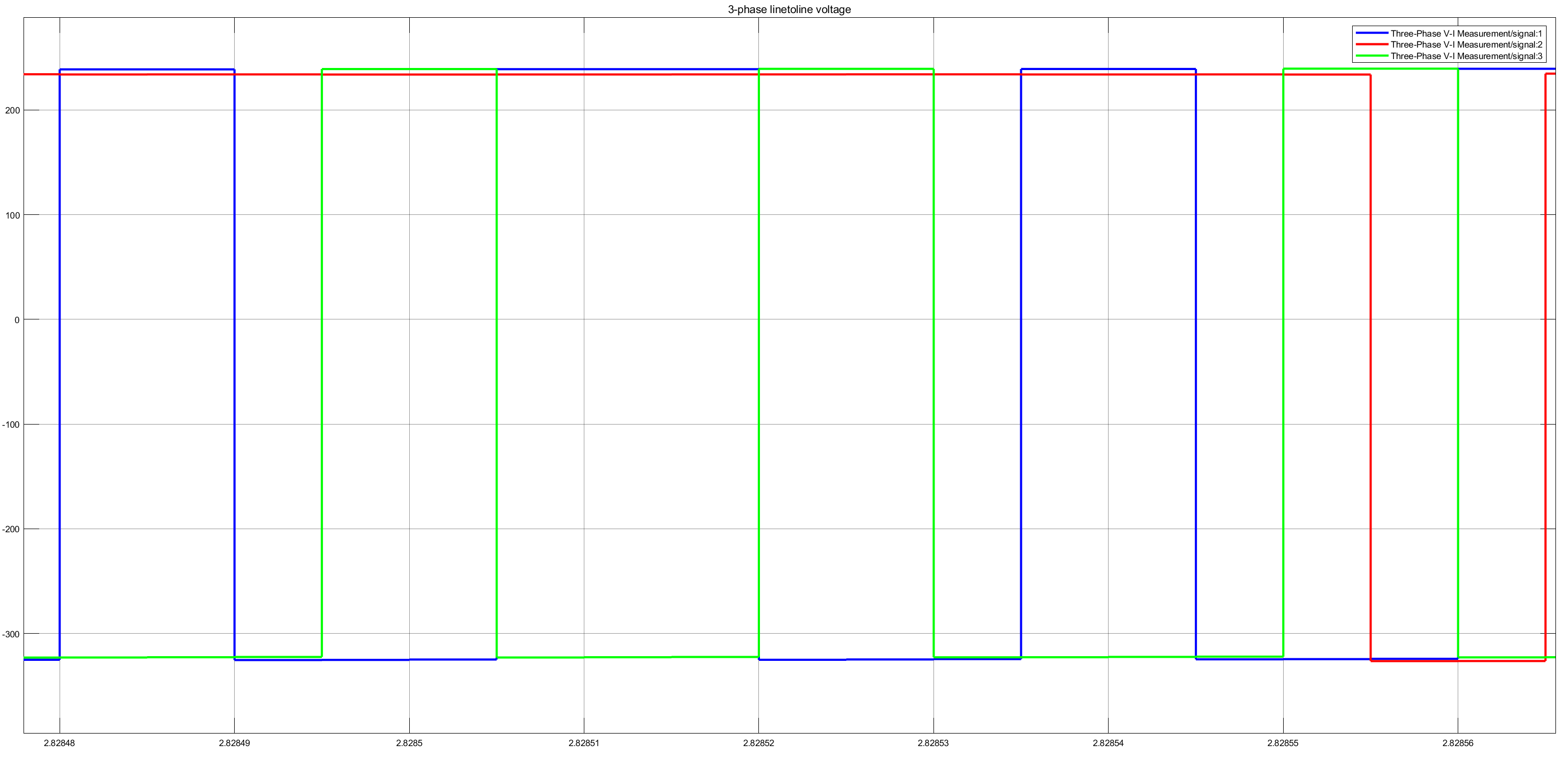


Figure 6: Three phase line voltages upon close look

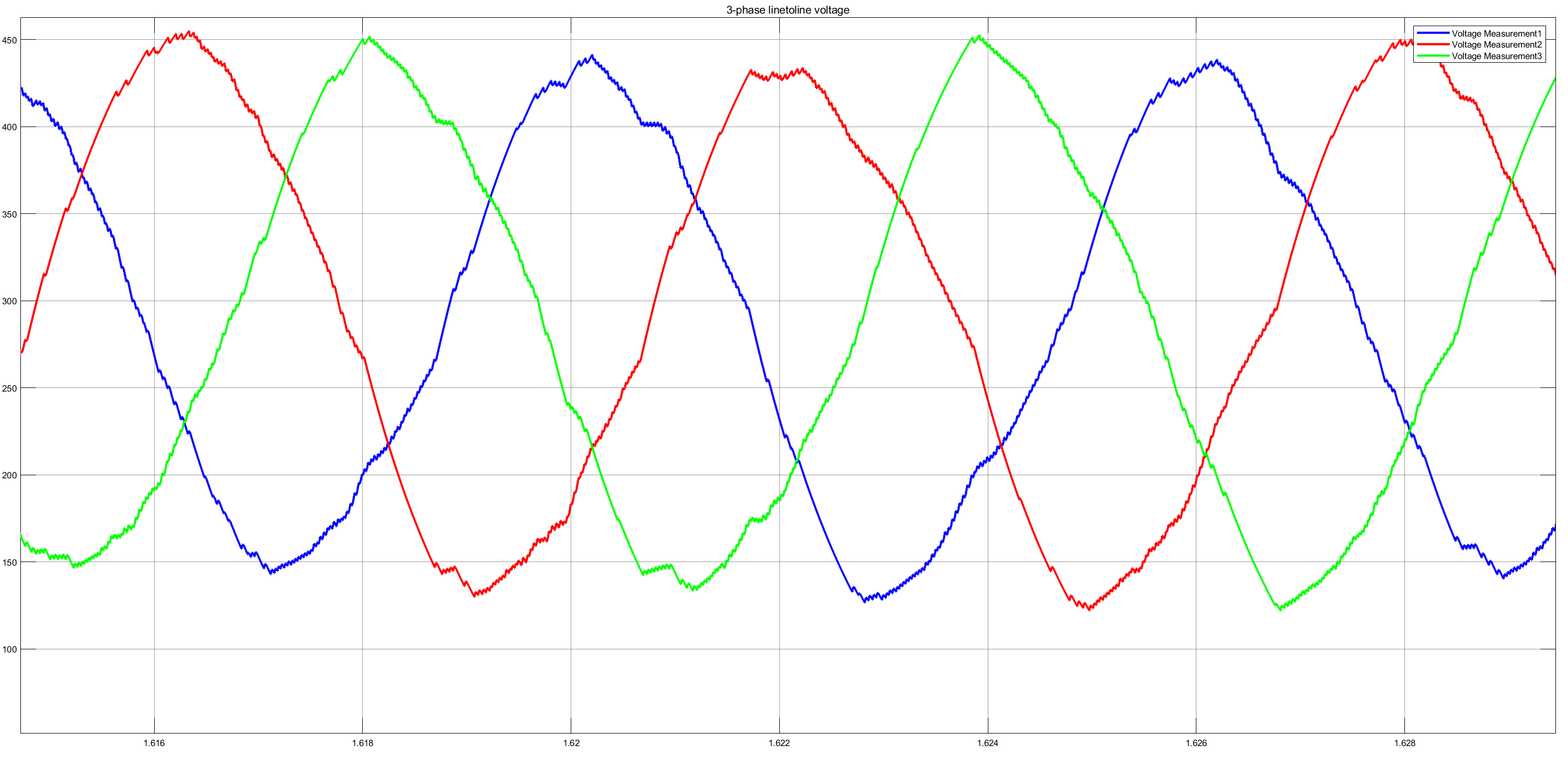


Figure 7: Three phase line voltages upon close look with low pass filter

The motor 3 phase voltages is not obvious since they occurs from square wave like in the figure 6. However, when we added low pass filter to output of inverter voltage, we can see clearly the sinusoidal waveforms in the figure 7.

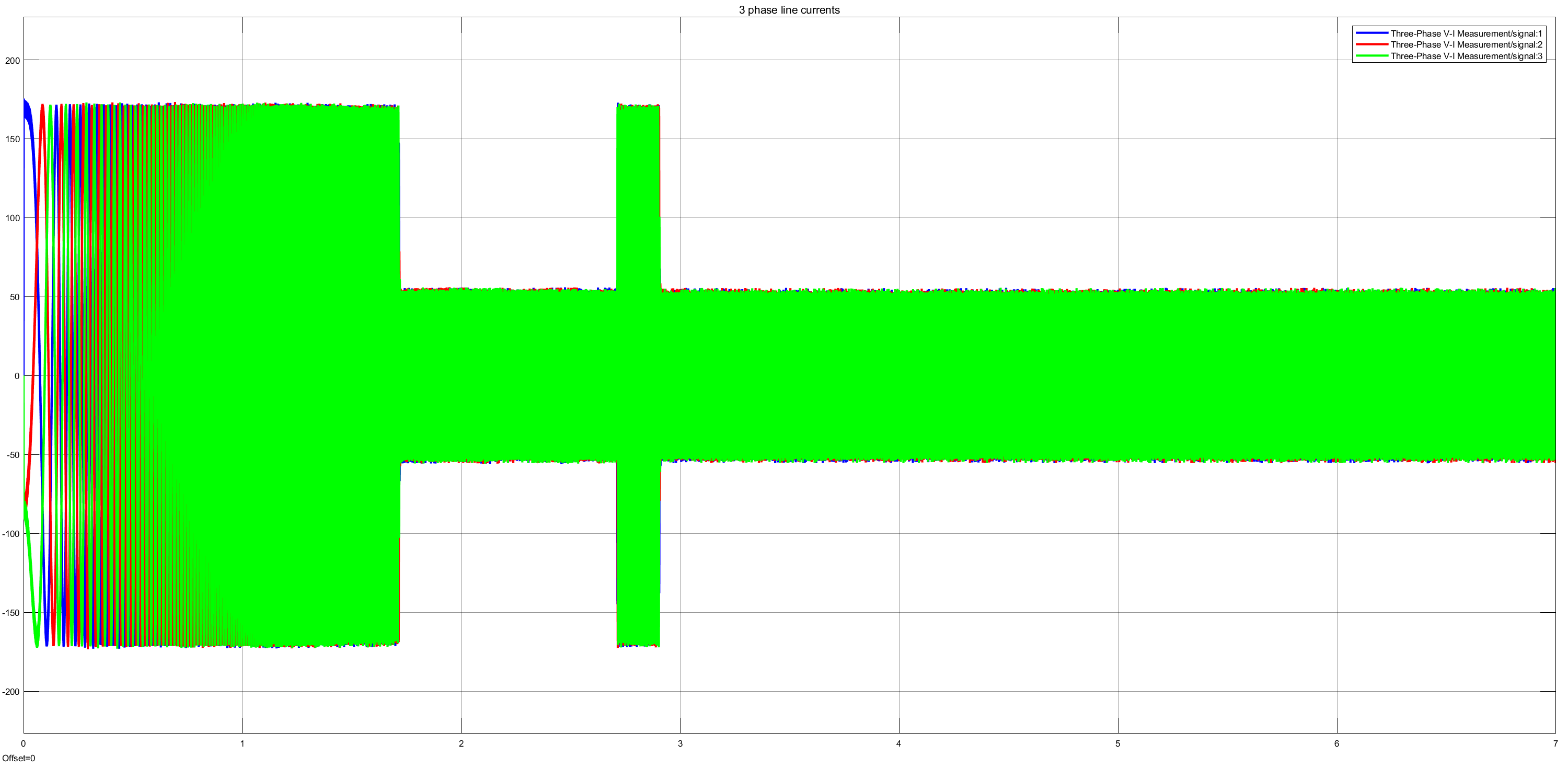


Figure 8: VABC line currents from a distance

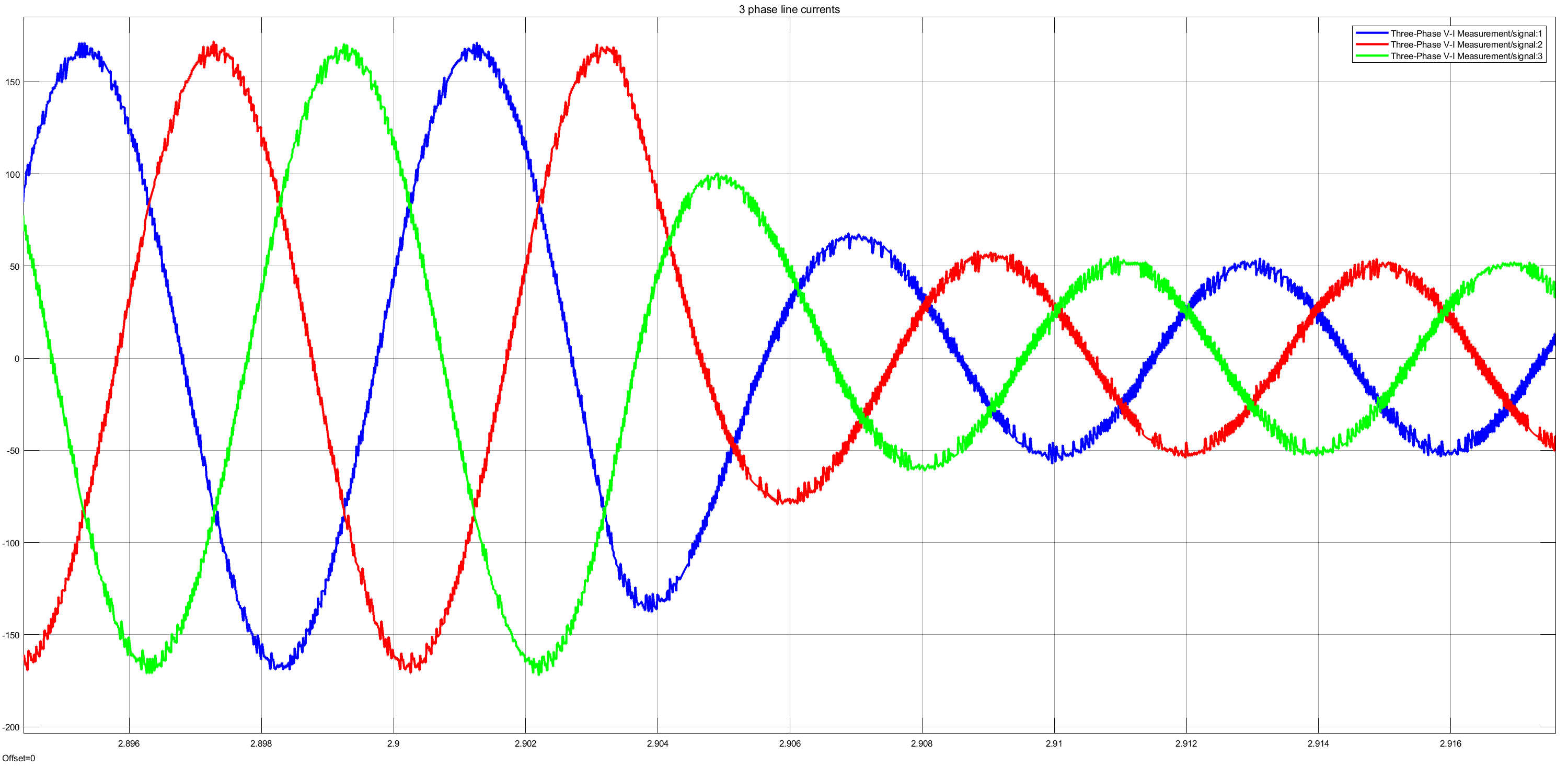


Figure 9: Three phase line currents upon close look

In the figure 8, we see the waveform of line currents from a distance. In the beginning of the simulation, motor draws huge current that is starting current. Then, when it reaches to steady state, current value decreases. In a moment, we change the speed reference, motor draws huge current to speed up. After reaching to the steady state, current decreases. We see this relation in the figures 10 and 11. One of them means torque and the other means d-q currents. We see that q current is responsible from torque since when torque increases, q current increases and vice versa. Moreover, current waveforms are sinusoidal and we expect these results.

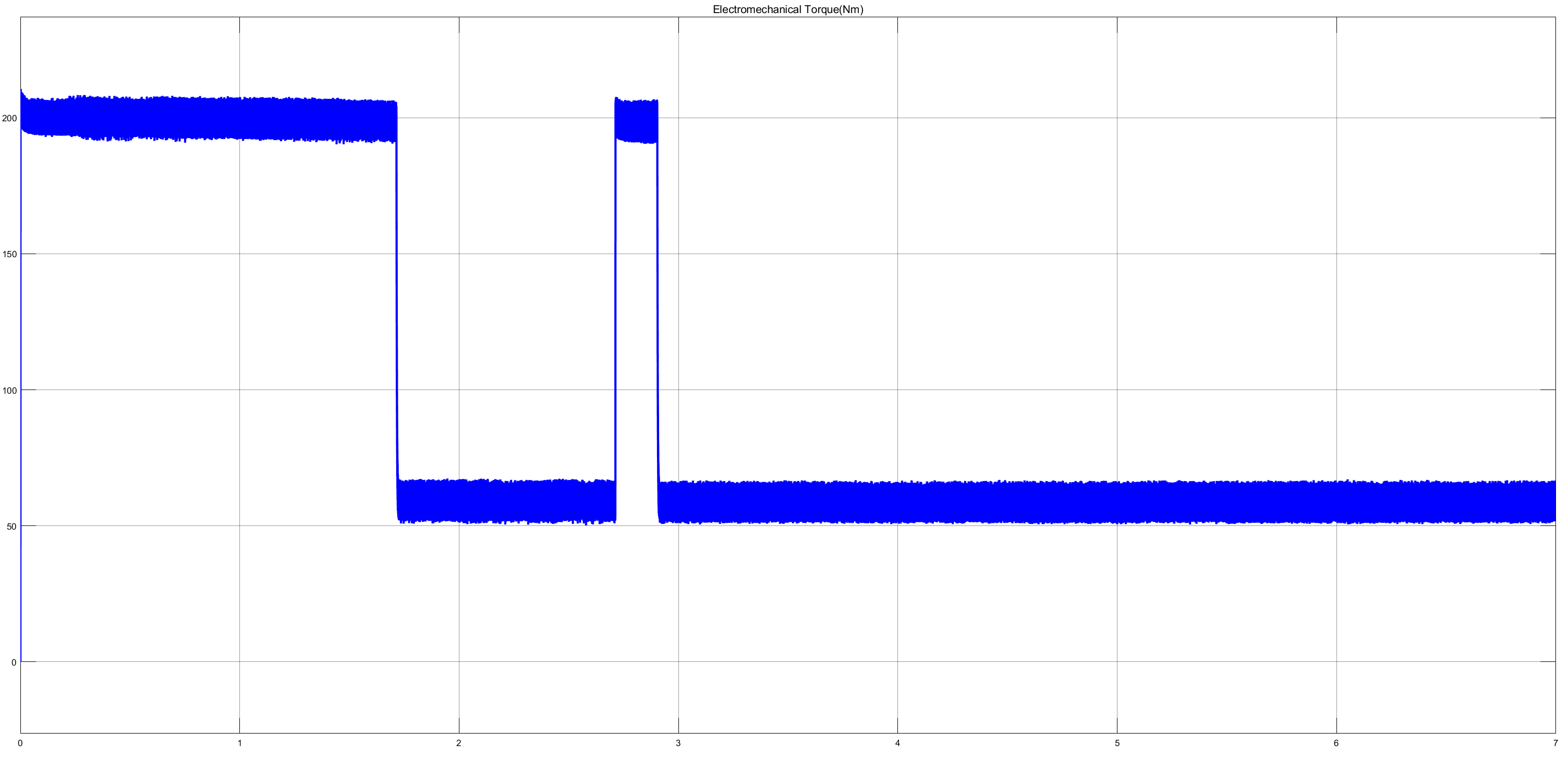


Figure 10: Electromechanical Torque (Nm) vs time characteristic

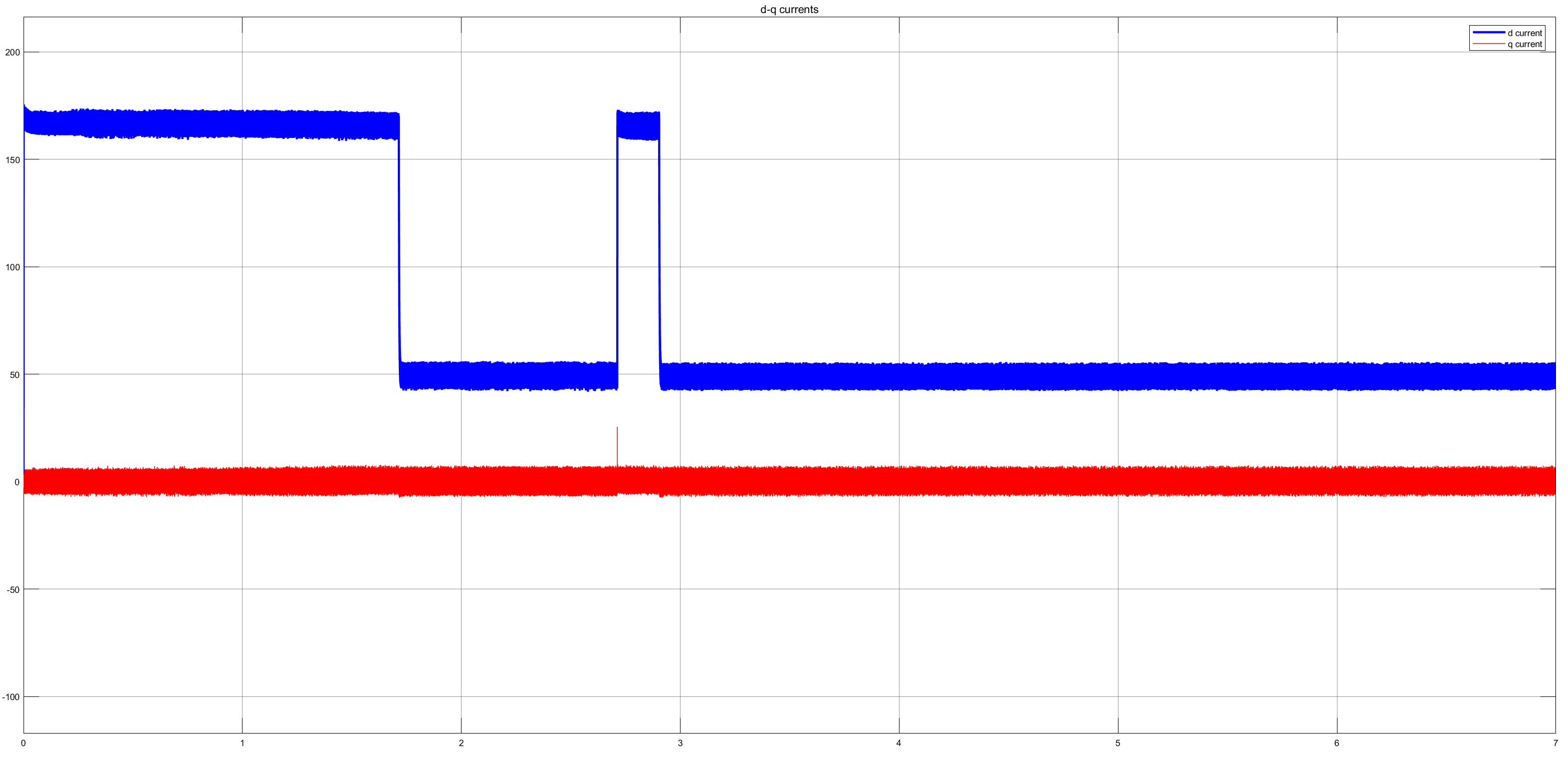


Figure 11: d (blue) and q(red) currents vs time characteristics

2-) In this part, when motor reaches to the steady state, we need to remove load. Then, as seen in the figure 12, rotor speed is changing a little bit, but, after a while, speed becomes reference speed.

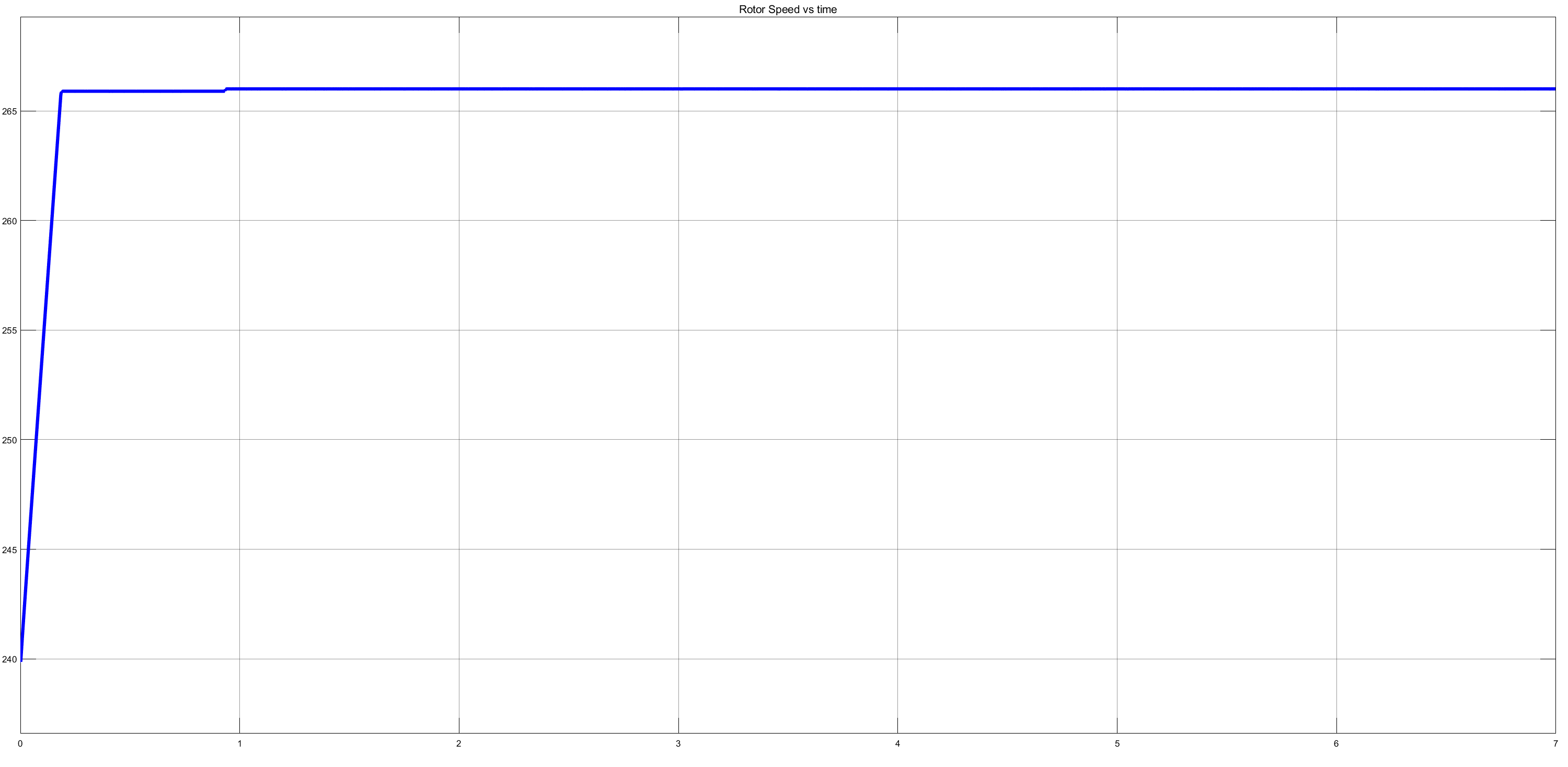


Figure 12: Rotor Speed(rad/sec) vs time(sec) characteristic

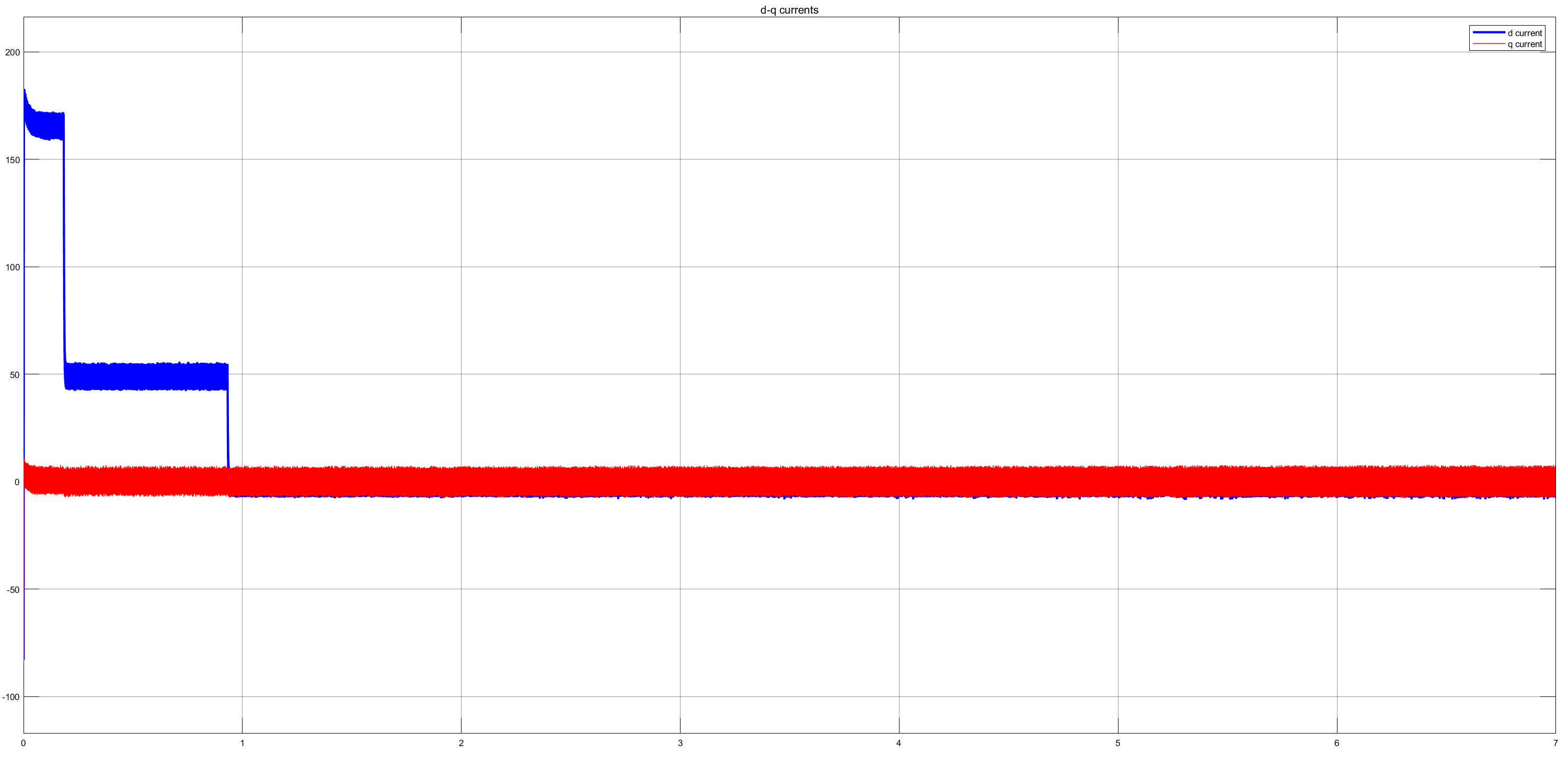


Figure 13: d (blue) and q(red) currents vs time characteristics

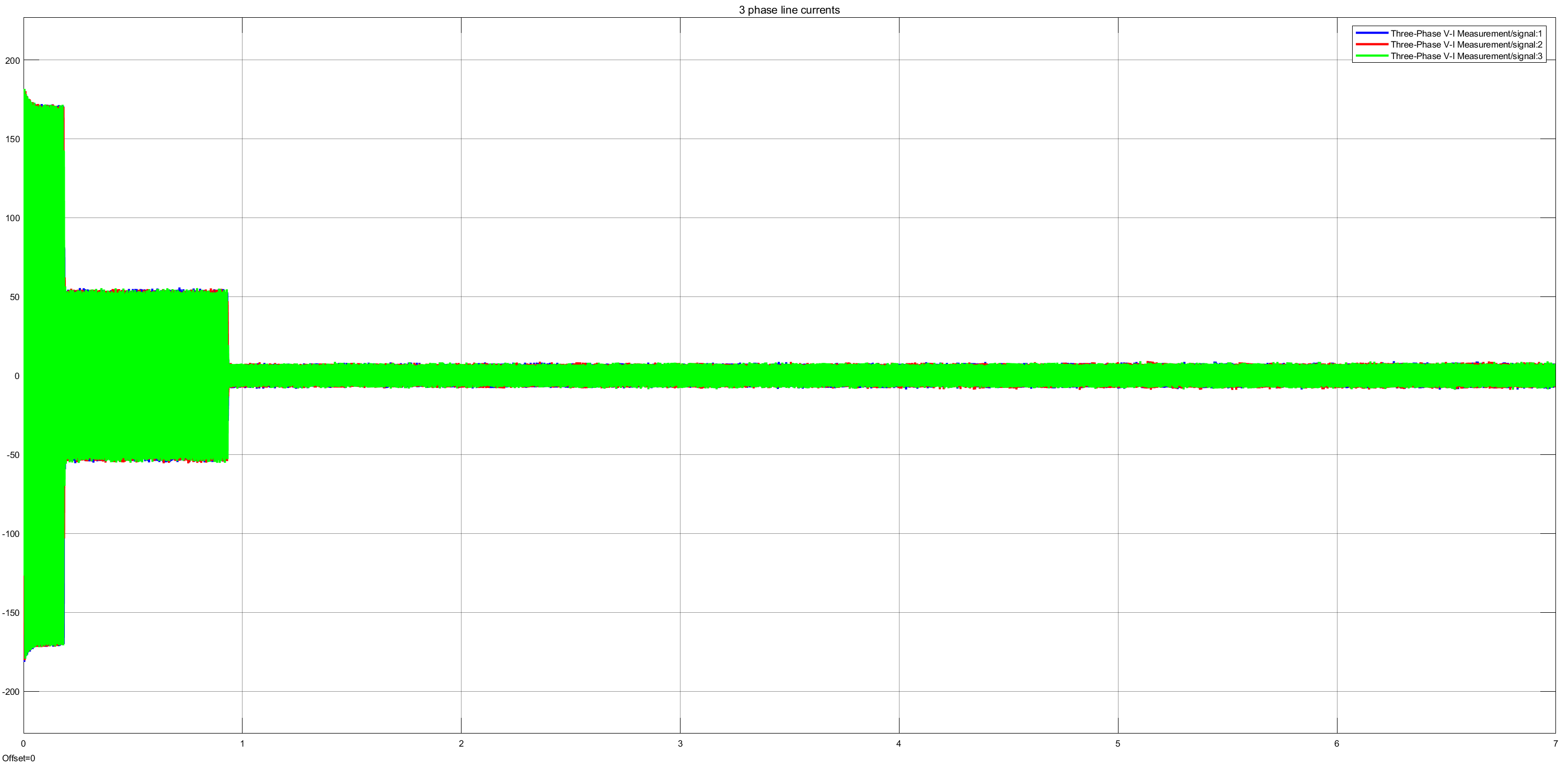


Figure 14: VABC line currents from a distance

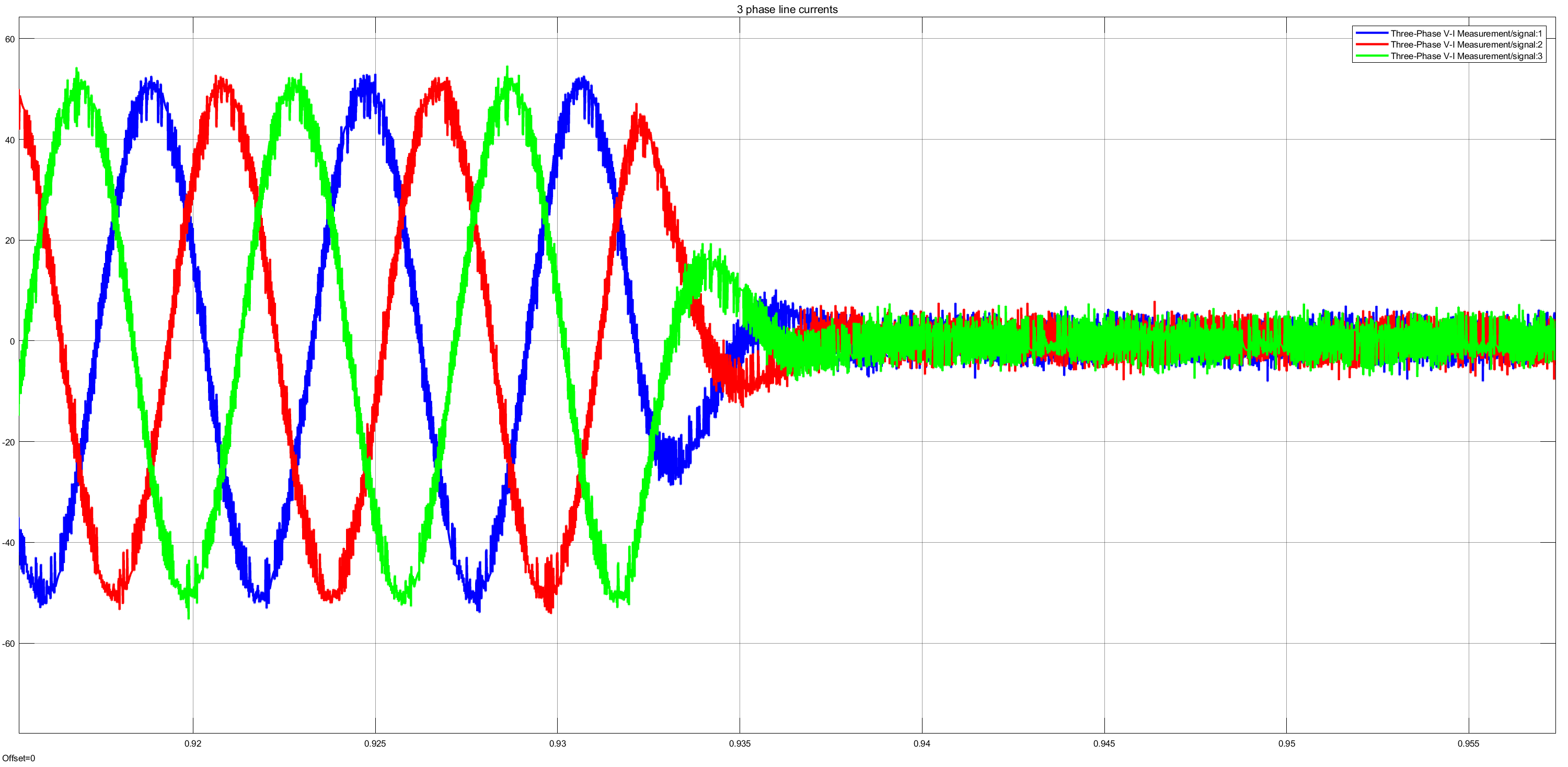


Figure 15: Three phase line currents upon close look

After removing the load, as seen in the figures 13, 14 and 15, all of them decreases. We can mention their relation in the part 1. Again, we that relation.

**PART C: SPACE VECTOR PWM (SVPWM)**

1-) For this part, we need to use space vector pwm technique. For generating space vector, we use Simulink block. That block takes alfa-beta transformation result as input and generates gate signal with respect to space vector modulation.

We need to arrange the reference speed as %90 of rated speed. After reaching the steady state, we need to change the reference speed as rated speed. We took the same result with part B for speed as seen in the figure 16.

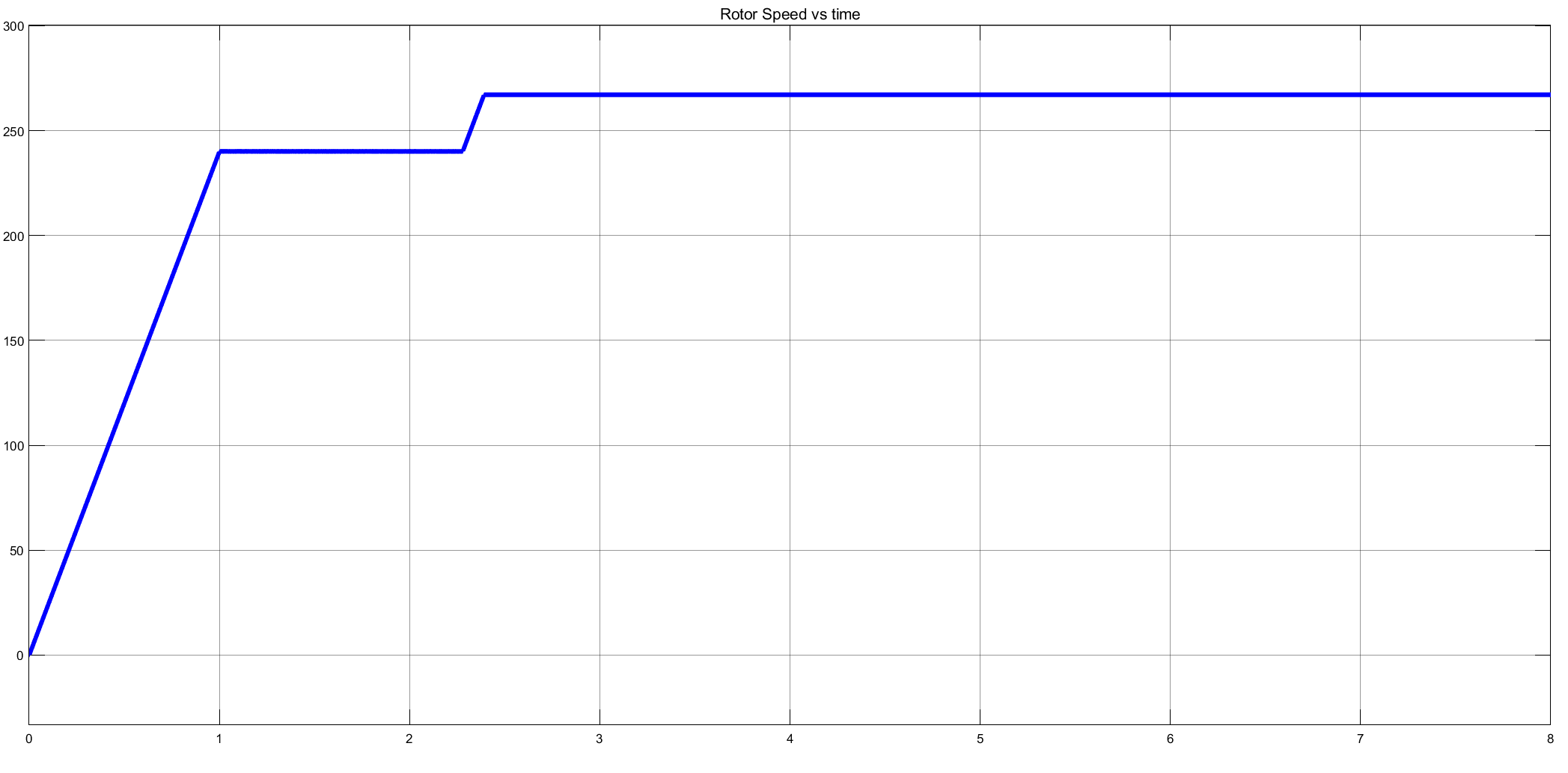


Figure : Rotor Speed(rad/sec) vs time(sec) characteristic

The shape of current and torque waveforms looks like the same, but the magnitudes are not the same since in the space vector modulation technique, effective phase voltage and current increase. Therefore, we see that changes in the figure 17, 18 and 19.

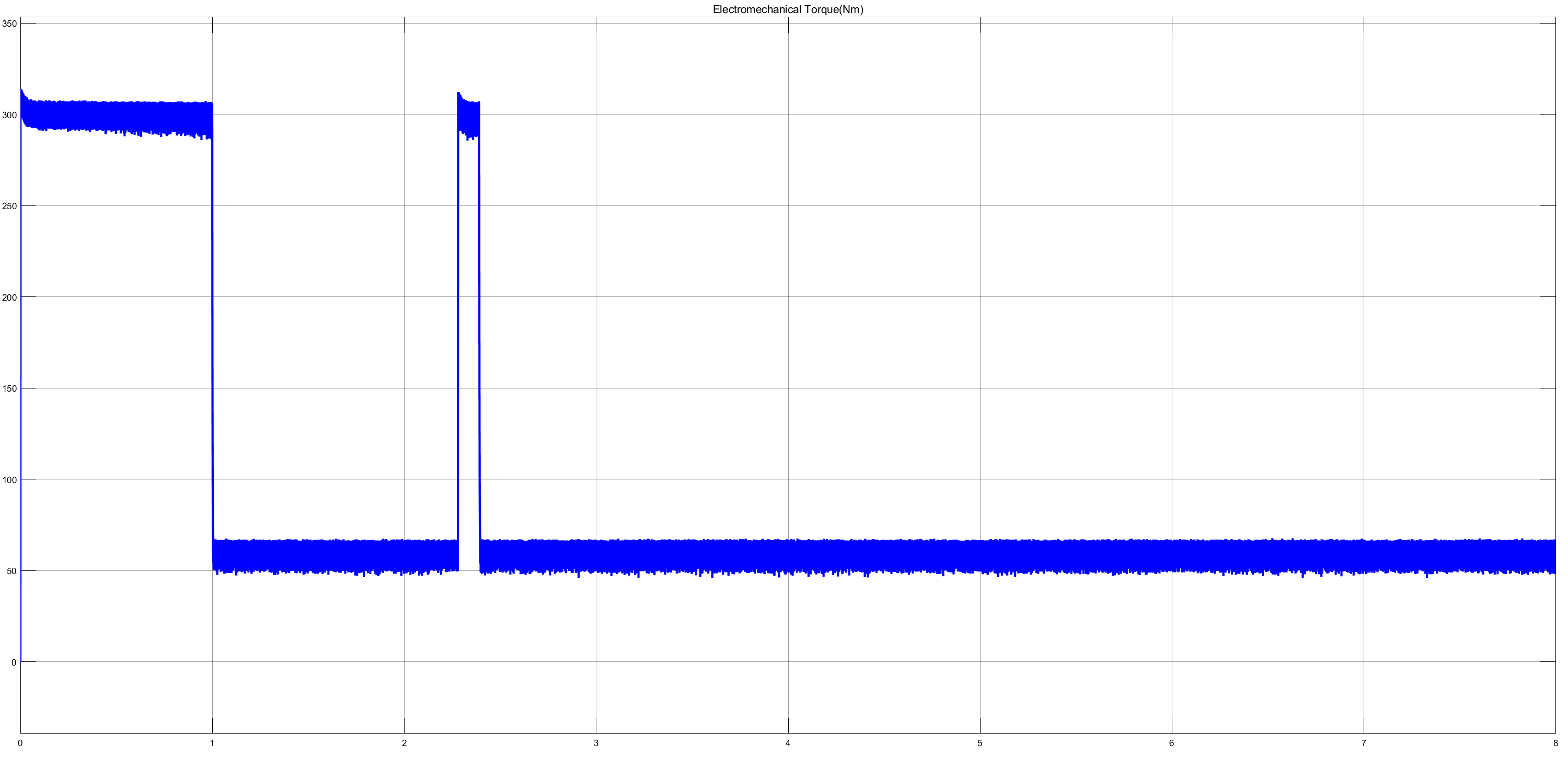


Figure : Electromechanical Torque (Nm) vs time characteristic

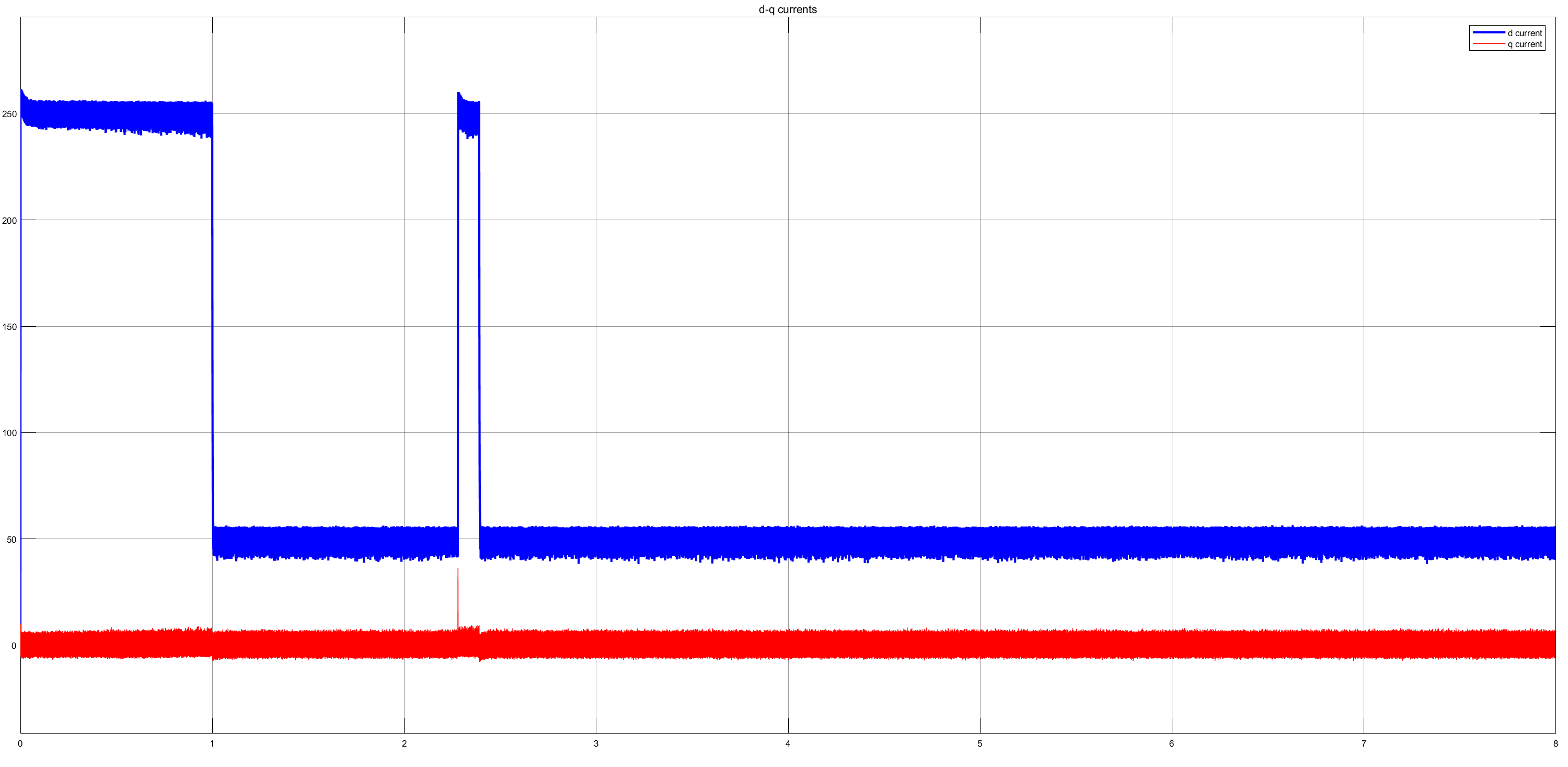


Figure :d (blue) and q(red) currents vs time characteristics

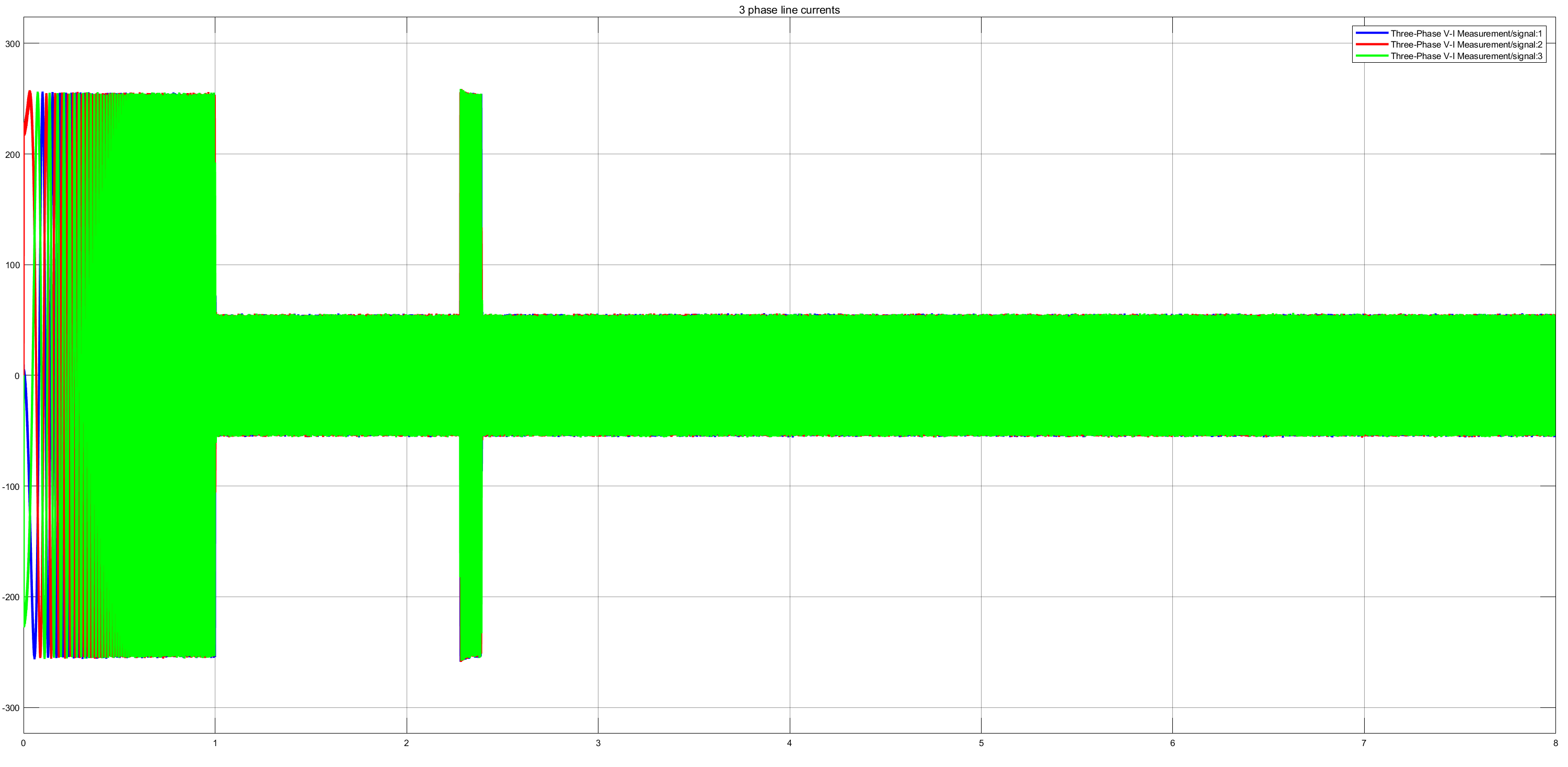


Figure : VABC line currents from a distance

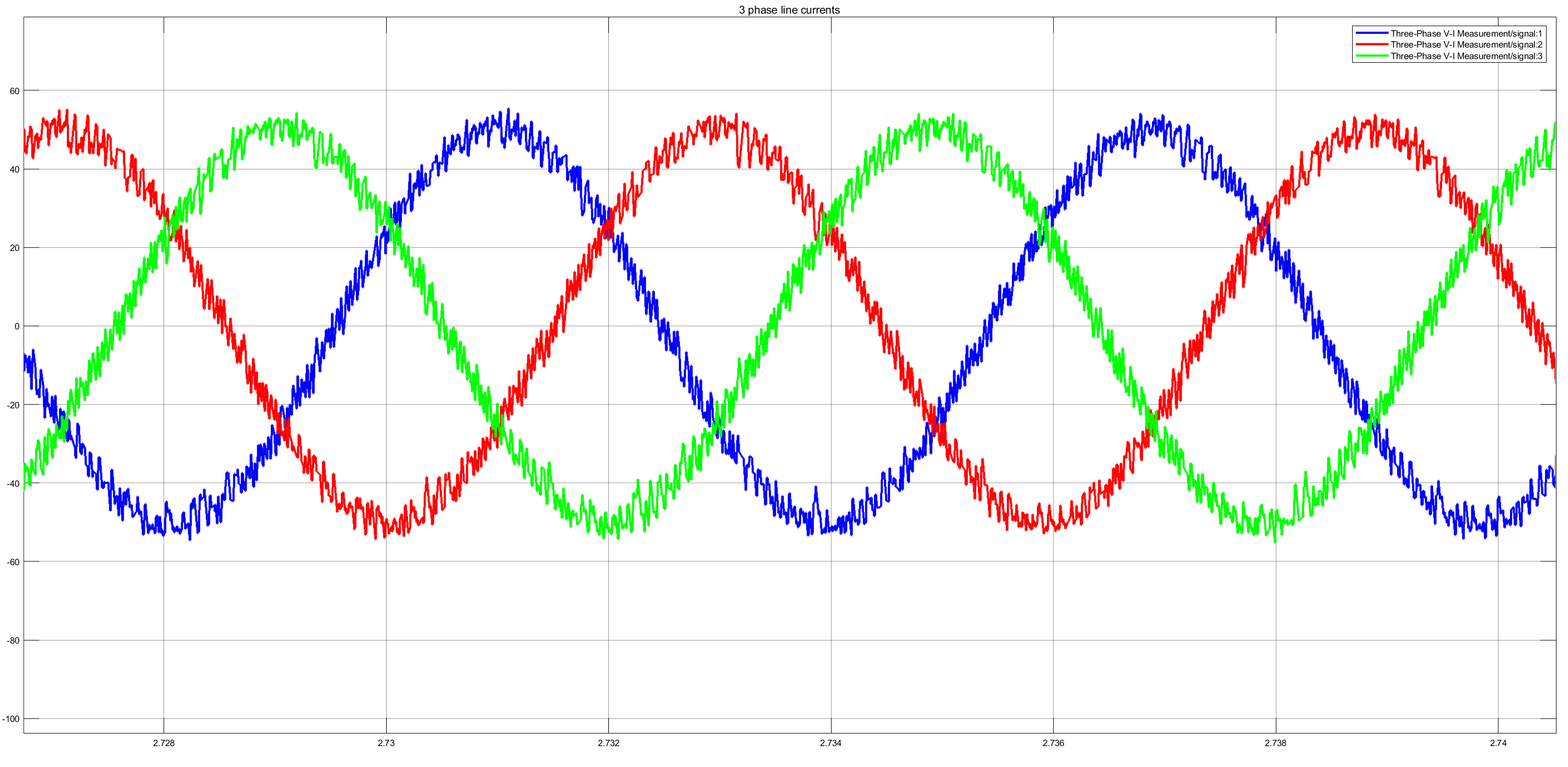


Figure : Three phase line currents upon close look

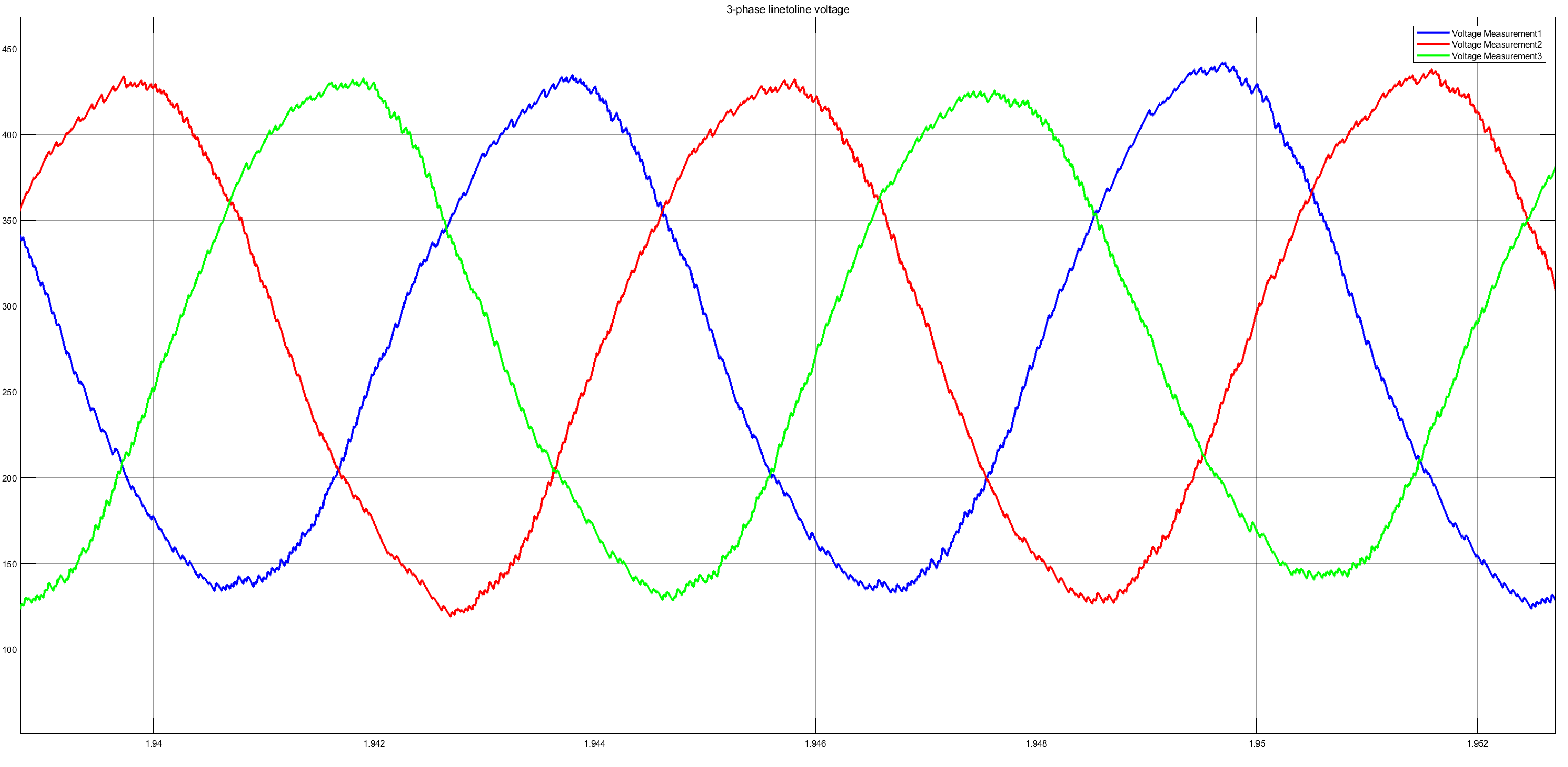


Figure : Three phase line voltages upon close look with low pass filter

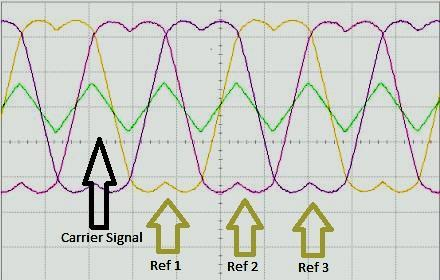


Figure : Three phase reference voltage of SVPWM

In the figure 21, we see the reference switching voltage of SVPWM output. However, we did not expect this result. The waveforms should be seen like in the figure 22. The problem can be that we could not use the Simulink block proper or reference voltages is changing continuously.

In the second part, when motor reaches to the steady state value, we need to remove the load. We simulate this test condition. In the figure 23, we can see the speed changing and it is changing a little bit.

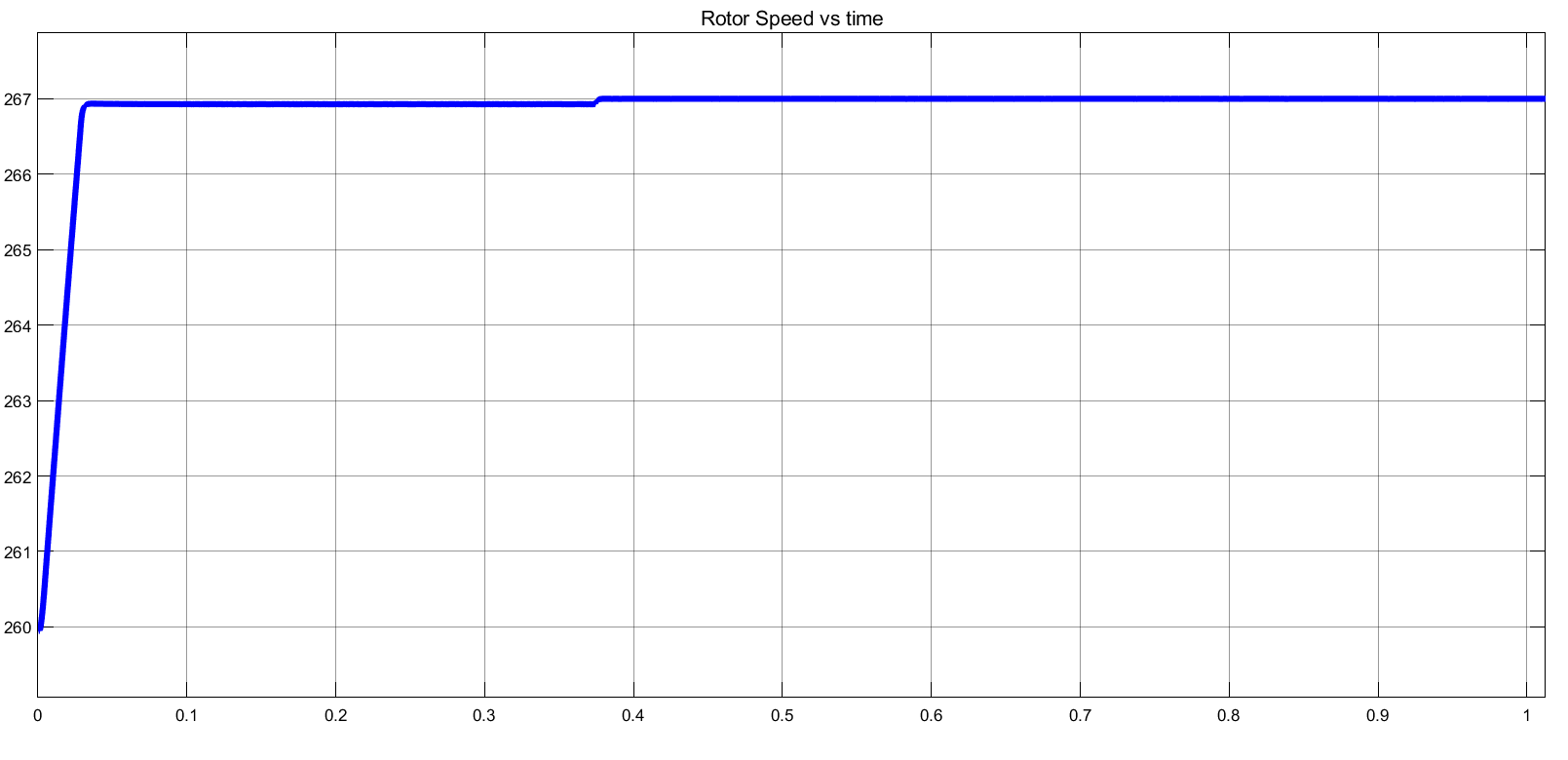


Figure : Rotor Speed(rad/sec) vs time(sec) characteristic

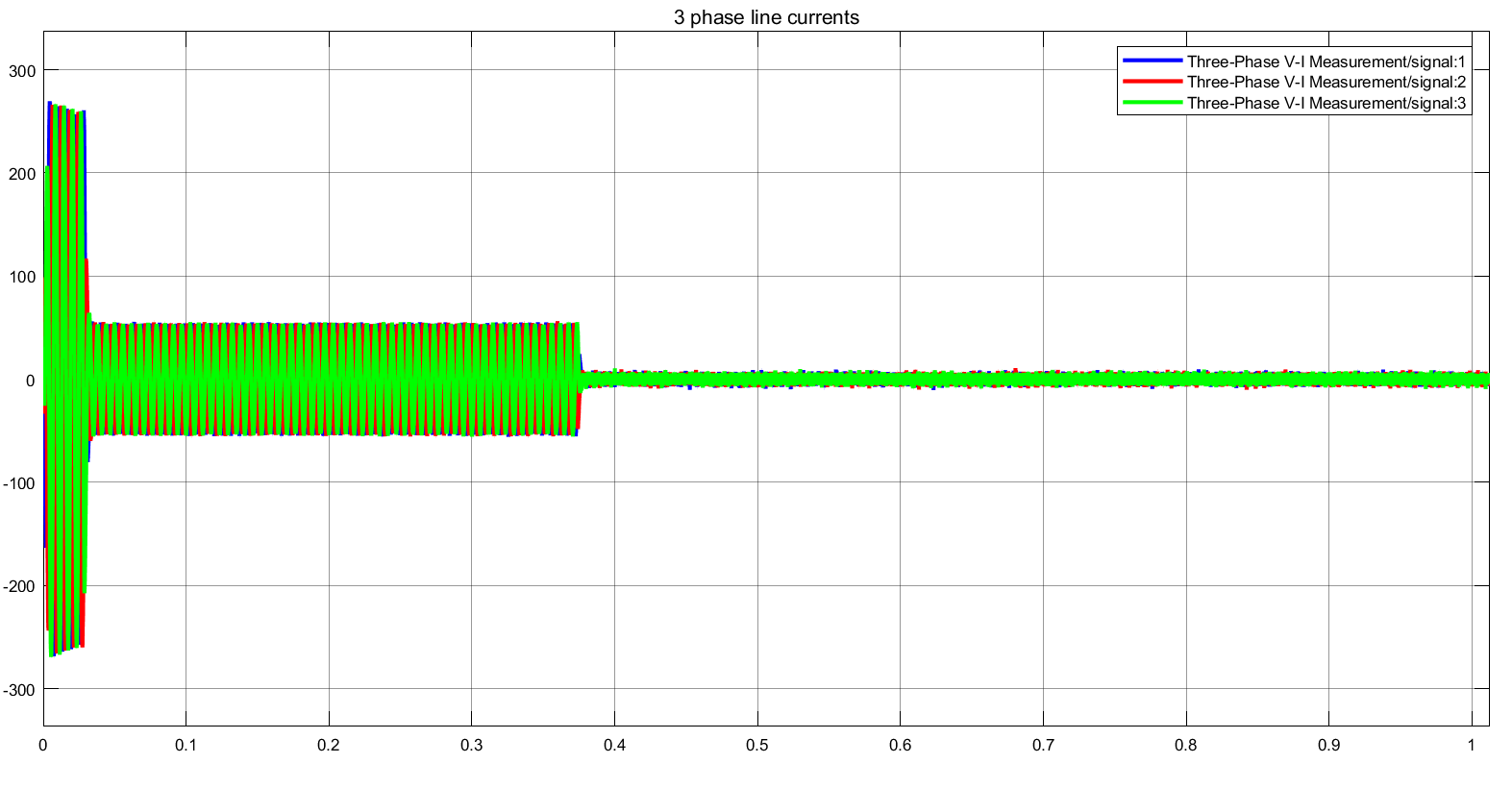


Figure : VABC line currents from a distance

In the figure 24, we can see current changing. It is the same with SPWM technique, but current magnitudes are not the same. In the figure 25, output is, also, zero.

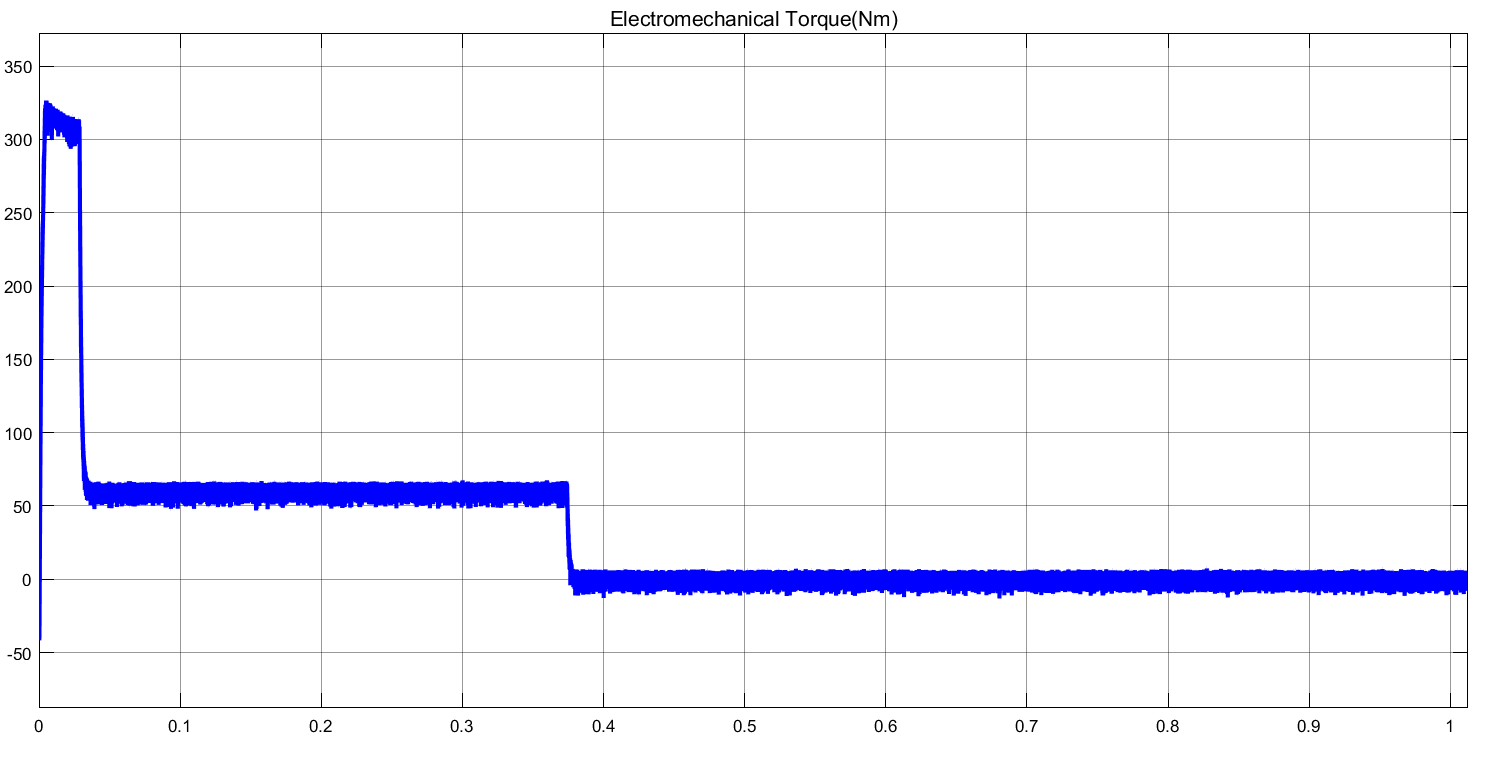


Figure : Electromechanical Torque (Nm) vs time characteristic

2-) The SVPWM technique gives higher level of fundamental voltage as compared to SPWM. The comparison of these two modulations gives the results that SVPWM is the best and most reliable modulation because it enables efficient use of DC voltages and smartly works with vector control thus, gives less Total Harmonic Distortion (THD), better PF, and less switching losses at high frequencies.

3-) In this part, we need to observe 3-phase reference voltages. As these waveforms are square waveform, to observe clearly, we put a low pass filter. As seen in the figure 26, there are huge distortion compared to in the figure 27. Also, Waveforms in the figure 26, looks like triangular. However, waveforms in the figure 27 looks like more sinusoidal. We expected these results since we learned that spwm has huge distortion.

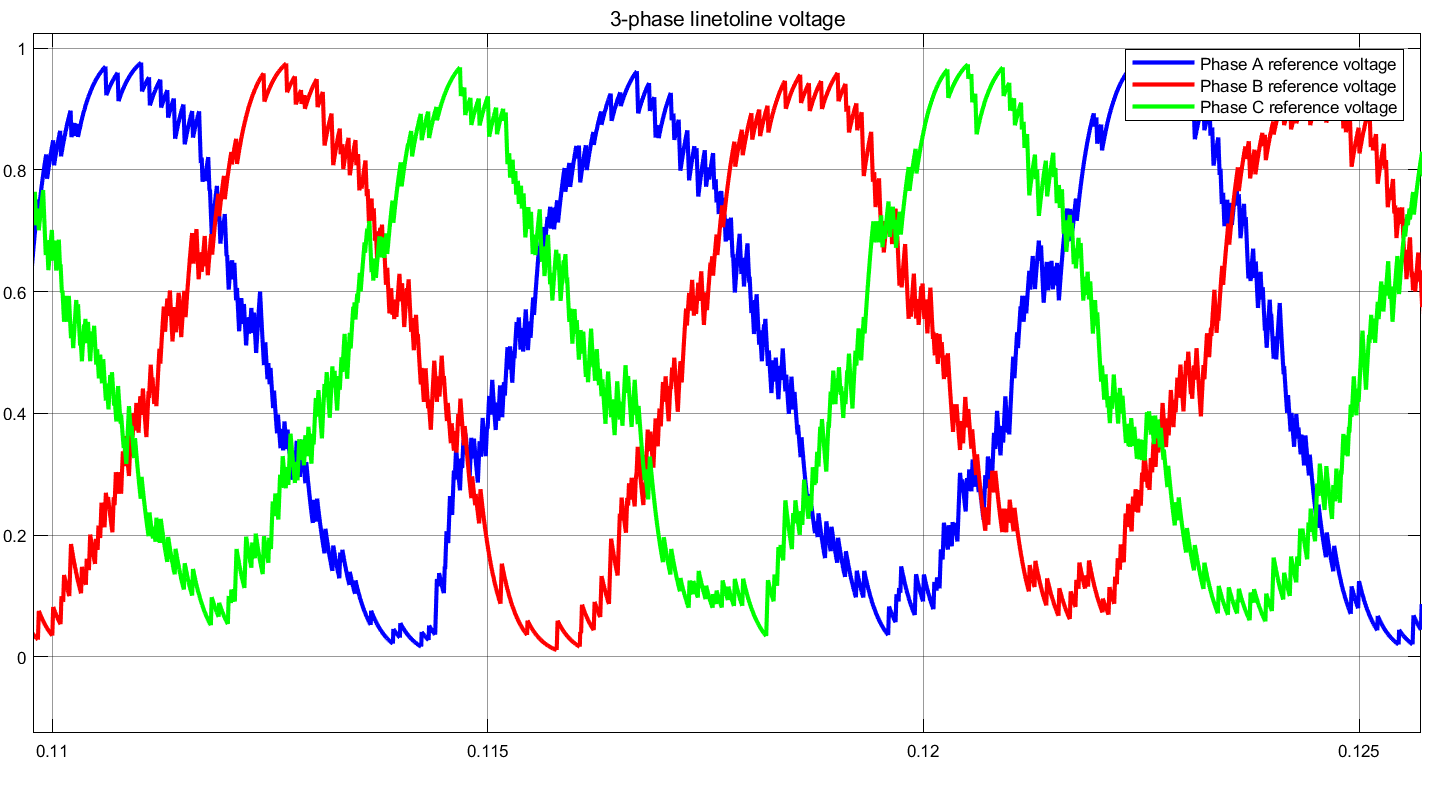


Figure : Sinusoidal PWM phase reference voltages

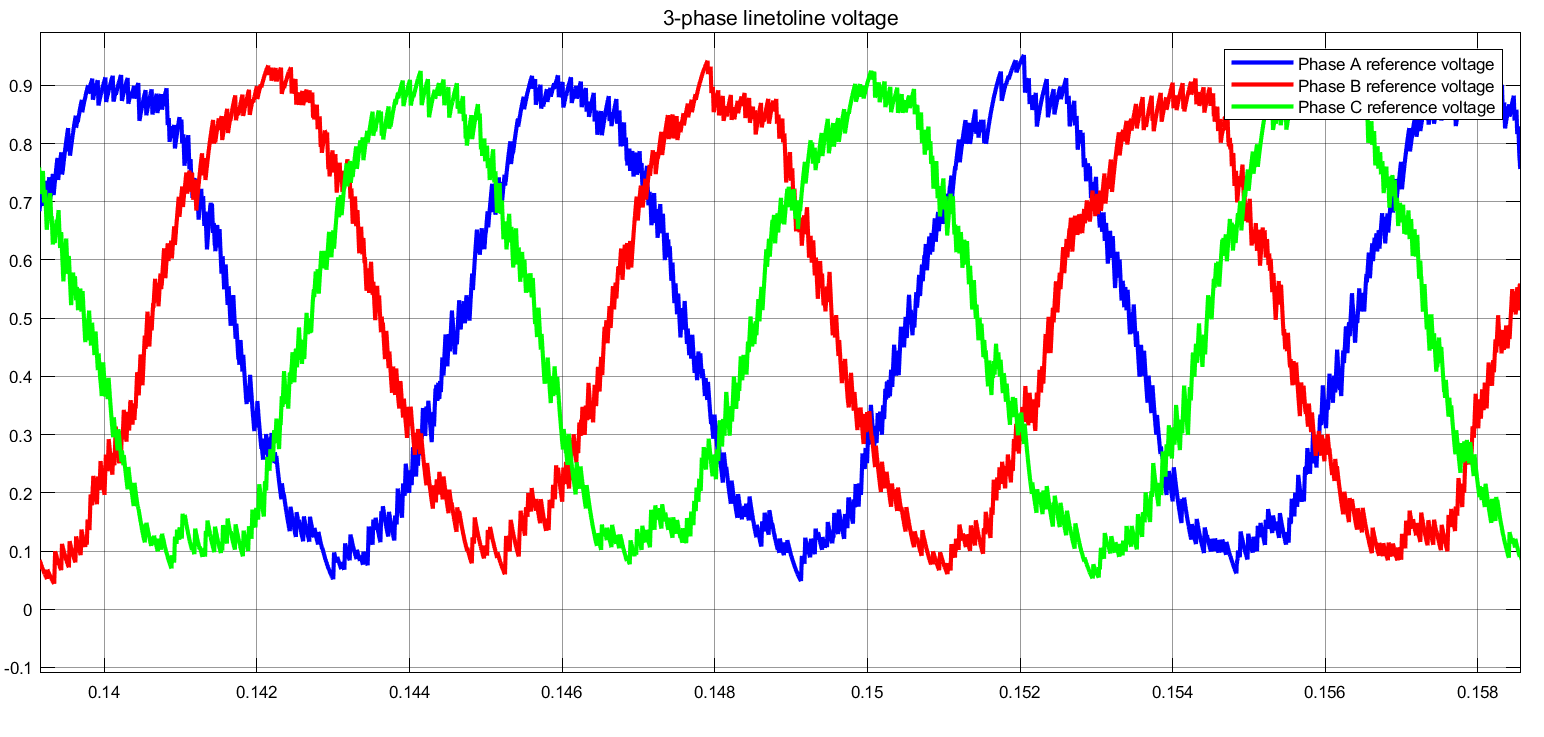


Figure : Space Vector PWM phase reference voltages

**PART D: COMPONENT SELECTION AND VERIFICATION**