Assignment 3 EECE571D

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Assignment Details

A three-phase MMC is connected to a constant DC voltage source on its DC-side, and its AC-side is connected to an infinite bus through an LR filter. The MMC system has the following specifications

- Grid voltage: 4.16 kV (line-to-line, RMS)
- Grid frequency: 50 Hz
- DC-link voltage: 8 kV
- Rated power: 1 MVA
- Number of submodules (SMs) per arm: 4
- Arm inductance: 3 mH
- No arm resistance
- SM capacitance: 5 mF
- Modulation scheme: Level-shifted PWM
  - Carrier frequency: 1650 Hz
- Control mode: GFL PQ control

1 LR Filter Values for the MMC

- $S_{base} = 1$ MVA
- $\omega_0 = 2\pi 50 = 314.16$ rad/s
- $V_{LL,RMS} = 4160$ V
- $Z_{base} = \frac{V_{LL,RMS}^2}{S_{base}} = R_{base} = X_{base} = 17.31\ \Omega$
- $L_{base} = \frac{X_{base}}{\omega_0} = 55.1$ mH

L should be between 10% and 20% of L_{base}. We select $L = 0.15L_{base} = 8.3$ mH and choose $R = L = 8.3$ mΩ.

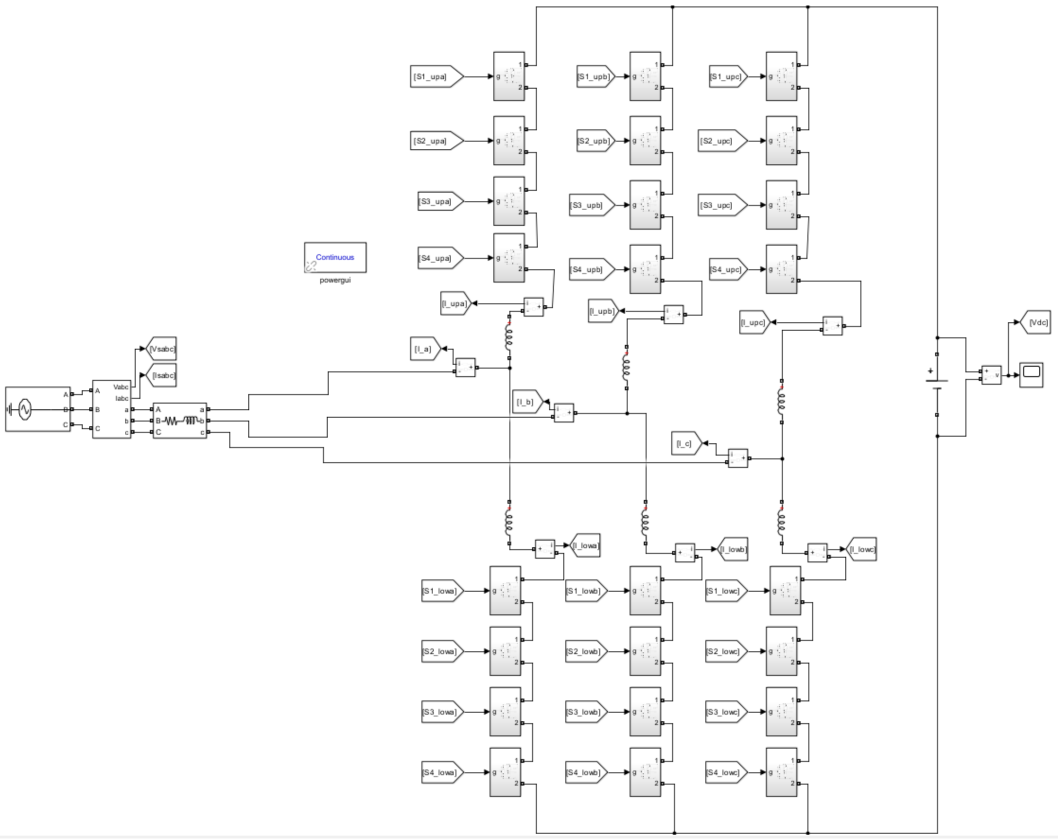


Figure 1: MMC Switching Diagram

2 Full MMC

We implemented GFL PQ control, circulating current control, and SM capacitor voltage balancing control for the MMC, and simulated the converter system. In the beginning, we set both the P^{ref} and Q^{ref} to 0, and subsequently, stepped up P^{ref} to 1 MW. Figure 1 displays the MMC switching diagram implemented in Simulink and Figure 2 displays the PQ control, circulating current control, inner current control, and PLL. The values for the PI controller for the PLL are $k_i = 1.099, k_p = 0.0267$ [V/A], for the current controller $k_i = 5.53, k_p = 0.53$ [V/A], and for the circulating current controller $k_i = 4, k_p = 0$ [V/A]. These values were determined following the procedures discussed in Assignment 1.

The results from the simulation are shown in Figure 3. We can see in Figures 3a and 3b that the d-axis current is tracking the reference both before and after the power step-up. The average q-axis current is tracking slighly above the zero reference before the power step-up, and then slightly below the zero reference after the power step up, but it is within 8 A from the reference. Looking at the real and reactive power from Figure 3c, we see that the real power tracks the power step-up to 1 MW. The reactive power is nonzero due to the inductors used in the model, but remains low, which makes sense according to our PQ control setting Q to zero. Figure 3d shows the three-phase circulating current, which averages around zero A with some noise before the power step-up, and then averages around -50 A after the power step-up and is stable. Figure 3e displays the upper and lower arm currents through phase a at approximately 180 degree phase shift. After the power step-up, the currents increase to accommodate the new power demand. Finally, we can tell that the voltage balancing algorithm is working correctly when we plot the voltages of each submodule in an arm- as in Figure 3f- where we can see that the voltages in each submodule in the upper arm of phase a are all overlapping to meet the power demand of the infinite bus.

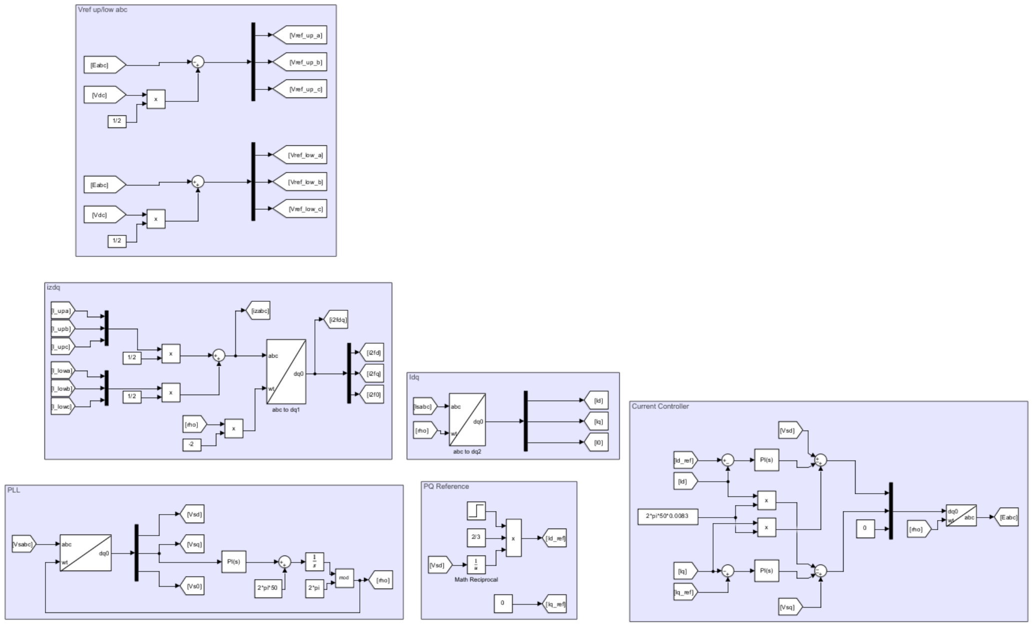


Figure 2: MMC Controller Diagrams

3 No Circulating Current Control

In this section, we omit circulating current control and expect to see much more noise and harmonic oscillations in our measurements compared to the simulation with the circulating current control. The results for the case of no circulating current control are shown in Figure 4. The d-axis and q-axis current control show more harmonics than the previous section, but continue to track the same values. The real and reactive power also looks very similar to the previous section in Figure 4c. Looking directly at the circulating current in Figure 4d, we can see that there are more harmonics than the simulation with the control implementation and the currents in each phase are more out-of-sync. There is not a notable difference in the upper and lower arm currents in phase a from Figure 4e compared to the simulation without the circulating current control, which makes sense as the regular current controller is working in the same way. Finally, we see in Figure 4f that the voltage balancing is still working, as the voltages across the submodules in the upper arm of phase a are perfectly overlapping.

4 No Voltage Balancing

Finally, omit voltage balancing from the system (but retain circulating current control and all other controllers). In place of voltage balancing, we just insert the submodules in their numerical order depending on the number of submodules determined by the PWM i.e. n=2, SM1 = 1, SM2 = 1, SM3 = 0, SM4 = 0 or n=3, SM1 = 1, SM2 = 1, SM3 = 1, SM4 = 0. By excluding the voltage balancing, we would expect that the system is eventually not able to supply the necessary power to the infinite bus as the capacitor in the first submodule would be reaching its maximum capacity and the capacitor in the fourth submodule would barely be used. This is what we end up seeing in the results in Figure 5. Looking at the d-axis and q-axis current tracking in Figures 5a and 5b, we see that the d-axis control does not track its reference for very long after the disturbance. In Figure 5c, this reflects in the system not being able to provide enough power to maintain real power at 1 MW. The three phase circulating current and upper/lower arm currents in phase a from Figures 5d and 5e remain fairly stable around their expected values, as the circulating current control and inner current control remain implemented. The result of the omission of the voltage balancing is most noticeable in Figure 5f, where we see that the voltages of the submodules begin to diverge in accordance to their submodule number and the capacity of submodule 4 is no longer able to contribute enough to maintain

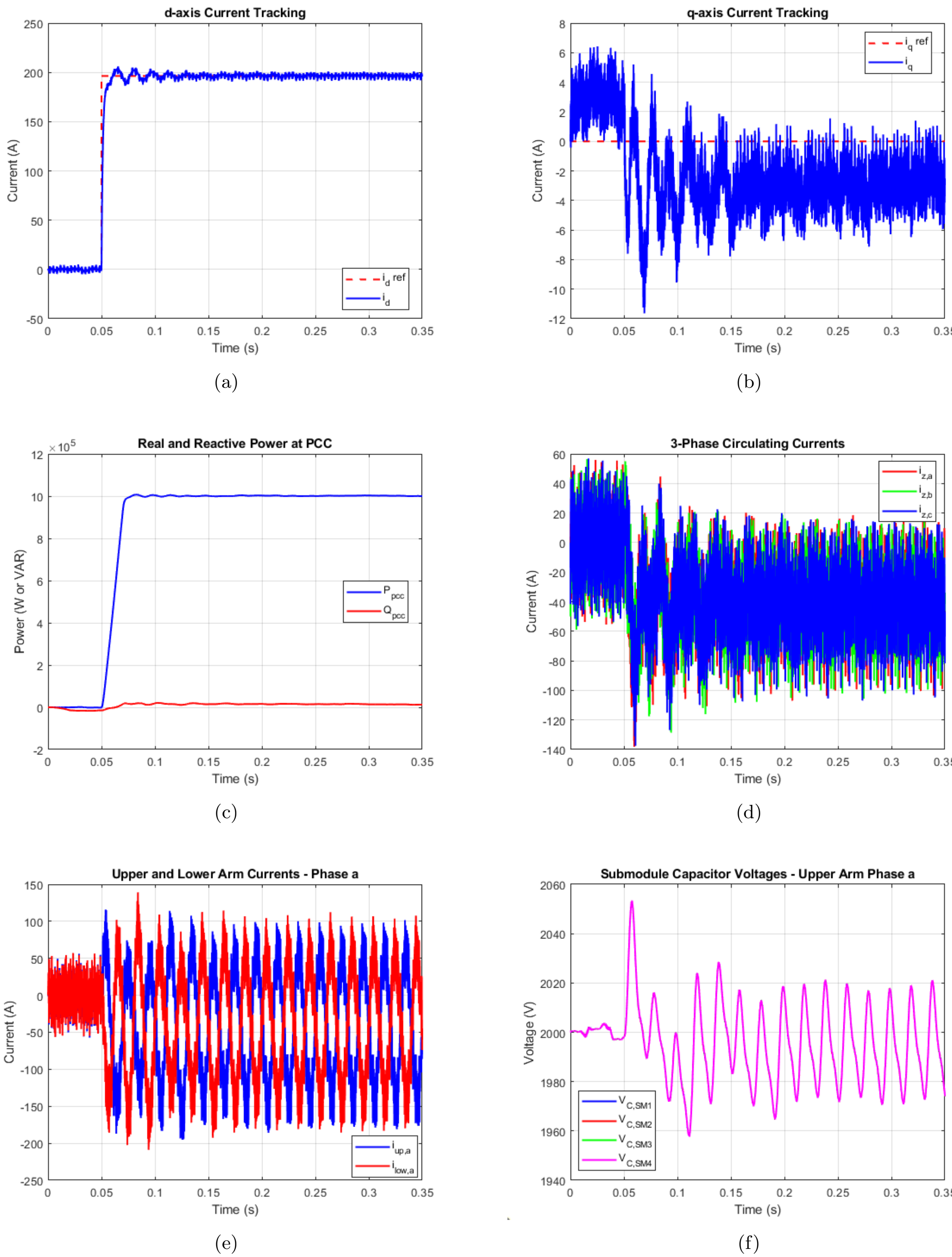
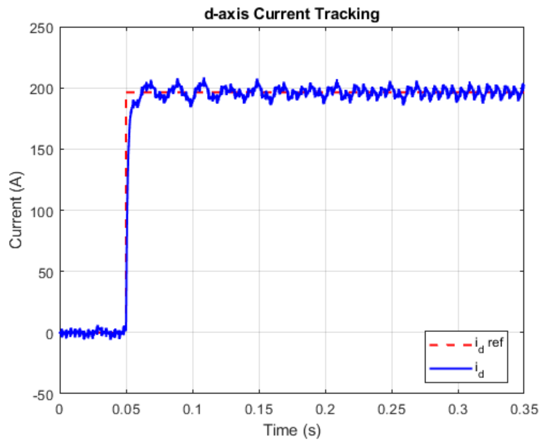
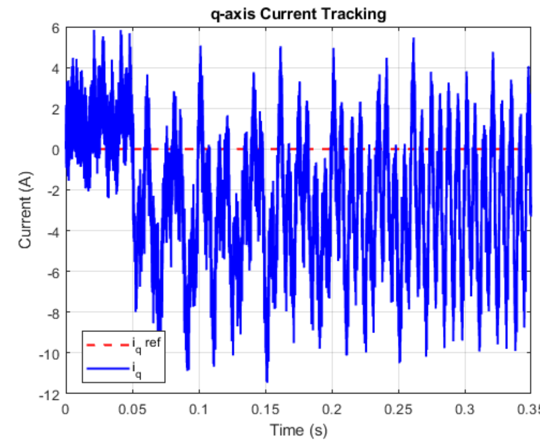


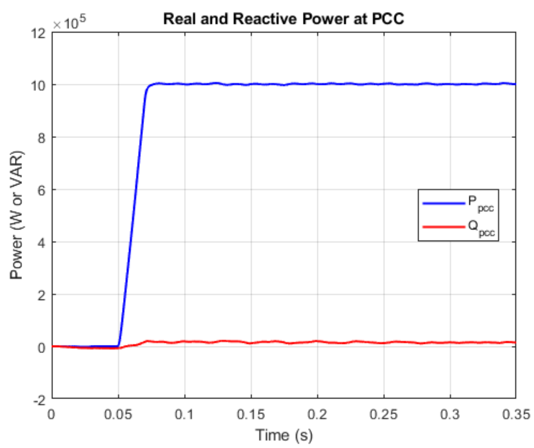
Figure 3: Question 2 MMC control system performance



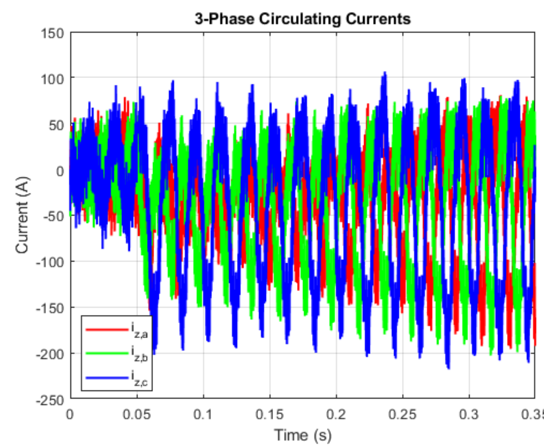
(a)



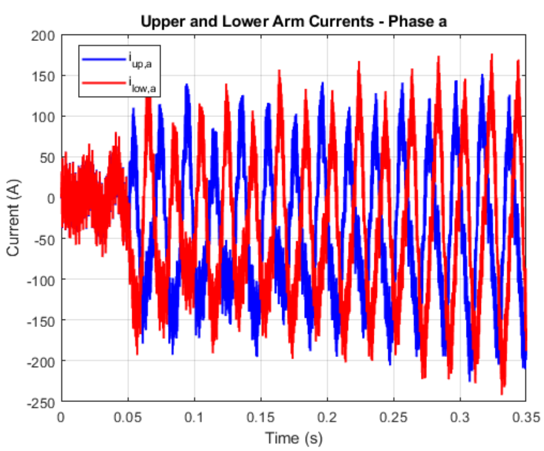
(b)



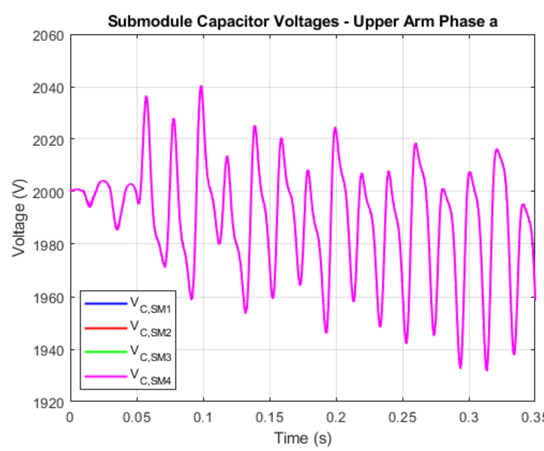
(c)



(d)



(e)



(f)

Figure 4: Question 3 MMC control system performance without circulating current controls

the power demand at 1MW due to it barely being called on.

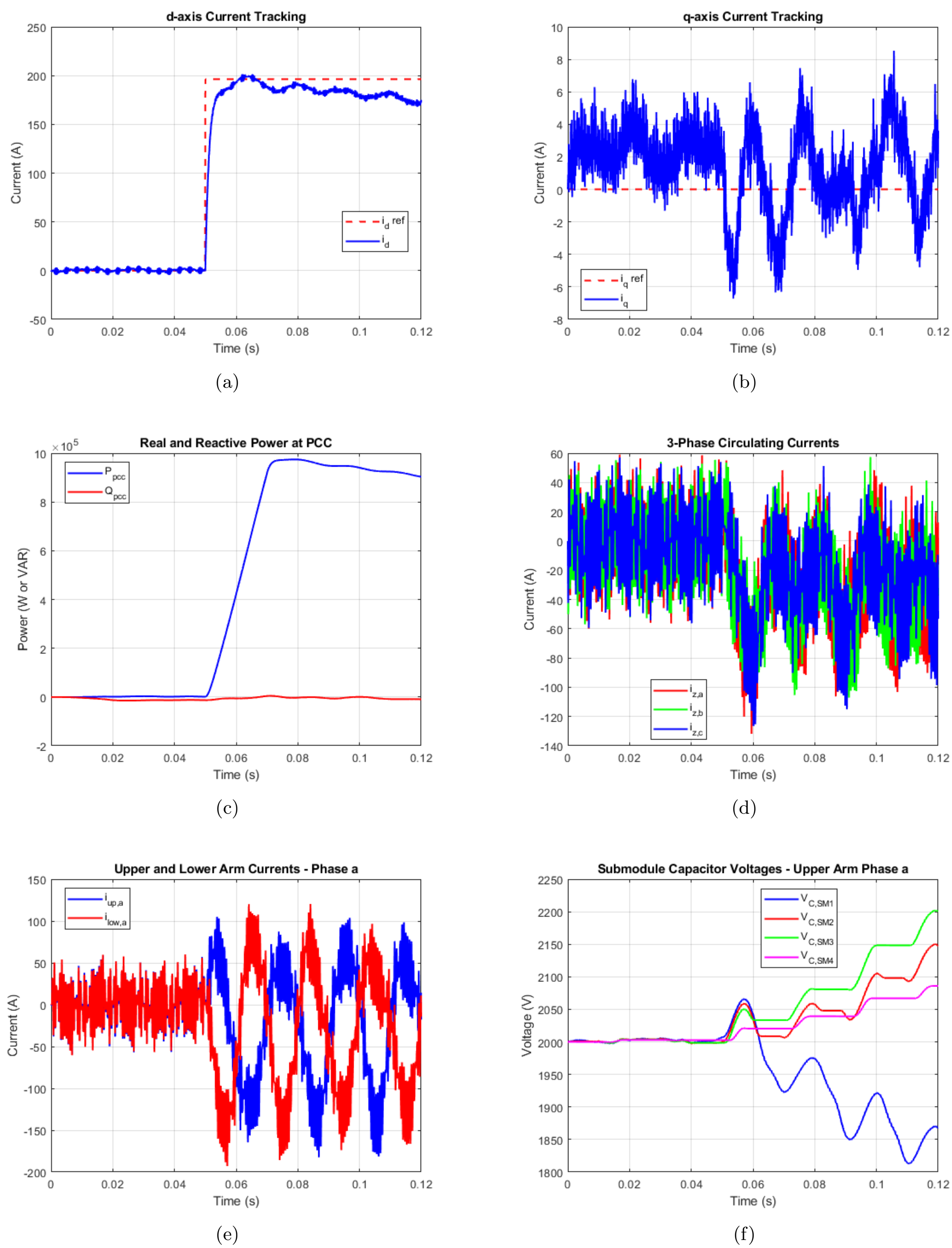


Figure 5: Question 3 MMC control system performance without voltage balancing