Design of a bidirectional power charger to serve for smart crowd-based grid stabilisation

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1 Introduction

The growing need for electricity is putting an increasing burden on the environment. To meet the goal of achieving net-zero emissions by 2050, countries are now prioritizing the use of renewable energy sources. However, integrating a higher proportion of renewable energy into the power system will pose additional challenges, considering the existing issues with aging infrastructure and the rising demand for electricity.

System inertia is a crucial parameter for the synchronized operation of modern power systems. The inertia present in traditional rotating masses of synchronous generators and turbines helps regulate the system's frequency in response to imbalances in power supply and demand. This means that any frequency deviation is compensated by this rotating mass. From the perspective of the power system, decentralized renewable electricity generation acts differently to traditional centralized facilities. These sources are often intermittent and lack the ability to contribute to the system's inertia due to their disconnection from the grid.

Thus, new strategies for converter connected generation are developed to combat this problem by providing virtual inertia. In this context, the design of a bidirectional power charger for smart crowd-based grid stabilization emerges as a promising solution. This report presents the design principles and key features for an active front-end converter of such a charger, focusing on its ability to balance power supply and demand while ensuring grid stability. The bidirectional power charger serves as a crucial link between the grid, electric vehicles, and renewable energy sources. It enables electric vehicles to not only consume energy from the grid but also act as energy sources, injecting power back into the grid when needed to maintain constant frequency and voltage.

This paper presents closed loop control diagrams for such systems with hybrid current control architecture to regulate the grid voltage and frequency. The results of a three phase three leg system, and three phase four leg system have been simulated for different scenarios. The results show that the hybrid current control system has increased advantage in bringing back the grid to the desired operating values quickly with only a maximum frequency deviation of 0.25 Hz. The use of droop control and grid-forming architecture also improved the stability of the system. However, the graphs for the 4-leg system did not turn out to be perfectly smooth due to issues with tuning the parameters.

The report also presents the hardware topology of a PCB circuit. This board is connected to an LCL filter and load, and then tested at low voltages. The three phase output agrees with the simulation results and hence proves that the designed prototype works well. The next steps to this project will be to test a complete three-phase closed loop system, and then implement it at high voltage.

2 Approach

Figure 1 shows a high level overview of the control architecture. It consists of an outer loop with droop control, frequency and voltage support. This is then connected to an inner loop which has cascaded PI controllers. This inner loop is essential to prevent damage to the converter caused by overcurrent. The VSG operates as a black-box, enabling the transfer of active and reactive power between the main grid and its terminals.

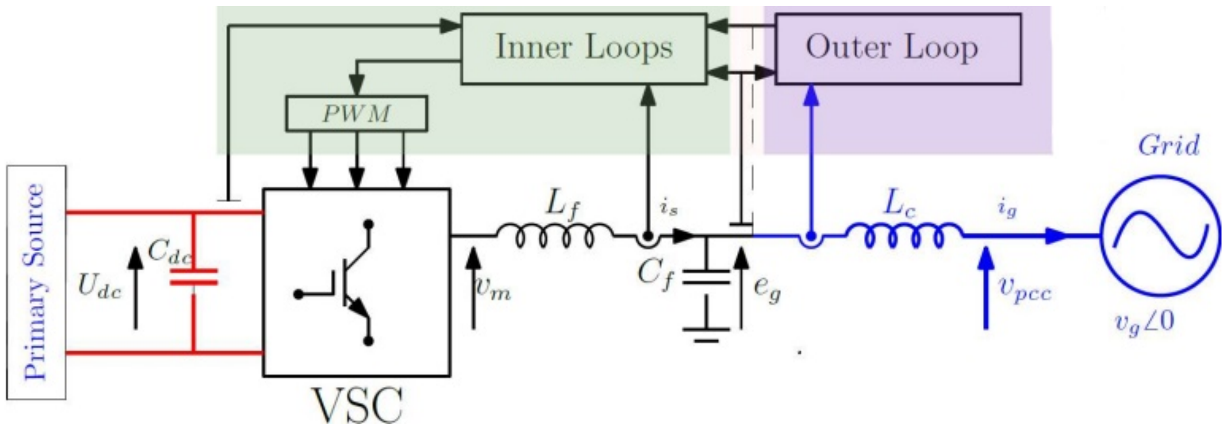
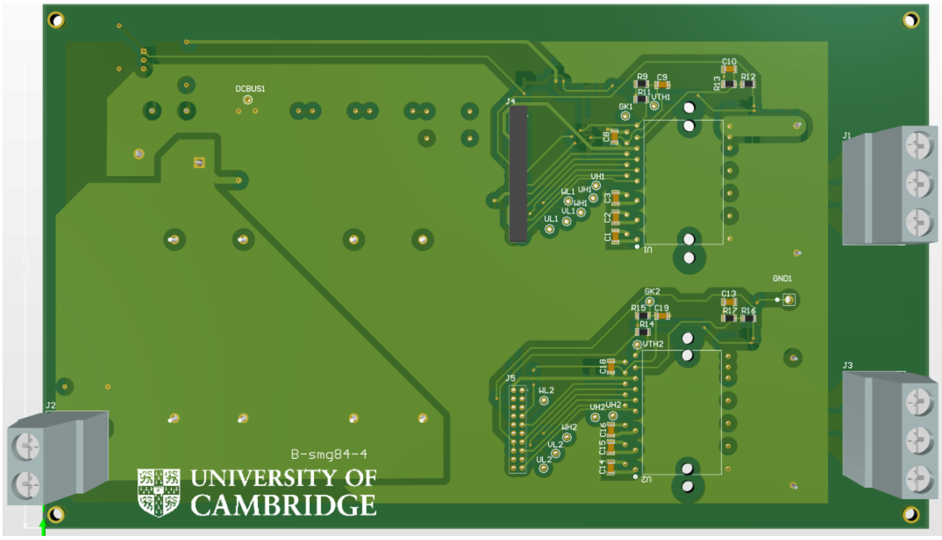
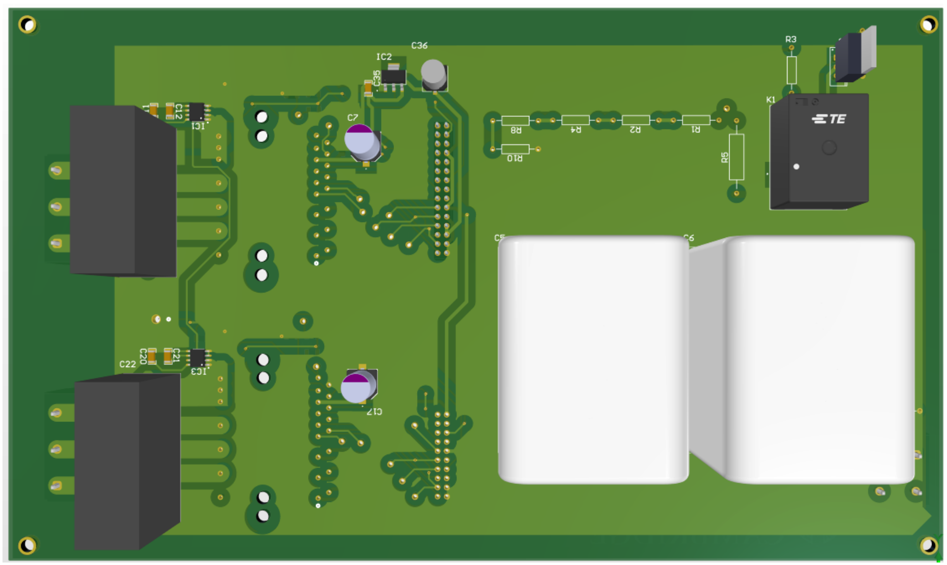


Figure 1: Control Architecture

Figure 2 shows the 3D view of the PCB design. We took care to set a clearance of at least 2.3 mm between different circuit groups, with appropriate widths of the track to withstand large currents. We also added a LCL filter. In order to avoid resonance problem, the resonance frequency of the filter was set to lie between $10f_{\mathrm{g}}$ and $0.5f_{\mathrm{sw}}$.



(a) Front side of PCB layout



(b) Back side of PCB layout

Figure 2: 3D view of PCB

3 Main Results

We simulated the load voltage and current, which is displayed by Figure 3. The peak value of the load voltage is also equal to 250 V, with a peak load current value of 1.5 A. The THD for the load measurements was then calculated to be equal to 0.16% for both voltage and current. Although there is no national standard for THD, according to IEEE Standard 519, the THD measurement should be less than 5% [1]. Since the THD is less than 5% in both cases, it can be concluded that that the system has high power factor, low peak currents, and high efficiency.

The nominal grid frequency in the UK is 50 Hz. Due to historical reasons, all electrical

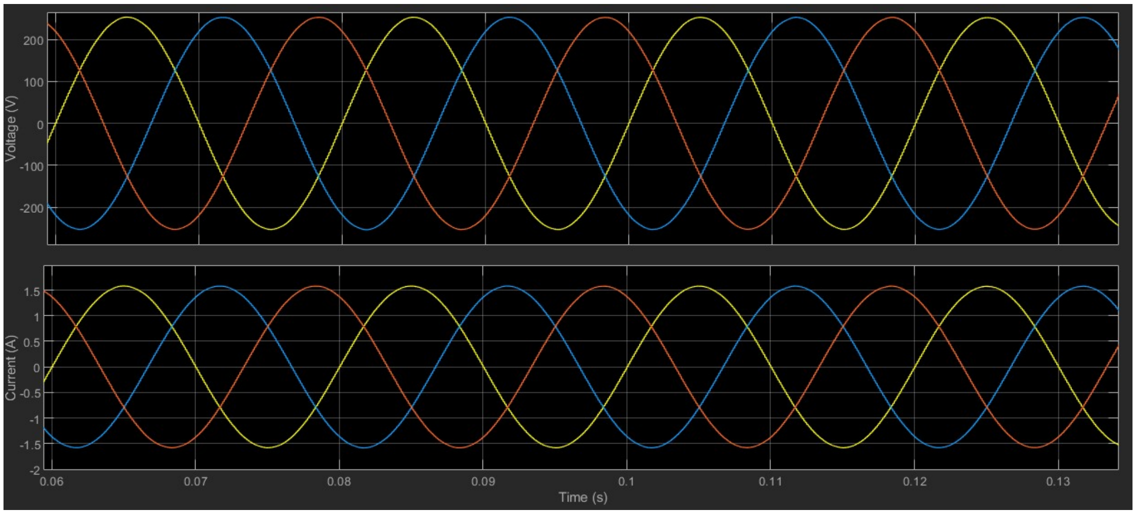


Figure 3: Simulation of load voltage and current

appliances in the UK are designed to work at this frequency with very little tolerance in deviation. Thus, it is very important to constantly monitor the frequency and ensure that the frequency is within one percent (0.5 Hz) of 50 Hz [2].

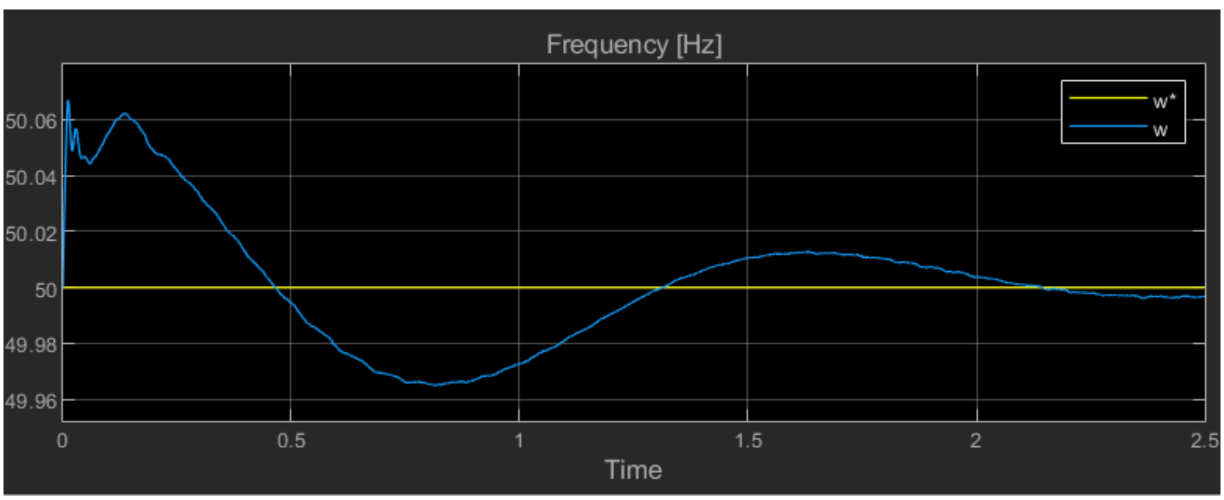


Figure 4: Simulation of VSG frequency

Figure 4 shows the target frequency of 50 Hz and the frequency of the VSG system. Initially, the frequency deviates to a maximum of 50.06 Hz. Then, at 0.125 s, the droop controller is activated. This brings the frequency back to the desired reference frequency. We also designed a printed circuit board. Then, the PCB board was tested using an LCL filter with an input DC of 5 V and 10 Ω resistor load for each phase. Figure 5 shows the output of the three phases measured at the load with respect to ground.

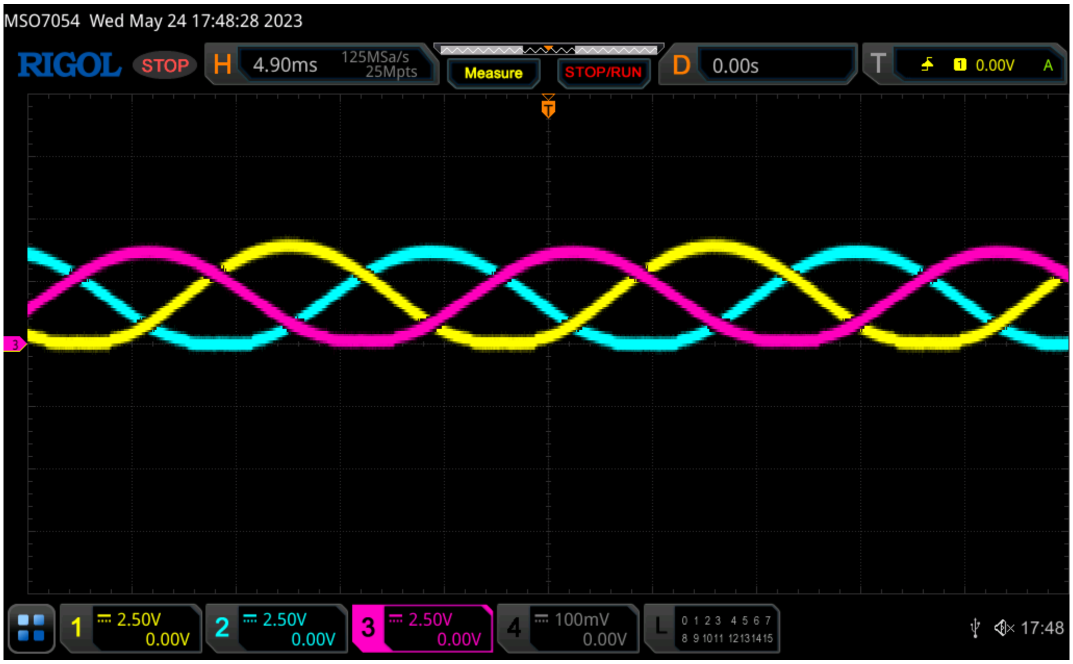


Figure 5: Three phase output at load for an input voltage of 5 V

4 Conclusion

The control loop diagrams and simulations presented in this report demonstrate the charger's ability to maintain stability. It responds well to being connected to load as well as directly to the grid. The simulation model uses a hybrid current control system consisting of virtual impedance and current saturation to maintain the voltage and current at constant sinusoidal levels. The 3-phase system performed very well with a total harmonic distortion in the grid voltage of just 0.3%. The maximum frequency deviation was also up to 50.06 Hz. These findings validate the effectiveness of the proposed design in mitigating frequency deviations and providing voltage stability.

The hardware implementation of the active front-end converter through PCB design, coupled with thorough testing, guarantees its functionality and reliability. Safety mechanisms integrated into the design protect against electrical faults, overcurrent, and overvoltage conditions, ensuring user safety and equipment protection. The PCB was tested for using a simple open-loop control system at voltages below 60 V, and it performed as expected from simulations. We also tested the voltage sensor for a single phase design in a simple closed loop model. The results agreed well with the simulation and thus proved that the closed loop model works.

However, further research and development efforts are necessary to refine the design, validate its performance on a larger scale, and address technical and regulatory challenges associated with the widespread deployment of bidirectional power chargers. The simulation needs to be tuned well for a 3-phase 4-leg system as currently, the THD of this is 40 times higher than the 3-leg system. The hardware also needs to be tested in a three-phase closed-loop system and then at high voltage.

In conclusion, the bidirectional power charger represents a significant step forward in achieving grid stabilization and maximizing the potential of renewable energy sources. Its implementation has the potential to revolutionize the way we consume and produce electricity, empowering individuals to participate in creating a greener and more resilient energy system.

References

[1] I. Power and E. Society, *Ieee recommended practice and requirements for harmonic control in electric power systems*, 2014. [Online]. Available: https://edisciplinas.usp.br/pluginfile.php/1589263/mod_resource/content/1/IEE%5C%20Std%5C%20519-2014.pdf.

[2] N. G. ESO, *What is frequency?: National grid eso*, 2023. [Online]. Available: https://www.nationalgrideso.com/electricity-explained/how-do-we-balance-grid/what-frequency.