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Military Fuel Cell Based Vehicles: Modular Power DC-DC Converter System

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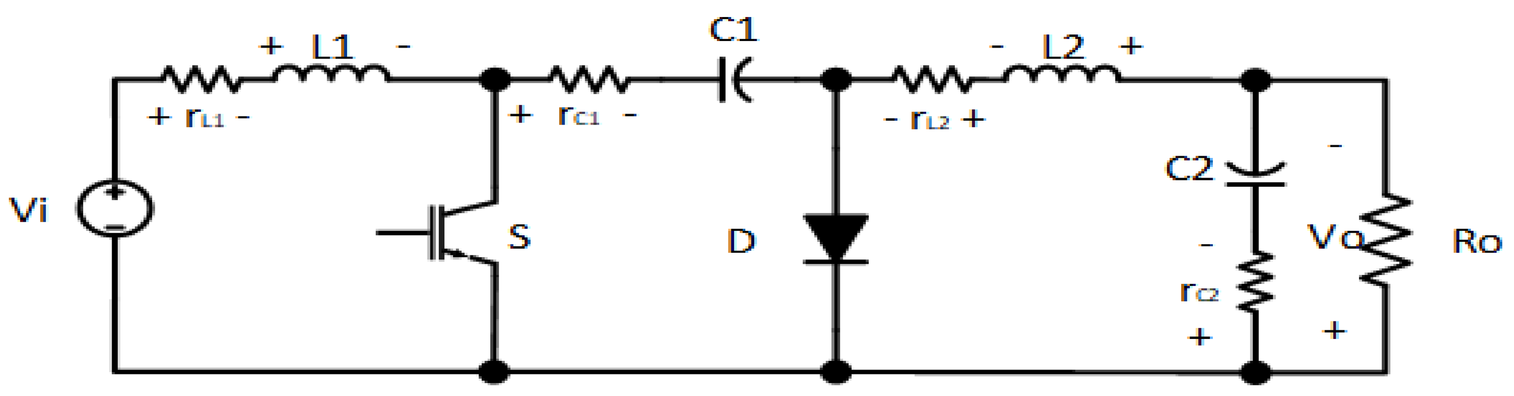
Abstract

Electric Vehicles (EVs) have attracted researchers' attention to further develop and enhance this strategic area. Compared with fuel-based vehicles, EVs are more demanded nowadays due to their high performance and new modern features. Integrating renewable energy sources such as PV and fuel-cells to EVs expands this technology's research area to increase system reliability. Fuel-cell electric vehicles (FCEVs) introduce more challenges to the researchers to integrate this type of renewable energy source to charge the EV battery while driving. In this paper, design and control of a modular DC-DC converter for fuel-cell based EVs. A maximum power point tracking (MPPT) technique is used to extract the FC's maximum power. Since the FC produces a relatively low voltage, a high gain DC-DC converter is required to step up the voltage to the battery's rated voltage. This can be achieved through an input-parallel output-series Cuk-based DC-DC converter. The system small-signal model and control are presented to ensure equal current sharing at the input side while maintaining equal output voltage sharing even with a mismatch in the system module. The presented concept has been elucidated through simulation using Matlab/Simulink platform.

System Design

- State-space model (SSM), this model represents the converter using the following equations: $\dot{x}$=Ax+Bu y=Cx+Du
- To ensure accurate results and realistic design, converter modelling considers non-ideal conditions of the converter components.
- Inductor resistance r_L, (ESR) r_c, On-state switch resistance r_s and on-state diode resistance r_D



Proposed Design

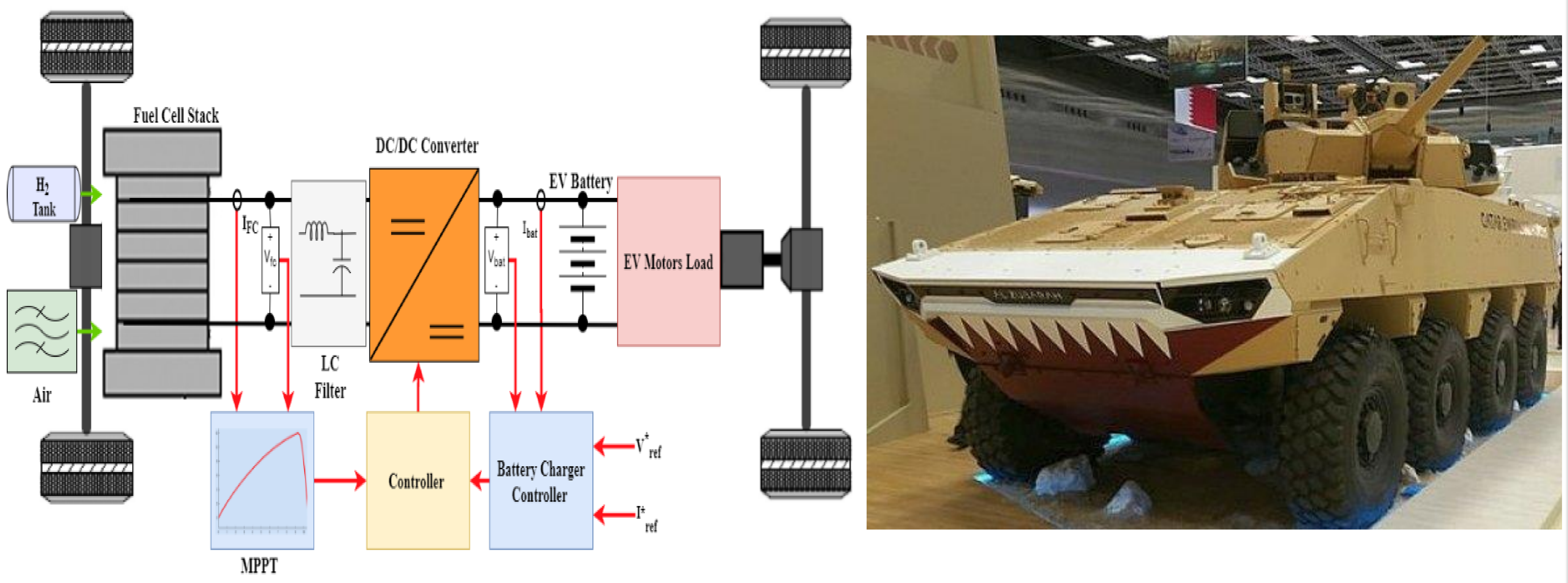


Figure 1. The typical configuration of fuel-cell based military vehicle

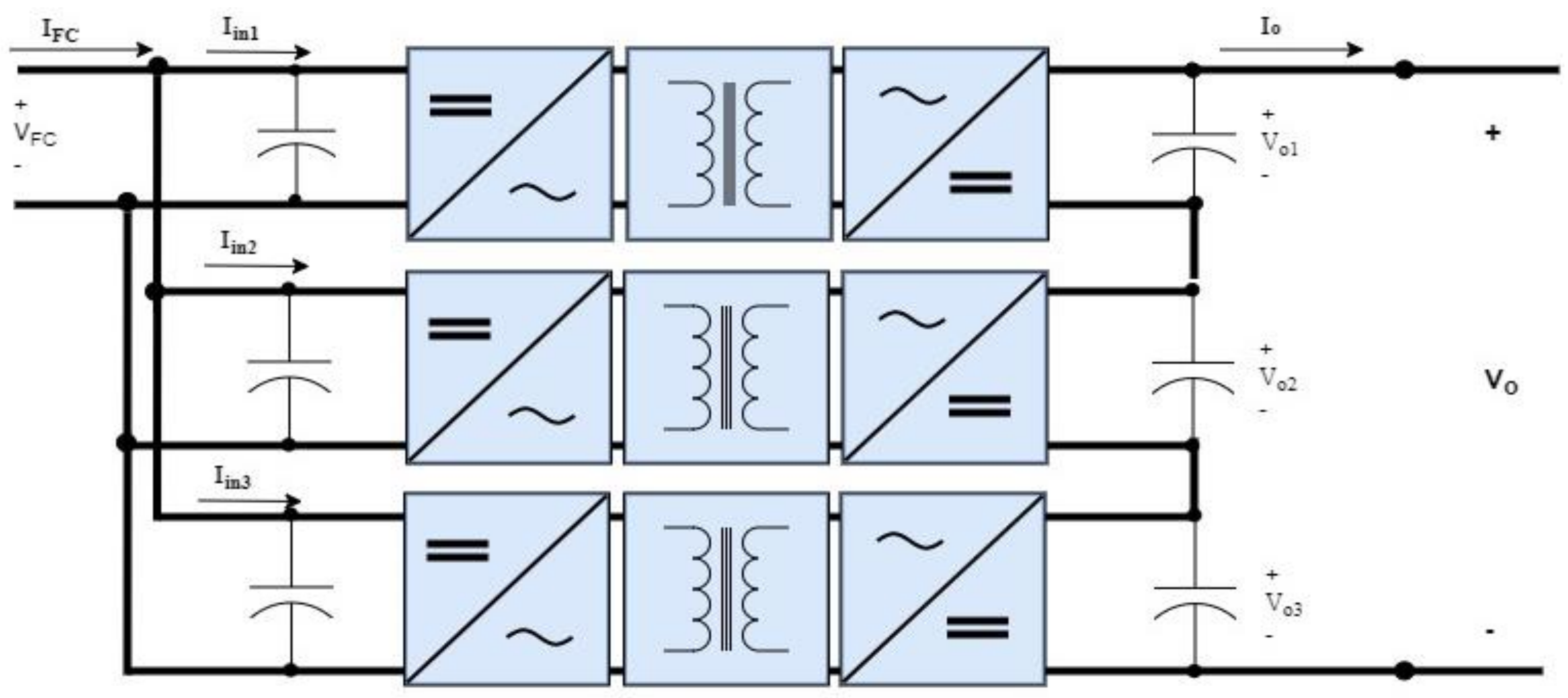


Figure 2: IPOS topology

Simulation Results

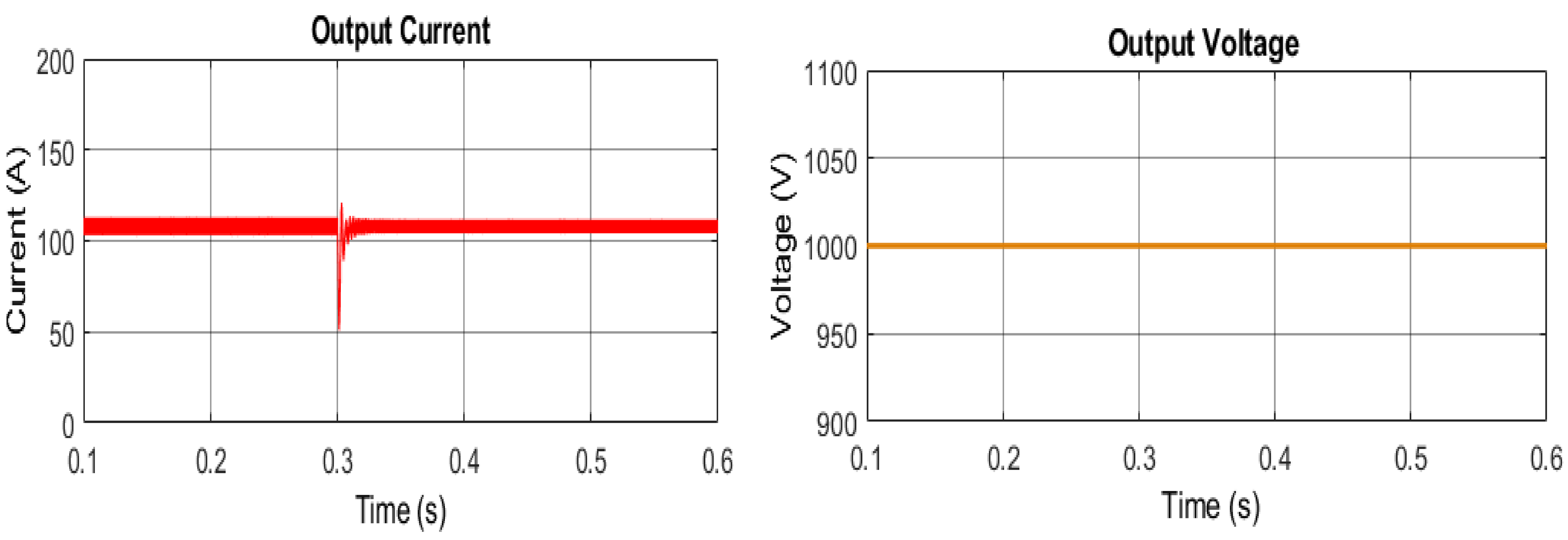


Figure 3: Overall system outputs, output current, and output voltage. One converter is removed at t=0.3s.

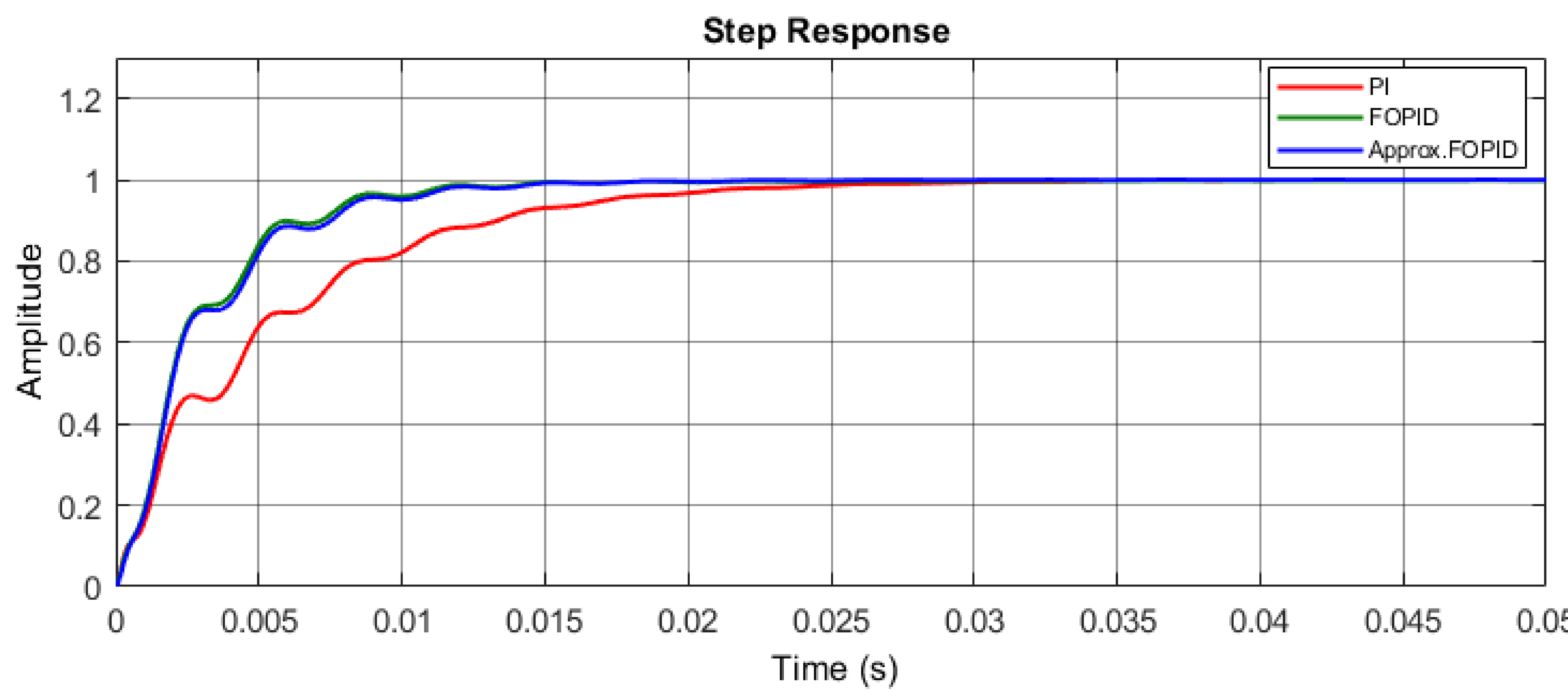


Figure 5: System step response using PI,FOPID and approximated FOPID

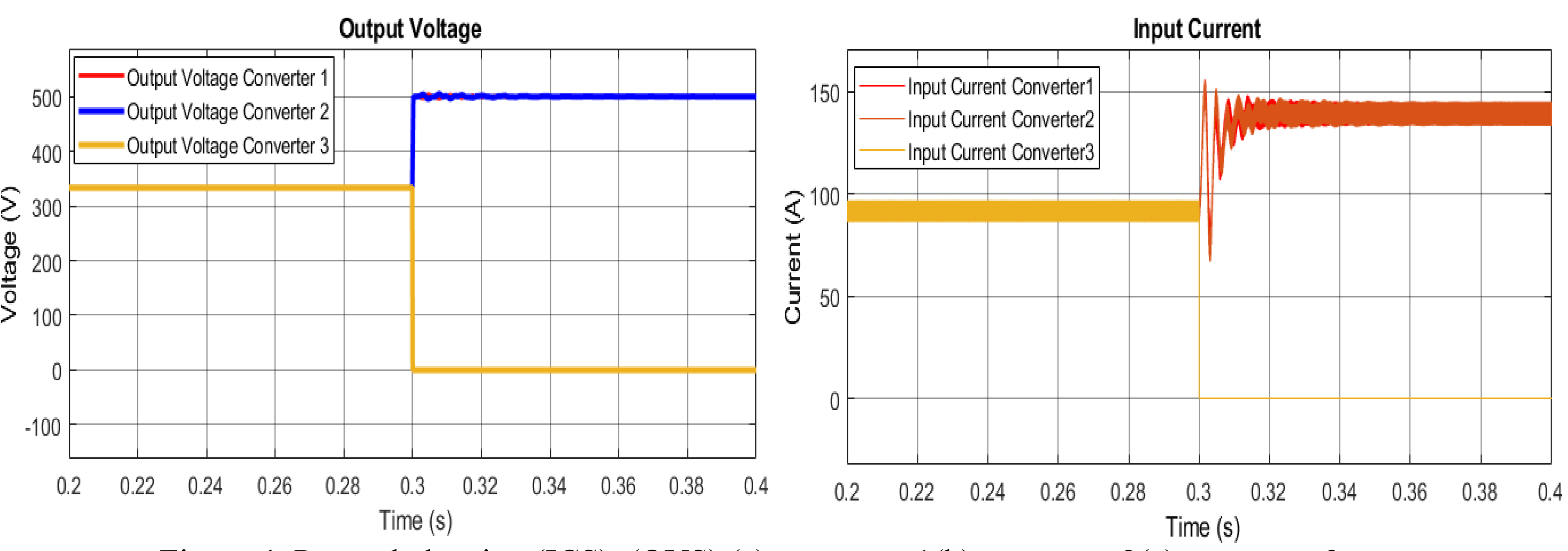


Figure 4: Power balancing (ICS), (OVS),(a) converter 1(b) converter 2(c) converter 3

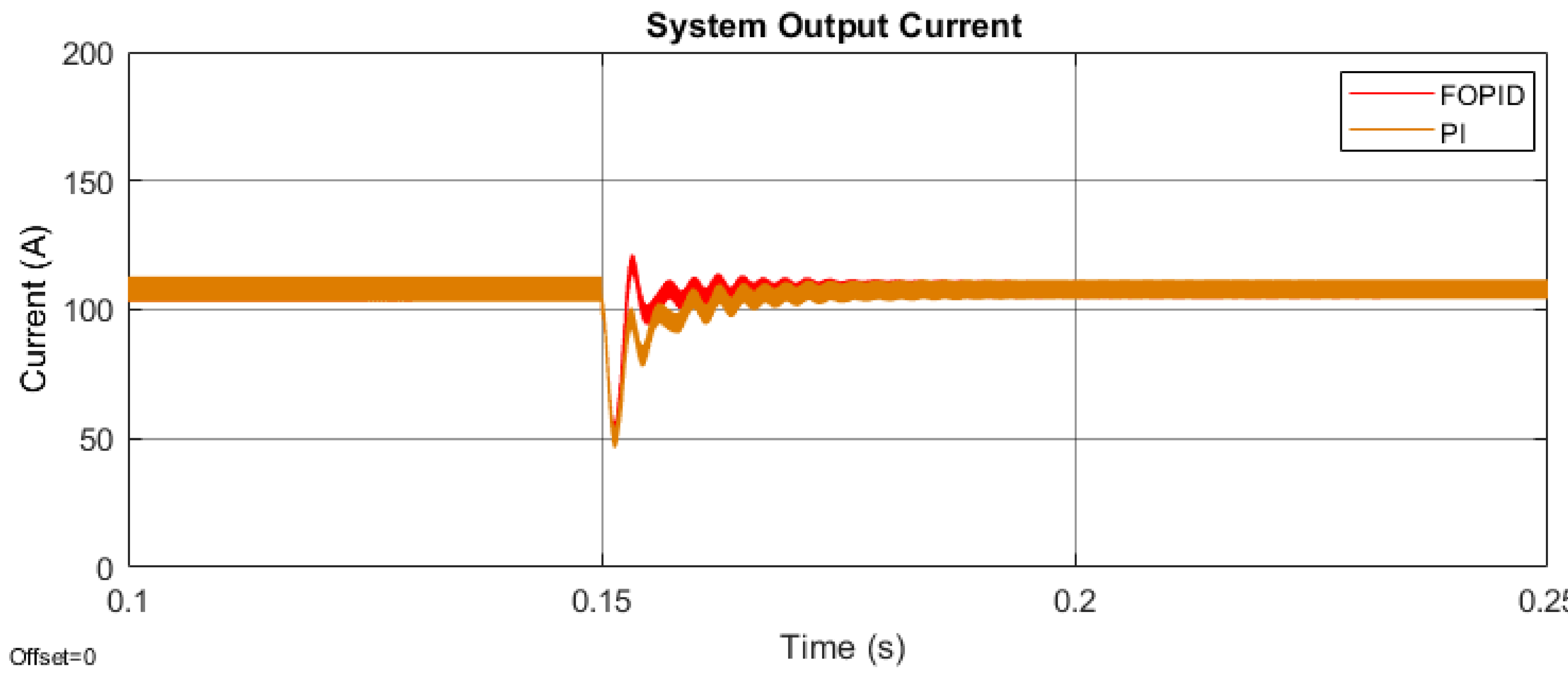


Figure 6: System output Current using PI and FOPID controller

Conclusion

- Highly efficient DC-DC converter was designed based on the fuel cell requirement such as low input ripple current and handling high power current.
- Modular topology was implemented using input-parallel-output-series configuration which will help in increasing the gain and system switching frequency that affect converter sizing.
- Equal power sharing was achieved by designing a proper control for the designed converter.
- Small signal model was obtained to design an accurate controller for the system considering parasitic elements such as inductor resistance r_L, (ESR) r_c, on-state switch resistance r_s and on-state diode resistance r_D
- Fractional order PID controller was designed and analyzed due to its advantages over the conventional controllers

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References

[1] A. Kolli, A. Gaillard, A. De Bernardinis, O. Bethoux, D. Hissel, and Z. Khatir, "A review on DC/DC converter architectures for power fuel cell applications," Energy Convers. Manag., vol. 105, pp. 716–730, 2015, doi: 10.1016/j.enconman.2015.07.060
[2] B. Somaiah and V. Agarwal, "Recursive estimation-based maximum power extraction technique for a fuel cell power source used in vehicular applications," IEEE Trans. Power Electron., vol. 28, no. 10, pp. 4636–4643, 2013, doi: 10.1109/TPEL.2012.2236688.
[3] F. L. Tofoli, D. de C. Pereira, W. J. de Paula, and D. de S. Oliveira Júnior, "Survey on non-isolated high-voltage step-up dc-dc topologies based on the boost converter," IET Power Electron., vol. 8, no. 10, pp. 2044–2057, 2015, doi: 10.1049/iet-pel.2014.0605.
[4] M. ElMenshawy and A. Massoud, "Modular Isolated DC-DC Converters for Ultra-Fast EV Chargers: A Generalized Modeling and Control Approach," Energies, vol. 13, no. 10, p. 2540, May 2020, doi: 10.3390/en13102540
[5] M. Sagar Bhaskar et al., "Survey of DC-DC Non-Isolated Topologies for Unidirectional Power Flow in Fuel Cell Vehicles," IEEE Access, vol. 8, pp. 178130–178166, 2020, doi: 10.1109/access.2020.3027041
[6] S. K. Han, H. K. Yoon, G. W. Moon, M. J. Youn, Y. H. Kim, and K. H. Lee, "A new active clamping zero-voltage switching PWM current-fed half-bridge converter," IEEE Trans. Power Electron., vol. 20, no. 6, pp. 1271–1279, 2005, doi: 10.1109/TPEL.2005.857525.