Short Bio – Dr. Simone Gelmini:

Simone Gelmini is a postdoctoral researcher in the GEAR Lab, Department of Mechanical Engineering at MIT. In February, he graduated with a PhD in information technology at Polytechnic Institute of Milan, Italy, where he also received his BS (2013) and MS (2015) degrees in Automation and Control Engineering. Before starting his PhD, he was a visiting research assistant at the International Center for Automotive Research (ICAR) at Clemson University. Simone has been doing research as undergraduate and graduate level for the past five years. His research interest includes control system and algorithm development, time series classification and forecasting, and their application in water desalination and the automotive industry.

Abstract:
The Global Engineering and Research (GEAR) Lab aims to provide low-cost, high-recovery desalination technology to water stressed communities. GEAR Lab has shown that batch Electrodialysis Reversal (EDR) is an enabling technology for rural villages in India. For off-grid applications, EDR can be paired with photovoltaic (PV) arrays, which limit available power at some hours of the day. Most recently, GEAR Lab has investigated how to tune the control actions of PV-EDR systems (i.e. voltage and flow rate) to increase solar power utilization and maximize desalination rate, which in turn reduces capital cost. By analyzing how the electrical and pumping power affects the desalination rate, we derived a time-variant control policy that adjusts the two variables in real time to maintain a high limiting current density, and thus applied current density.

GEAR Lab's work at BGNDRF has validated the time-variant operation of batch PV-EDR, demonstrating maximized solar power utilization while lowering the levelized cost of water (LCOW) as compared to conventional PV-EDR systems and on-grid RO systems commonly used today in India. Results of the testing at BGNDRF have also provided valuable insights for further developments. In fact, weather uncertainty leads to a conservative design, which is intrinsically suboptimal. Energy buffers, such as battery packs, are traditionally added to decouple the uncertain power source with the demand in renewable-energy applications. Following this approach, PV-EDR systems were traditionally equipped with expensive, large battery packs to secure sufficient energy for overnight operations. GEAR Lab's experimental work showed a 92% reduction in battery capacity needed by using time-variant PV-EDR control theory as compared to conventional PV-EDR operation. However, batteries cannot be removed entirely; for time-variant control operation, battery power is necessary at batch startup, when the estimate of the stack current is less accurate, and thus the voltage controller overestimates the power required. Additionally, on-site experiments at BGNDRF elucidated that directly coupling PV panels and EDR reduces the system efficiency, as the desalination-specific energy consumption increases nonlinearly with the system's power consumption. In this limited-power setting, batteries become necessary to increase the system efficiency and make the best use of the power available.

We have also created a power management controller to balance low system cost and high system reliability by using the smallest battery possible to reshape the consumption power profile. This

controller minimizes specific energy consumption when producing water using energy stored in batteries, and provides additional power in the case of low irradiance days. This controller, acting as supervisor, optimizes the use of batteries and water desalination rate, predicting future needs and ensuring production targets can be met. Using this optimal control strategy, GEAR Lab can perform system-level optimizations to determine the equipment needed to build reliable but low-cost PV-EDR systems that utilize time-variant operation and an optimal power management strategy. GEAR Lab plans to demonstrate the optimal system design and control for a time-variant PV-EDR system at BGNDRF in 2021.