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Integration of Solid Oxide Steam Electrolyzer System into the UCI Microgrid to Support High Renewable Use

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The goal of this study is to evaluate the impacts and capabilities of dynamically dispatching Solid Oxide Steam Electrolysis (SOSE) systems to support high penetration of renewable photovoltaic sources in the UCI microgrid. The UCI microgrid operation has been simulated as a linear programming problem in Matlab® considering all of its operational constraints to analyze the microgrid behavior to the additional PV installed capacity. Simulations cases consist of current 4 MW PV installed capacity and future PV installed capacities up to 35 MW. The integration of modular SOSE systems in the University of California, Irvine (UCI) microgrid, to absorb the excess Photovoltaic (PV) generated power is investigated in this study for different PV installed capacity. Also, the possibility of utilizing the available excess steam produced in the Heat Recovery Steam Generator (HRSG) as a portion of the required steam in SOSE systems is evaluated. Microgrid simulation results prove that for cases with PV installed capacity greater than 10 MW, the otherwise curtailed excess electricity would be a great potential to be used in SOSE for hydrogen production. The produced hydrogen in high installed capacities would be enough to feed the gas turbine with a gas mixture containing 15% volumetric hydrogen together with hydrogen used in the UCI hydrogen fuel stations. Consequently, natural gas consumption and carbon dioxide production are decreased substantially.

Introduction

Distributed generation (DG) is a promising solution that uses small-scale technologies i.e., modular renewable-energy generators to produce electricity at the point of the end-users (1)-(4). Renewable DG resource characteristics, especially geographical distribution, seasonal and daily variability, as well as uncontrollability to match demand and generation time, pose challenges to the operability of the electric system as it increasingly adopts renewable DG (5). Power-to-Gas (P2G) technology can overcome some of these challenges and effectively utilize the otherwise curtailed renewable electricity, store large quantities of renewable energy, and store it for long periods of time. Utilizing renewable electricity and water in an electrolyzer produces carbon-free hydrogen fuel (6)-(10). The produced hydrogen can be utilized as a fuel in the same type of low-emitting power plants in use today (11), or used as a transportation fuel for fuel cell electric vehicles.

The UCI microgrid, which serves a community of more than 40,000 people, is following the path to meet the University of California (UC) goal of zero carbon emissions by 2025. The UCI campus central plant utilizes a gas turbine that provides electric power and exhaust heat for use in the HRSG. The gas turbine has a rated capacity of 14 MW, a

minimum power level of 8 MW, and is fueled by natural gas. The exhaust stream of the gas turbine is used in HRSG to produce as much steam as possible. The priority usage of this steam is to meet the heating demand of the campus (12). The UCI central plant also utilizes a 5 MW steam turbine unit fed by steam produced in HRSG. The UCI microgrid has been installing 4 MW of PV sources.

To achieve the carbon reduction goal of the UC in the UCI microgrid, much larger amounts of intermittent solar power generation must be deployed on the campus microgrid. These increased intermittent renewable generators create operational challenges related to the increasing mismatch between electricity demand and production that must be managed with long-duration energy storage systems. P2G technology can overcome these challenges and effectively utilize the otherwise surplus renewable electricity.

SOSE is a high temperature highly efficient electrochemical conversion technology that produces hydrogen from electricity and water. One of the main aspects that must be taken into account when coupling electrolysis with variable renewable energy sources is the dynamic operation and the control strategies that can be employed to allow such operating conditions without compromising cell integrity and system performance. The effect of strong dynamics has been evaluated at cell and system levels (13)-(14). These electrolysis systems have been shown that can be operated dynamically to store excess renewable wind and solar (14)-(16).

In this study, the impacts and capabilities of dynamically dispatching SOSE systems to support high penetration of renewable PV generation in the UCI microgrid are investigated. The UCI microgrid operation has been simulated as a linear programming problem in Matlab® considering all of its operational constraints to analyze the microgrid behavior to accommodate the additional PV installed capacity. Simulations cases consist of current 4 MW PV installed capacity and future PV installed capacities up to 35 MW. Increasing the PV installed capacity results in having excess PV generated electricity and excess thermal energy (in the form of steam) that would be utilized in the SOSE for hydrogen production. Utilization of the produced hydrogen in high installed capacities to feed the UCI microgrid gas turbine with a gas mixture containing 15% volumetric hydrogen together and to provide hydrogen for fuel cell vehicles that use the UCI fueling station.

Scientific Approach

SOSE Stack and System Model

A SOSE system physical model has been developed in MATLAB® software which consists of a temporally and spatially resolved quasi-3D sub-model for a SOSE stack and balance of plant's dynamic sub-models (14). 2500 unitary cathode-supported (fuel electrode supported) planar square-geometry cells with an active surface area of 100 cm² are assumed to be assembled into several unit stacks to comprise a 300 kW (nominal power) SOSE stack module. Figure 1 shows the schematic of the SOSE system layout. Modeling details of both stack and balance of plant components as well as the control strategies that are used to control operating parameters and to thermally manage the stack were explained in detail in (14).

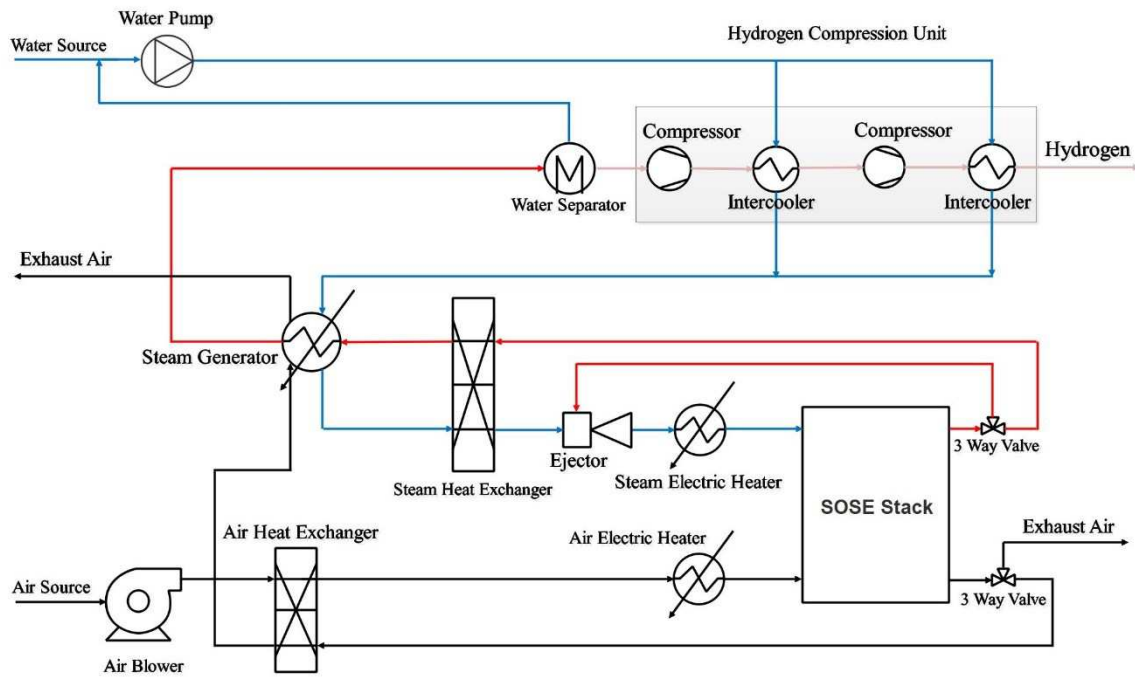


Figure1. Schematic of 300 kW SOSE System layout (14).

UCI Microgrid

The UCI campus central plant utilizes a gas turbine that provides electric power and exhaust heat for use in the HRSG. The gas turbine has a rated capacity of 14 MW, a minimum power level of 8 MW, and is fueled by natural gas. The exhaust stream of the gas turbine is used in HRSG to produce as much steam as possible. The priority usage of this steam is to meet the heating demand of the campus (12). The UCI central plant also utilizes a 5 MW steam turbine unit fed by steam produced in HRSG. The UCI microgrid has been installing 4 MW of PV sources, while it is capable of accommodating up to 35 MW of PV capacity. The operational parameters and assumptions of the microgrid model and the linear programming optimization model developed in Matlab® were discussed in detail in (17).

SOSE System Dispatch

To store the otherwise curtailed excess PV generated electricity, the SOSE system is integrated to convert electricity to hydrogen. The portion of the generated steam in HRSG, that is not needed for campus thermal load and is not consumed in the steam turbine, would be utilized in the SOSE system as a part of the required steam to increase the efficiency of the SOSE system. 300 kW SOSE systems are dispatched sequentially to cover all the excess electricity generated by PV in different PV installed capacity scenarios. The schematic of the UCI microgrid considering the integration of the SOSE systems is shown in Figure 2.

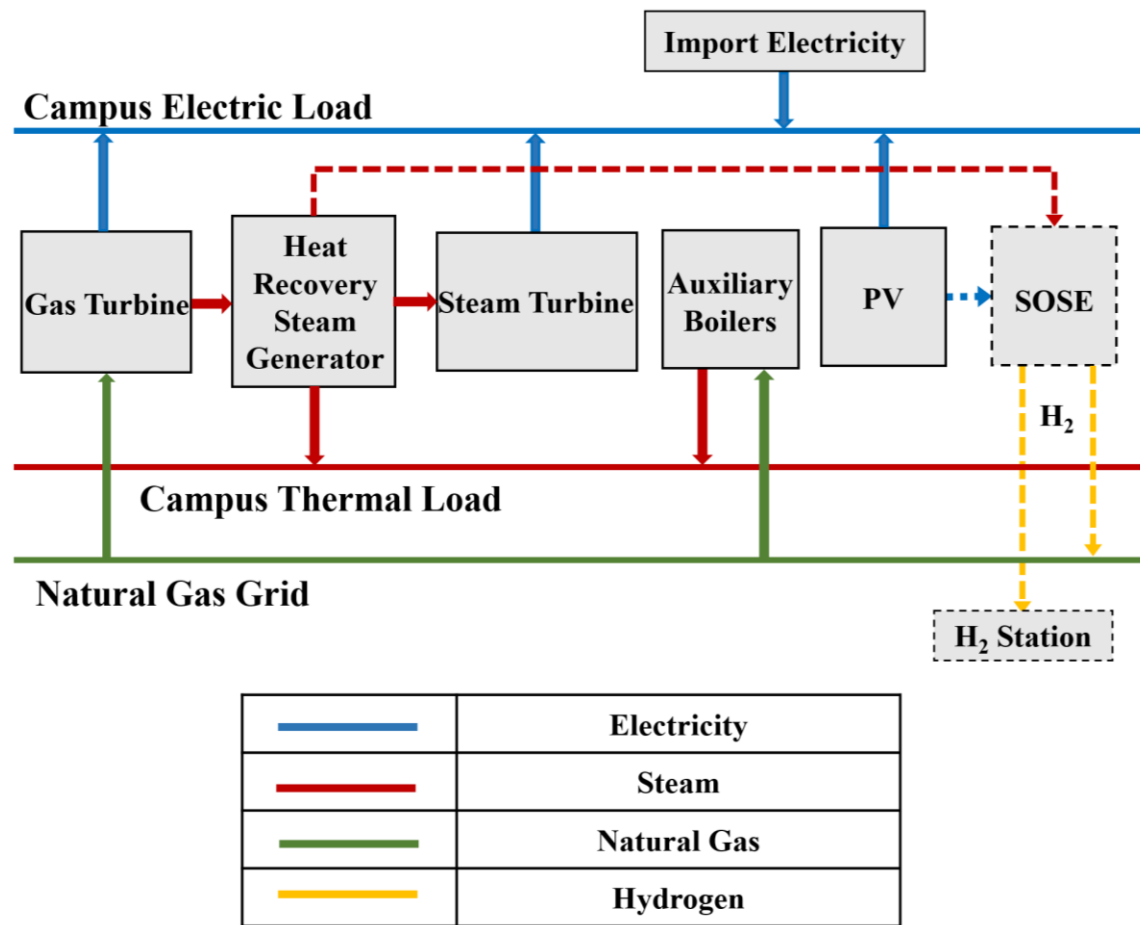


Figure 2. Schematic of UCI Microgrid.

Results and Discussion

UCI Microgrid

The UCI microgrid simulation results are presented in Figure 3. Contribution of different electrical generated sources to meet the UCI campus electric demand is shown for different PV installed capacity. The PV source contribution increases from 5% in the current 4 MW of PV installed capacity to about 20% in 35 MW maximum local PV installed capacity. Up to 6 MW of PV installed capacity, the microgrid can fully absorb the PV generated electricity. However, for PV installed capacity greater than 6 MW, the microgrid has to curtail a portion of the PV generated electricity due to the operating limitations of other electrical generated sources existing in the microgrid, as shown by a dashed line. According to Figure 3, for 35 MW of PV installation, the microgrid would annually curtail about 32 GWh of PV generated electricity out of 57 GWh PV generated electricity due to its limitations and lack of energy storage.

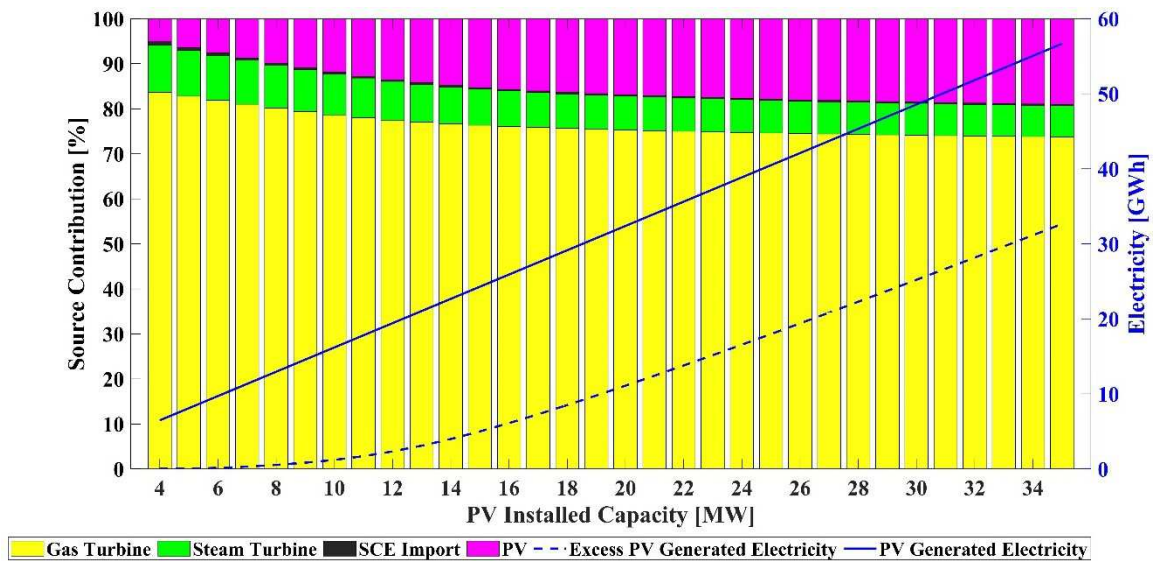


Figure 3. Annual UCI microgrid electric energy generation mix, Annual PV generated electricity and annual excess PV generated electricity in future scenarios with increased PV installed capacity.

SOSE System Dispatch

Figure 4 shows the electrical power balance of a representative week in January corresponding to 35 MW of PV installed capacity. In this scenario, in all of the days, the UCI microgrid would have excess PV generation that could be utilized in the SOSE system to store otherwise curtailed excess electricity in the form of hydrogen. Figure 4 proves how dynamically the dispatched SOSE systems can store the excess renewable electricity. It should be noted that the required SOSE power capacity to convert almost all the PV generated excess electricity would be about 12 MW, which is about one-third of the PV installed capacity. Figure 5 shows the thermal power balance of the same week in January. Since the UCI campus thermal load is high in winter, the UCI microgrid faces a lack of steam to meet the thermal demand. As a result, every day this week, the UCI microgrid needs to burn natural gas in auxiliary boilers to provide the required extra heat that is shown in Figure 5. Consequently, in this representative week, there is no excess steam available to be utilized as a portion of the required steam in SOSE systems to increase the overall efficiency and produce more hydrogen with the available excess electricity.

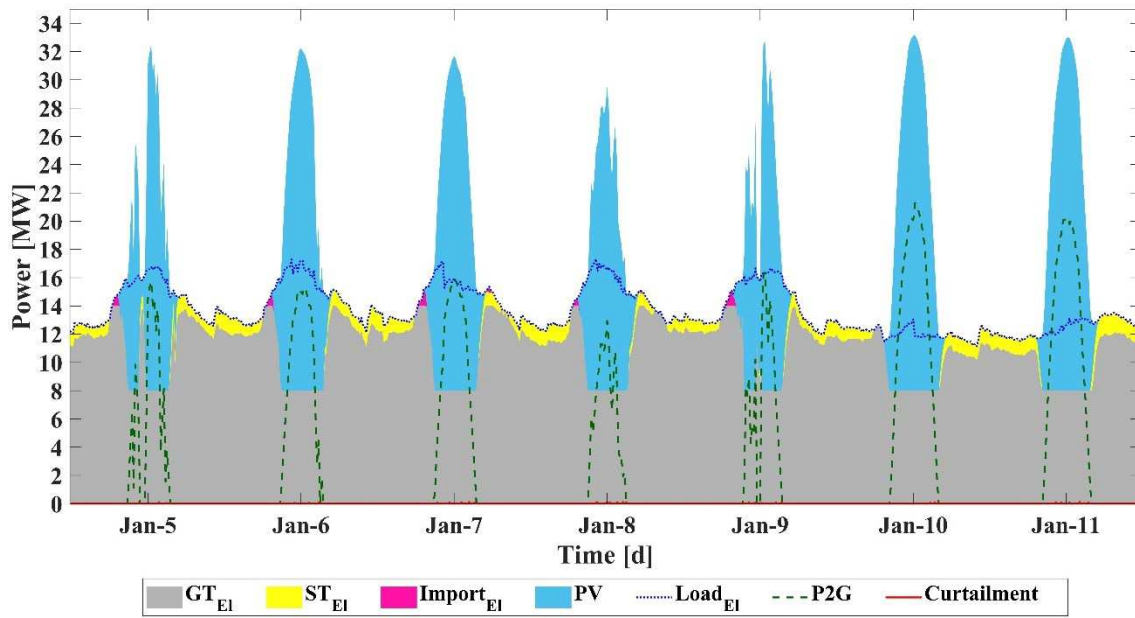


Figure 4. Microgrid-SOE dispatch simulation in a week of January: electrical power balance with 35 MW of PV installed capacity.

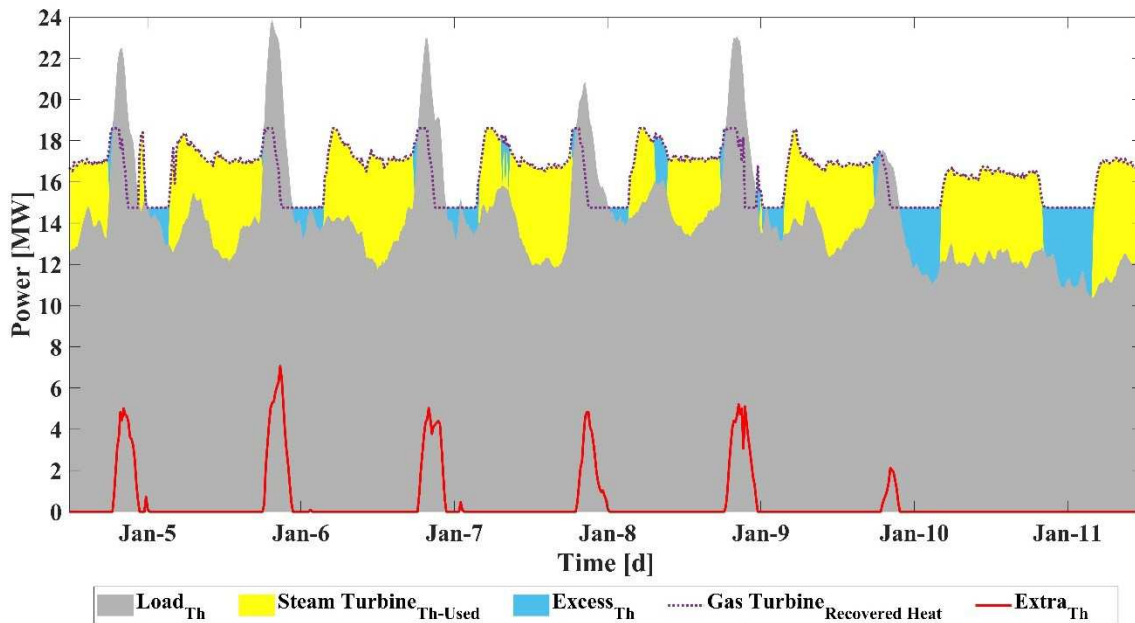


Figure 5. Microgrid-SOE dispatch simulation in a week of January: thermal power balance with 35 MW of PV installed capacity.

Figure 6 shows the electrical power balance of a representative week in September corresponding to 35 MW of PV installed capacity. In this scenario, in all of the days, the UCI microgrid would also have excess PV generation that would be utilized in the SOSE system to store otherwise curtailed excess electricity in the form of hydrogen. The main differences between this representative week in September and the representative week in January that was shown in Figure 4 are 1- The average electrical demand is higher in September. 2- The average contribution of the steam turbine in meeting the campus electrical demand is higher. The latter would be due to the lower thermal demand in the UCI campus and utilization of available steam, which is mainly prioritized to be used to

meet the thermal load, in the steam turbine to generate electricity. Figure 7 shows the thermal power balance of the same week in September. Since the UCI campus thermal load is lower compared to a week in winter, the UCI microgrid faces excess every day that would be utilized as a portion of the required steam in SOSE systems to increase the overall efficiency and produce more hydrogen with the available excess electricity. Also, it should be noted that the excess electricity and excess steam are available at the same time which enables the UCI microgrid to utilize both of them as energy and steam fuel required for SOSE system operation.

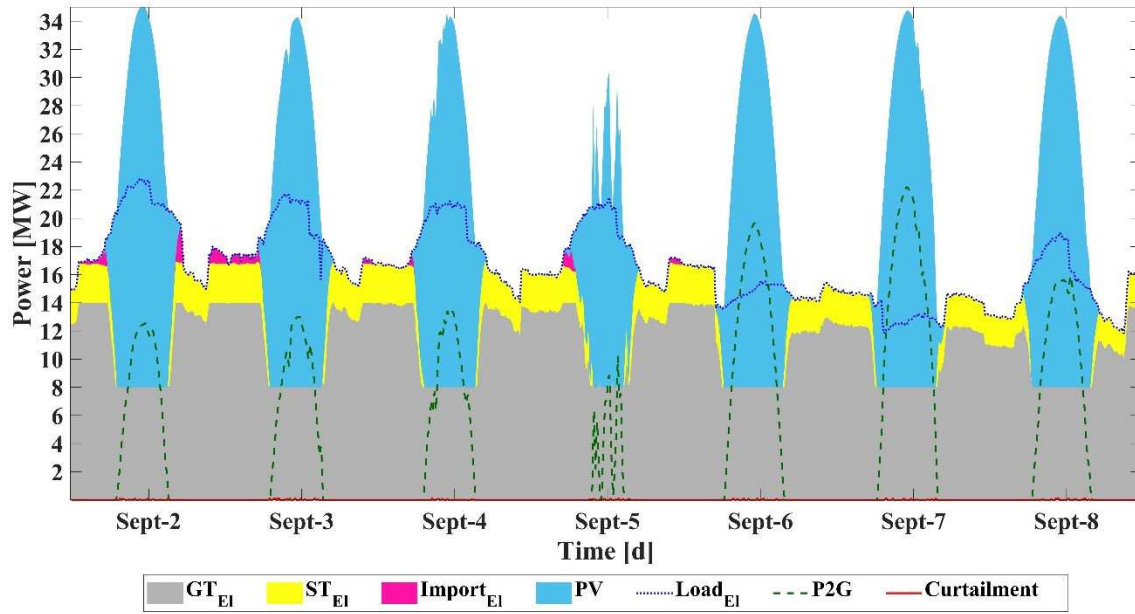


Figure 6. Microgrid-SOE dispatch simulation in a week of September: electrical power balance with 35 MW of PV installed capacity.

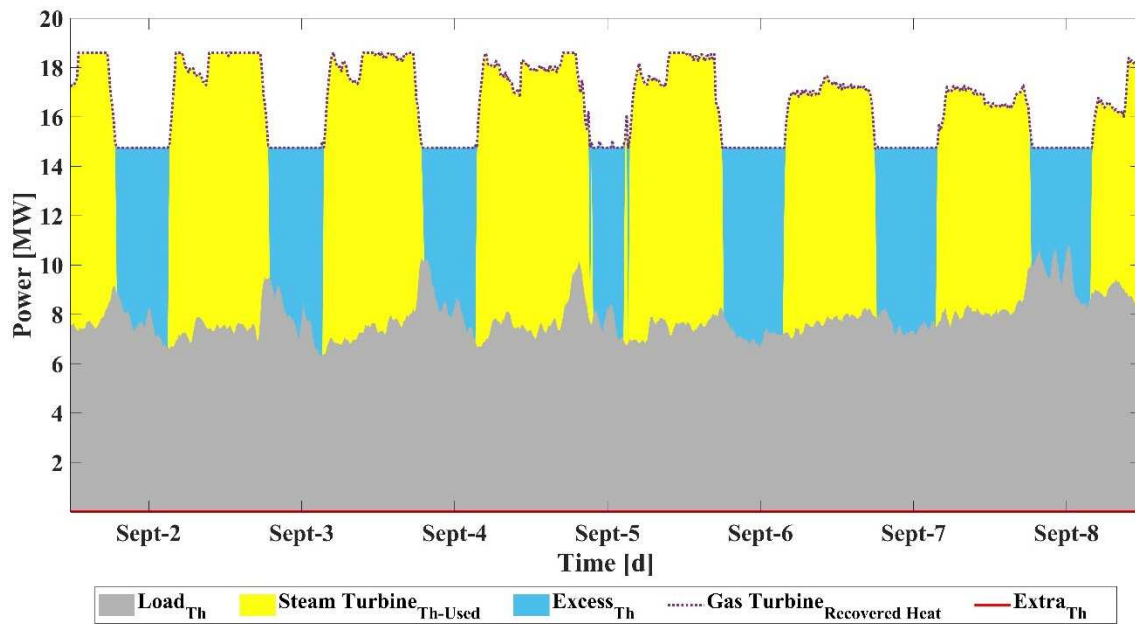


Figure 7. Microgrid-SOE dispatch simulation in a week of September: thermal power balance with 35 MW of PV installed capacity.

Hydrogen Production and Utilization

Figure 8 shows annual hydrogen production by integrating the SOSE systems into the UCI microgrid for different PV installed capacity. Also, it shows the annual amount of hydrogen that would be used in the microgrid to feed the gas turbine with a gas mixture containing 15% volumetric hydrogen and 85% volumetric natural gas. As it is shown in Figure 8, the UCI local hydrogen fuel station annually consumes about 50 metric tons of hydrogen. According to Figure 8, having PV installed capacity greater than equal to 29 MW enables the UCI central plant having enough locally produced renewable hydrogen to inject 15% volumetric hydrogen into the gas turbine which would reduce both natural gas consumption and carbon dioxide emissions. Furthermore, for PV installed capacity greater than equal to 32 MW, there would be enough hydrogen to meet the UCI local hydrogen fuel station and to feed gas turbine with 15% volumetric hydrogen.

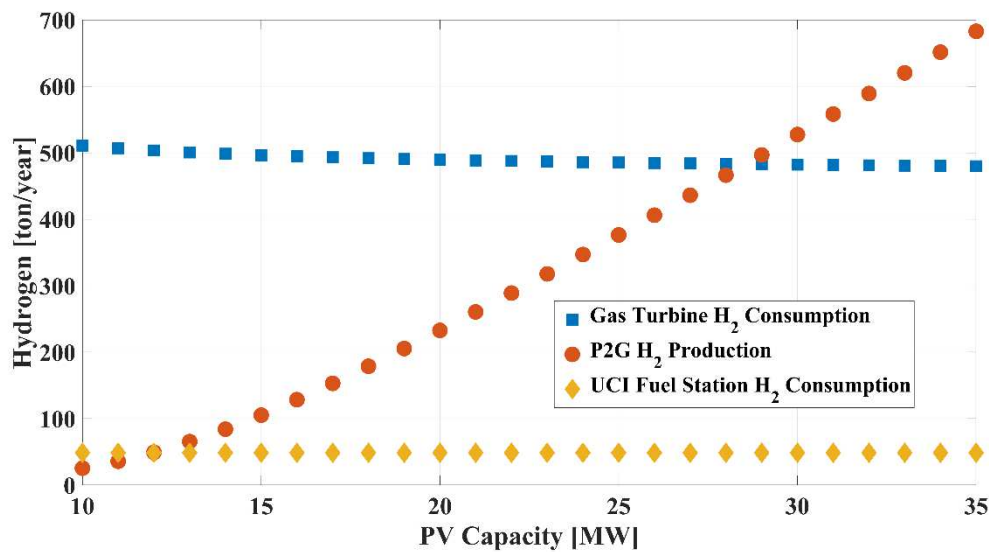


Figure 8. Hydrogen production and possible on-site utilization for different PV installed capacity.

Conclusions

In this study, the integration of multiple 300 kW SOSE systems into the UCI microgrid to support high renewable use is investigated. A spatially and temporally resolved physical SOSE system model has been used to simulate the dynamic behavior of the SOSE system. The UCI microgrid operation has been simulated as a linear programming problem in Matlab® considering all of its operational constraints to analyze the microgrid behavior to accommodate additional PV installed capacity. The microgrid simulation results show that excess PV generated electricity is negligible when the PV installed capacity is lower than 10 MW, since almost all of the PV generated electricity can be absorbed by the microgrid. However, for PV installed capacity greater than 10 MW, the microgrid cannot absorb all the renewable generated electricity which would have to be curtailed or converted into the hydrogen using the integrated SOSE systems. Without integrating SOSE systems into the

UCI microgrid, more than 50% of the annual PV generated electricity would be curtailed in high PV installed capacities. The microgrid-SOSE integrated results show that such systems have the potential to utilize both excess electricity and excess steam produced by the combined cycle power plant in the hot season (when the campus thermal load is low), which results in an increase the P2G efficiency.

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