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Above Solar-to-Hydrogen Efficiency Limits: The Supremacy of Electrolyser-Battery Synergy

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Abstract : Coupling of Photovoltaics (PV) to water electrolysers for production of hydrogen via water splitting holds great potential for long term energy storage and transportation. Similarly, the intermittency of PV power on short timescale from hours to days is more efficiently covered by batteries. In this work, we present two different system configurations. The first is the connection of a PV module to an alkaline electroylser/electrochemical (EC) cell stack referred to as a PV-EC system. This is carried out using a direct coupling approach for simplicity, implying the absence of any power electronics for the PV module maximum power point (MPPT) tracking. The second system involves connecting a lithium-titanium-oxide (LTO) battery (B) pack parallel to the electrolyser which is connected to a PV module and referred to as a PV-EC-B system also using a direct coupling approach. The first motivation of studying the two different systems is the possibility of improved stability and round-the-clock operation of the electrolyser in the presence of the battery pack connected to it. In PV-EC configuration the electrolyser remains naturally idle during night times/ periods of insufficient irradiance which can lead to accelerated degradation and safety concerns. For the PV-EC-B configuration, the power of the PV is split between the electrolyser and the battery during the day enabling an extended operation of the electrolyser during the night/periods of insufficient solar irradiance as the battery powers the electrolyser. We delve into two major implications of this effect using optimized experimental procedures with the use of GaAs concentrator PV modules with an efficiency of 34.5% at 17.3 suns. The first implication deals with how the solar-to-hydrogen (STH) efficiency of the systems is affected. The STH efficiency limit of the PV-EC configuration is obtained using an already established theoretical analysis of the electrolyser polarization curve. We therefore show that the experimental result of the PV-EC system yields an STH efficiency of 23.0% which is only 0.5% absolute less than its obtainable STH limit of 23.5%. However, the STH efficiency of the PV-EC-B is obtained to be 25.4% which is not only above the STH efficiency in the PV-EC configuration but also 1.9% absolute above the theoretical STH efficiency limit in the PV-EC configuration. The gain in STH efficiency is synergistic despite battery related losses as the electrolyser in the PV-EC-B configuration converts the same solar power as in the PV-EC system but at lower overpotentials. The second implication is the possibility of the electrolyser downscaling since the battery provides the possibility of running the electrolyser at lower potentials/ peak power. Our results show that the relative electrolyser size can be downscaled by a factor of 2 with the addition of a battery pack while keeping the STH efficiency without batteries. These two orthogonal investigations will be presented in well-defined steps showing determination of power requirements of the electrolyser, PV sizing, PV operation methodology using PV emulation, experimental obtained parameters and analysis of results. The results form a basis for investigation into more realistic operation, upscaling and techno-economic implications.

Keywords : photovoltaic, electrolyser, battery, solar-to-hydrogen efficiency
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