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Hydrogen electrolyser capacity investment in the Australian context

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Abstract: A growing national and global focus on low greenhouse gas emission fuels, and cost reductions in renewable electricity generation and energy storage, has given rise to renewed attention to water electrolysis to produce hydrogen. While the current dominant form of hydrogen production is steam methane reforming of natural gas, water electrolysis is the principal method of generating hydrogen from renewable energy. When coupled with large-scale renewable energy technologies, renewable hydrogen production may serve as a zero-carbon feedstock for industrial processes.

In this paper, we investigate the optimisation of both capacity investment in electricity generation, electricity storage and hydrogen electrolysers as well as the hourly least-cost operation of the same electrolysers simultaneously with generation and storage operation. We use a custom model capable of considering these within a time horizon of one year using annualised discounting. We consider how to design a least-cost system out to 2050 that meets hydrogen off-take requirements through the development of prospective variable renewable resources.

We study the relevant trade-offs that are shown between: capacity investments costs in electrolysers and renewable electricity generation and storage; electrolyser sizing and utilisation, and; operational profiles in established networks compared to greenfield development.

In each region an annual minimum hydrogen production requirement was imposed. That requirement must be met by new investment in PEM and alkaline electrolyser technology fed by grid-connected electrical energy. The model was free to determine the aggregate regional electrolyser capacity and the utilisation of that capacity for each hour of the year subject to a minimum utilisation or "minimum run" constraint. The STABLE model (Spatial Temporal Analysis of Balancing Levelised-Cost of Energy, adapted from the DIETER open-source model to the Australian context) is a large-scale linear optimization model minimising system cost, deciding hourly operational variables simultaneously with capacity investment in transmission, generation, storage and electrolysers.

Results have been presented and compared for the following cases in the Australian context:

Case I - National Electricity Market (NEM): The NEM is an extensive network of interconnected regions servicing the Eastern and Southern states of Australia. It is geographically and climatically diverse. Each state has a distinct mix of electricity generation and storage technologies, with constrained interconnection capacity between states. The overall system has large and diverse electricity generation and storage capacity and allows for large electrolyser capacity investment.

Case II - Wholesale Electricity Market (WEM): The WEM in Western Australia is located at the capital city of Perth and surrounds. It has a less diverse mix of generation and storage technologies than the NEM, with a smaller scope for new renewable energy and long duration storage investment due to network limitations.

Case III - Remote systems: Multiple isolated networks were considered together, each strongly defined by industrial electricity consumption. Existing capacity is dominated based on natural gas-fired electricity generation. Our focus here is on greenfield investment in electricity generation for new electrolyser-based hydrogen production.

Typical electrolyser operational profiles were found to maintain a minimum 'base load' on average, despite the highly flexibility allowed to the PEM electrolyser model in its ramping. This suggests a correlation between optimal capacity investment with a certain utilisation level across the year.

Overall, we have found that optimal renewable-based electrolyser production is a product of the trade-off between upfront investments that can flexibly make best use of available energy (solar electricity generation in particular) in the broader context of co-optimisation within the wider system.

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