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Hybrid hydrogen-battery systems for renewable off-grid telecom power

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ABSTRACT

Off-grid hybrid systems, based on the integration of hydrogen technologies (electrolysers, hydrogen stores and fuel cells) with battery and wind/solar power technologies, are proposed for satisfying the continuous power demands of telecom remote base stations. A model was developed to investigate the preferred role for electrolytic hydrogen within a hybrid system; the analysis focused on powering a 1 kW telecom load in three locations of distinct wind and solar resource availability. When compared with otherwise equivalent off-grid renewable energy systems employing only battery energy storage, the results show that the integration of a 1 kW fuel cell and a 1.6 kW electrolyser at each location is sufficient, in combination with a hydrogen storage capacity of between 13 and 31 kg, to reduce the required battery capacity by 54–77%, to increase the minimum state-of-charge from 37 to 55% to >81.5% year-round despite considerable seasonal variation in supply, and to reduce the amount of wasted renewable power by 55–79%. For the growing telecom sector, the proposed hybrid system provides a 'green' solution, which is preferable to shipping hydrogen or diesel to remote base stations.

Introduction

The world faces a revolution in energy systems as it seeks to satisfy a growing global energy demand from an increasing population while dramatically reducing greenhouse gas emissions. In some regions and some applications, off-grid energy systems powered by renewables could contribute to the 2050 goal of cutting carbon emissions by $\geq$80% relative to 1990. Such systems gradually become more affordable as manufacturing production rates increase. For example the IEA indicates that solar photovoltaic power sources could overtake coal power sources by 2050 by making a 27% contribution to the total supply, which when considered in conjunction with hydro, wind and biomass the total renewables contribution could amount to 79% [1]. In Asia, Africa and the Middle East, plentiful resources and a lack of existing infrastructure could allow many developing countries to apply off-grid systems for decentralised power. For example, sub-Saharan Africa's population is expected to double to 1.75 billion by 2040 with energy demand increasing by 80%, but leaving 530 m people without power, primarily in rural communities. Renewables are expected to provide two-thirds of the capacity in mini-grid and off-grid systems in these rural areas where low population density makes grid connection uneconomic [2].

One early market where global demand is showing considerable growth is telecommunications. The requirement

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for more widespread use of remote base stations is becoming increasingly important with 3G and 4G networks in emerging markets and the added advantage of not requiring the installation of a telephone cable network. China has the world's largest mobile telecommunications network with over 1 million telecommunications base stations, a number which is growing at ten to twenty thousand *p.a* [3]. Telecom towers, by their nature, are often positioned in remote locations where reliable grid electricity is not present and network operators have no option but to pursue alternative power sources. Diesel-fuelled generators suffer from low efficiency, the high costs of fuel replacement and delivery, the emission of carbon dioxide and other pollutants, and the risk of fuel theft and degradation. Hence there is a growing interest in the use of renewable power sources by telecom stations in order to replace diesel [4,5]. One recent study estimated that by 2020 there could be 400,000 off-grid telecom base stations operating on renewable power, particularly in remote parts of the developing world, with an associated market size of $10.5 billion *p.a.*, [6].

Telecom applications require an extremely reliable 24-h supply of power, resulting in the need for energy storage for providing backup power during grid outages or primary power during lulls in wind or solar photovoltaic (PV) generation. Historically this has been performed primarily by batteries for backup power (*i.e.* to cover a defined period of failure in the primary power system) [7–10], with $4.7 to $7.9 billion of battery sales per year recorded in China for the telecom industry alone [3]. Lead acid batteries are the main technology used in off-grid systems due to their maturity and low cost. However 'battery-only' solutions have uncertain life expectancies, especially for off-grid applications at sites with large seasonal variations in renewable power production. In such systems batteries encounter long periods at a low state-of-charge (SOC), numerous partial cycles at low SOC and other periods at full charge so preventing the absorption of available renewable electricity. These factors negatively affect battery lifetime [11–14] and distinguish the telecom application from automotive, portable or uninterrupted power supply applications where deep discharges are experienced but then batteries tend to be quickly recharged and remain near full charge for much of their working lives. Self-discharge mechanisms over time serve to reduce a battery to a partially-charged state, reducing its life expectancy and making it unsuitable for seasonal storage. In a well-designed system with appropriate maintenance batteries can last up to 15 years, but they have been found to fail after only a few years in systems served by solar/wind power. This makes battery lifetime quite short compared to other system components, leading to system unreliability and frequent replacements, making batteries a weak link in remote telecom systems [11–15]. In general batteries are best operated at high SOC to optimise lifetime, as discharging at low SOC degrades batteries more than discharging at high SOC [16]. Some manufacturers have responded by designing deep-cycle batteries specifically for remote power applications, but the potential for extending battery life this way is limited. Whichever battery chemistry is used, there is considerable potential for a solution which can extend battery life by maintaining the SOC within a limited range year-round (e.g. 80–100%).

Interest in the use of hydrogen, as an alternative to batteries and diesel-fuelled generators, is growing for telecom power [4,5,9,10]. Existing commercial solutions ('hydrogen-only' systems) require bottled hydrogen to be delivered to site [17–19]. This hydrogen tends to be characterised by a high carbon footprint because it is usually produced centrally via steam methane reformation, then compressed and transported by diesel truck. Alternatively hydrogen-only systems may be powered by on-site renewables, but these are inhibited by the poor round trip efficiency of an electrolyser/fuel-cell combination, which forces the specification of high capacities for the power source, electrolyser and hydrogen store. Therefore hybrid off-grid systems, and the complex sizing, storage and control challenges they present, are receiving considerable research attention [20–22].

Previous investigators have noted that, in systems incorporating hydrogen storage, hydrogen is ideal for seasonal bulk energy storage while batteries are best suited for short-term storage [23]. PV-powered systems incorporating fuel cells and batteries have been found to achieve lower costs and lower PV requirements than battery-only and hydrogen-only systems based on delivered hydrogen [21]. Telecom applications usually need 3–5 days of backup to navigate periods of cloudy weather, and fuel cells are able to offer longer runtimes than batteries (because hydrogen storage tanks are scalable) as well as environmental benefits due to a reduced reliance on lead-acid systems [3]. Hybrid systems have been found to be cheaper than battery-only systems due to lower O&M costs, and with greater efficiency and reliability than hydrogen-only systems [24]. Previous studies of hybrid hydrogen-battery storage systems have shown that heavy battery use can lead to more efficient systems with reduced PV/wind requirements, but with deep discharges and/or long periods at low SOC which adversely affect battery life [17,19,25]. Others have shown that batteries can be protected through reduced usage by placing a heavy reliance on hydrogen, but with adverse impacts on system efficiency and renewable power capacity [20,26,27]. Here we show that a compromise can be reached, with batteries improving system efficiency and reducing PV/wind capacity requirements through regular daily cycling, while the hydrogen component serves to maintain battery SOC within narrow limits and so extend battery life.

We propose a hybrid system for off-grid telecom power comprising on-site hydrogen generation by electrolysis, gaseous hydrogen storage and power generation by a PEM fuel cell. The hydrogen technologies are integrated with batteries and a renewable power source(s) to form a 'hydrogen-battery' system. This hybrid configuration, which may be compared with a conventional 'battery-only' system, provides an off-grid solution based entirely on renewable energy. Wind and/or solar energy can be either stored in the battery, or used by the electrolyser to produce hydrogen for storage and later use by the fuel cell. The fuel cell and battery work together to ensure year-round uninterrupted power for the telecom application, while the electrolyser and battery function to capture the electricity generated by the on-site renewable power source(s). The envisaged operating logic is for the hydrogen technologies to support the battery technology, with the hydrogen store providing a seasonal buffer. The foremost