Sensitivity Analysis of Hybrid Energy Storage Systems Utilising Adaptive Power Pinch Analysis

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Abstract

Renewable energy (RE) sources such as photovoltaics, wind turbines for distributed generation (DG) has had widespread penetration mostly due to growing concerns over global warming and climate change [1, 2]. Furthermore, RE usage has been encouraged by the mounting fears over the depletion of fossil fuel reserves. The solar energy despite being the most favourable and fastest growing in the RE domain exhibits an intermittent characteristics which is stochasticity and impedes short term prediction [1]. Therefore integration of the solar energy technologies with hybrid energy storage systems (HESS) such as batteries, supercapacitors, flywheels and hydrogen energy storages in the stand-alone smart microgrid does not only enhances reliability but also minimises the usage of fossil fuel generator. However, proper sizing of the assets is a fundamental issue and significantly influences the techno-economic feasibility of the hybrid plants [3]. Furthermore, the utilisation of heterogeneous assets introduces new challenges which bothers mainly on the co-ordinated flow and control of power amongst the assets while emphasizing the necessity for an energy management strategy (EMS). The power pinch analysis concept an insight based method realised as an algebraic or graphical tool for power systems which was recently adapted from heat exchanger pinch analysis serves as a reliable method for enhancing the reliability and optimal operation of HESS [4-6]. The PoPA aided by the composite curve has been utilized for short-term energy planning to determine the minimum/maximum electricity targets. Furthermore, in [6] the PoPA concept was combined within a model predictive control (MPC) framework for the first time to infer and effect energy management decisions in a hybrid stand-alone micro-grid. Additionally, the Day –ahead forecast was utilised with the PoPA to infer the optimal PMS. However, it was shown that the effect of forecast error impedes the performance of the DA-PoPA as the variance causes the system and model to mismatch. Hence, the adaptive receding horizon PoPA was recently proposed to minimise forecast variance and enhance reliability and was shown to perform better than the normal DA-PoPA.

This paper presents a sensitivity analysis to assess the impact of hydrogen storage sizes as it affects the efficacy of the adaptive PoPA utilised within a robust model predictive control framework for energy management in an isolated hybrid energy storage system. As a case study, the hybrid renewable system comprises of the photovoltaic system, Fuel cell and electrolyser with hydrogen and water tanks, a battery as the primary energy storage as well as a diesel generator for backup. During summer periods, the electrolyser creates hydrogen using the excess energy in the system while the battery state-of-charge is maintained (at $SOAcc_{BAT} \leq 90\%$). Alternately, the fuel cell, in turn, charges the battery using the stored hydrogen when the battery's SoC is below the minimum set limit (30%). The adaptive PoPA energy management strategy is proposed, to ensures the $SOAcc_{BAT}$ remains within the acceptable operational region (30%<$SOAcc_{BAT}$<90%).

Objectives and context

The main objectives to be achieved by this work are as follows;

a. Sensitivity analysis to highlight the dependency of Adaptive-PoPA PMS on both hydrogen and water tank capacity.
b. Highlight cost effective and simplistic energy storage tank sizing methodology.
c. Autonomous online optimal decision making.

Methods/approach

This work would be carried out in MATLAB, using realistic yearly realistic load demand and weather profile from [7] and [8] respectively. The work would assess the impact of various sizes of hydrogen and water tank as regards the efficiency of the adaptive PoPA PMS.

Outcomes

The adaptive PoPA method has been shown to perform better than the normal DA-PoPA method in previous work by the authors. However, a sensitivity analysis as regards the successful implementation of the adaptive PoPA PMS shows its dependency upon the size of both the hydrogen and water tank. As seen in Figure 1, the blue plot which represents the batteries state of charge $SOAcc_{\ BAT}$ for a period of one year (8760) with hydrogen (HT) and water tank (WT) capacity of 0.13 m^3 and 48 m^3 respectively. The normal sizing configuration results in an upper and lower violation of 705 and 2068 times respectively. Additionally, the red plot which indicates the $SOAcc_{BAT}$ when the HT and WT are sized at 1.3 m^3 and 730 m^3 respectively, shows improvement as the upper and lower violation decreases by 19% and 47%. Consequently, the diesel activation is reduced from 1038 to 815 times as a consequence of the increased HT and WT storage size. Figure 2, shows the cumulative probability distribution of the $SOAcc_{BAT}$ as the capacity of the HT and WT are varied. The $SOAcc_{\ BAT}$ (red plot) derived from the increased HT size had fewer deficits during winter as the Fuel cell was utilised compared to the smaller sized HT tank (blue dashed plot). Furthermore, during summer since the larger HT tanks is able to store more hydrogen hence, fewer upper constraints are also violated.

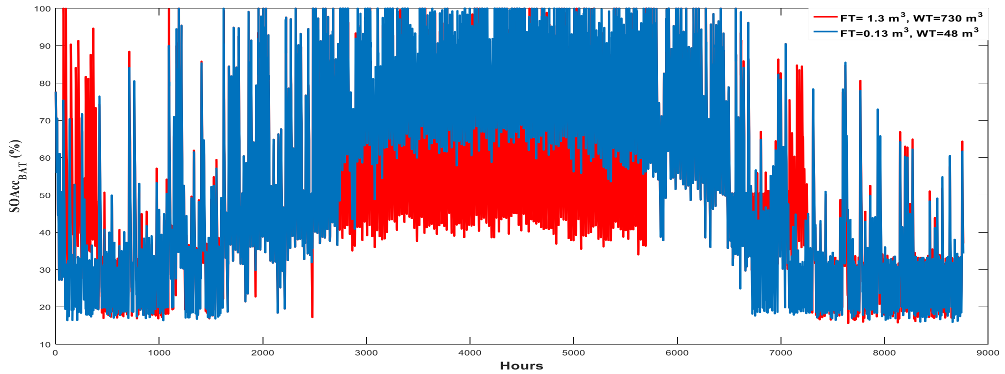

Figure 1: The Battery's state of charge for the different hydrogen tank and water tank sizes.

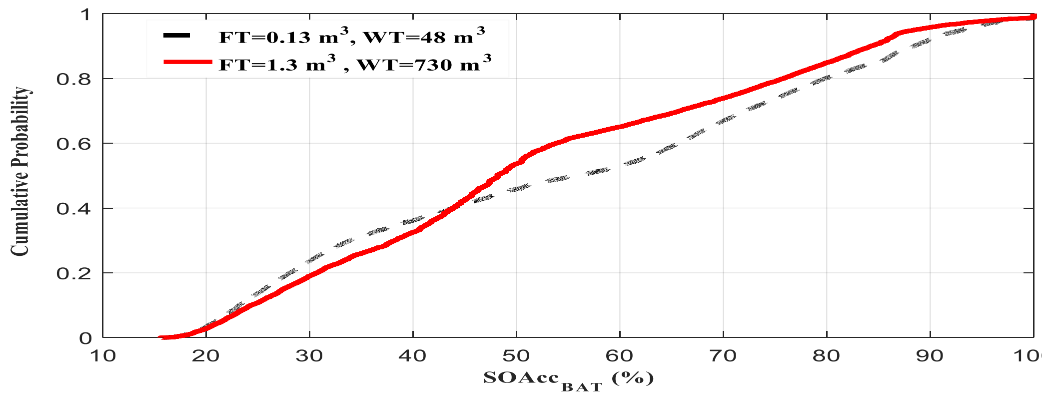

Figure 2: The probability distribution of the battery's state of charge for the different Tank sizes.

Conclusions

The adaptive PoPA utilised in a receding adaptive model predictive framework been shown to reduce the upper and lower set point violation as well as fossil fuel emission impact by 19%, 47% and 21%, if the HT and WT size are increased from $0.13\ m^3$ to $1.3\ m^3$ and $48\ m^3$ to $730\ m^3$. This is due to the receding online adaptive mechanism which recomputes the PGCC after a variance greater than 5% occurs. However, the optimal operation and effecting of the adaptive PoPA PMS was shown to be dependent on both the size of the hydrogen and water Tanks. This work, therefore, seeks to highlight the problem and also proffer a suitable sizing approach for the assets.

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