Mitigating Large Power Spills in a Stand-Alone System with Wind Generation and Storage

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***Abstract*—The challenges related to the integration of unpredictable wind energy into a power system can be alleviated using energy storage devices. We performed an overall assessment of a single domestic energy system with a wind turbine supported by an energy storage device (battery). We investigated the best operation mode of the battery such that the occurance of large power spills can be minimized. For estimating the small probability of large power spills, we used the *splitting technique* for rare-event simulations and formulated an appropriate *Importance Function* such that the workload of the probability estimator is reduced compared to the conventional Crude Monte Carlo (CMC) probability estimator. Simulation results show that the *ramp constraint* imposed on the charging/discharging rate of the battery plays a pivotal role in mitigating large power spills. A new charging strategy for the storage device is applied to minimize the large power spills further which results in a trade-off between reductions in large and average power spills, respectively.**

I. Introduction

To improve the practical efficiency of renewable energy generation and to minimize the need of drastic actions (like using expensive fast ramping generators) to have uninterrupted power supply, it is important to store the excess power generated in the system. We investigate a stand-alone single domestic power system with local wind generation supplemented with an energy storage device (battery). For this system we aim to answer the following question: what is the best way to operate the battery such that the *probability of large power spills* (PLPS) is minimal? In other words, PLPS quantify the probability of occurrence of high value of curtailed or wasted wind energy in the system.

We devise models for simulating the wind speeds and power demand such that the invariant probability densities of the data generated by the models are comparable to the data from measurements. With these models for power generation and demand, we analyze how the *ramp constraints*, the imposed maximal charging/discharging rates on the battery affects the PLPS. We define a new charging strategy for the battery to reduce the PLPS further but it results in the increase of the average power spill of the system. We study the trade-off between reducing PLPS and reducing the average power spilled by the system.

The probability of occurrence of large power spill is small. To reduce the workload of CMC we use a variant of the *splitting technique* for rare-event simulations called the Fixed Number of Successes (FNS) proposed in [1] for calculating the PLPS. It is of great relevance to find an appropriate *Importance Function* (IF) for the splitting technique, as it plays the most significant role in the efficiency of splitting [2]. We formulate an appropriate IF for our hybrid stochastic power system described previously.

II. SYSTEM SET UP

Let the power mismatch between the wind power generation $W(t)$ and demand $D(t)$ at time t be defined as $P(t) := W(t) - D(t)$. The battery is modeled according to $\frac{dB}{dt} := \alpha P(t)$, where α is the charging/discharging efficiency and $\alpha \in (0, 1]$. The battery is subjected to the following battery constraints [3]:

1) *Ramp constraints:* it is the maximal rate at which the battery can charge/discharge, i.e. $\gamma \leq \frac{dB}{dt} \leq \beta$, where $\gamma < 0 < \beta$. It is also known as the power rating of the battery.
2) *Capacity constraint:* it is the maximum storage capacity (also known as energy rating) of the battery, i.e. $0 \leq B(t) \leq B_{max}$ for all $t \in [0, T]$.

Thus, in principle, the battery is charged when $P(t) > 0$ and discharged if $P(t) < 0$ unless the battery constraints are met.

a) Power Spill: Let $F(t) := P(t) - \tilde{P}(t)$ be the *residual power* in the system, where $\tilde{P}(t)$ is the power getting absorbed or delivered by the battery. When $F(t) > 0$, power spill occurs: there is more power production than demand and the battery cannot absorb all the excess power because of the *battery constraints*. The PLPS over a time length T is given by

$$\gamma := \mathcal{P}(\sup_{t \in [0,T]} \{F(t)\} \geq F^*), \quad (1)$$

where $F^* > 0$ is the large power spill threshold.

b) Importance Function: We formulate the IF as the distance of the system from rare event sets in the phase space of $B(t)$ and $P(t)$. There are two rare event sets for this model. Set 1 occurs when the battery is fully charged to B_{max} and $P(t) \geq F^*$ and set 2 occurs when the battery cannot absorb all the power because of the imposed ramp constraints, i.e. when $P(t) \geq F^* + \beta$.

c) New charging Scheme: To reduce the PLPS further a fraction of the battery $1 - \epsilon$ is reserved for absorbing only those values of excess power which are greater than F^*, where $0 \leq \epsilon \leq 1$.

III. RESULTS

For simulations we take $\gamma = -\beta$, $T = 24$ hours, $dt = 0.01$ hours, $B(0) = B_{max}/2$ and $F^* = 850$ W. We take the charging/discharging efficiency of the battery to be $\alpha = 1$, i.e, it is 100% efficient. We study how the PLPS varies with β for different B_{max}. It is observed that PLPS reduces with β till an optimal value β^* where it is minimal, then again increases and becomes constant. This imply either a very fast or a very slow charging/discharging battery leads to more power spills. The value of PLPS around β^* reduces with increasing B_{max}.

Implementing the new charging scheme shows that, as the value of ϵ reduces, PLPS gets smaller. The more we reserve the battery for only storing values of generated excess power greater than F^* the lower the PLPS gets. PLPS drops by a factor of 100 when ϵ is reduced from 1 to 0.8. The reduction in ϵ nominally increases the average power spill.

We find that the proposed IF for FNS splitting technique significantly enhances the time efficiency of FNS over CMC. It is observed that for PLPS $\sim 10^{-3}$ FNS is 60 times faster than CMC and for PLPS $\sim 10^{-4}$ FNS is 300 times faster than CMC.

A similar problem in energy systems that is generally studied is the probability of shortage of power in the system. However, we only focus on the large power spills, i.e. the instances where the power generation is substantially larger than the locally consumed power because, a large injection of this excess power into the power grid can lead to voltage imbalances and current overloads in the grid thus making it unstable. Both these problems of probability of shortage and probability of excess power in the system are mathematically similar.

A similar version of the abstract has appeared in [4]. A much more detailed presentation and discussion of these findings including numerical details and results can be found in [5].

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