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Power System Technical Performance

10857_2022

CYCLE LIFE ASSESSMENT OF BATTERY ENERGY STORAGE SYSTEMS FOR PRIMARY FREQUENCY CONTROL BY RAINFLOW COUNTING ALGORITHM

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Motivation

- Increased renewable production in power systems cause falling system inertia and consequently changing system frequency behavior. An important solution can be created to this problem via participation of storage systems in frequency control.
- As the frequency response of batteries is dependent on the nature of the various contingencies which can occur on power systems, cycle life assessment of the battery is a very complicated issue.
- In this study, BESS degradation, which performs primary frequency control, was evaluated by rainflow counting algorithm.

Method/Approach

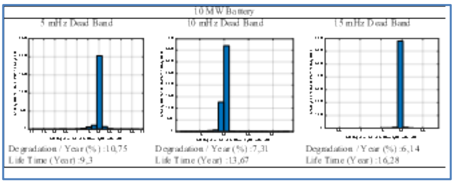
- The rainflow counting method is considered as the most accurate fatigue identification method in complex alterations.
- In this study, frequency response of 10 MW has been analyzed. One-day real frequency measurement values of ENTSO-E system were used in the analyses. Analyses were repeated for 5mHz, 10mHz and 15 mHz dead band values and increasing the frequency deviation and the battery SOC change was recorded.

Objects of investigation

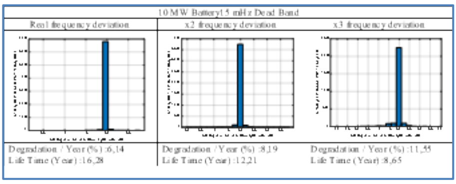
- Performing a pre-operational battery degradation analysis is important for accurately scaling battery capacity and providing accurate bid within market mechanisms .Cycle-life degradation analysis involves determining the total number of cycles spent by a BESS in a given period of time. Rainflow cycle counting method identify accurately cycles in an irregular battery state of charge (SOC) profile
- The degradation analysis of the battery which is used in different applications by rainflow counting algorithm is available. However, the cycle life evaluation of battery energy storage systems for primary frequency control with rain flow counting algorithm has not been performed. The effect of frequency deviation, dead band and speed droop value on battery life was investigated using the method specified in this article.

Experimental setup & test results

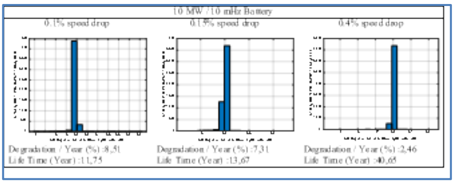
- Degradation Values and Histograms of rainflow cycles mean value of 10 MW Battery for 5, 10 and 15 mHz dead band



- Degradation Values and Histograms of rainflow cycles mean value of 10 MW Battery in 15 mHz dead band for different frequency deviation



- Degradation Values and Histograms of rainflow cycles mean value of 10 MW Battery for different speed droop setting values



Conclusion

- Battery life is significantly increased under high deadband operating conditions. If the frequency deviation is increased by 3 times, the battery life is reduced by about half.
- Speed drop setting values are another important factor affecting battery life. While the outputs of the analysis give the expected results, it reveals the importance of performing a feasibility study on the measured actual frequency values of a battery to be used for primary frequency control..

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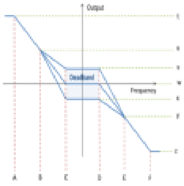
Use of Battery Storage Systems in Primary Frequency Control

- Balancing the grid at a rated frequency requires the management of many different generation resources depending on varying loads. This situation becomes more difficult as the amount of renewable energy sources increases and the traditional generation sources that provide inertia to the system decrease [2].To overcome this problem, the UK main transmission network operator National Grid has defined a new fast frequency service called Enhanced Frequency Response (EFR), which aims to keep the system frequency closer to 50 Hz under normal conditions., BESS is an ideal solution to deliver such a service to the grid[1].



Reference Point	Service 1 (% Capacity)	Service 2 (% Capacity)
l	100%	100%
m	44.44%	48.45%
v	9%	9%
w	0%	0%
x	-9%	-9%
y	-44.44%	-48.45%
z	-100%	-100%

Reference Point	Service 1 (HZ)	Service 2(Hz)
A	49.5	49.5
B	49.75	49.75
C	49.95	49.985
D	50.05	50.015
E	50.25	50.25
F	50.5	50.5

Figure-1 Enhanced Frequency Response service limit values in the UK[2]

- In Figure-1 shows Enhanced Frequency Response service limit values in the UK. According to this graph, two different dead band and response set values can be defined. In Figure-2, the operating range of the battery systems in Germany is given according to the MWh/MW ratio. primary frequency reserve should be maintained for 30 minutes. For example, if a battery has storage capacity of 2.5 MWh and has primary reserve of 1 MW, it should operate in the

Figure-2 Battery operating limit values in Germany [4]

- The maximum frequency deviation value at any sudden loss of generation is critical in system operation. When the battery storage system, which is included in the primary frequency control increases, this deviation value decreases significantly. The main challenge for batteries in primary frequency control is charge level management [1].

Rainflow Counting Method for Estimation of BESS Cycle-Life Degradation

- It is easy to assess fatigue damage in the case of periodic loading. As load history becomes more complex, determining fatigue damage is no longer easy. These values need to be classified. Rainflow cycle counting method was invented to classify load history data into mean stress and amplitude. Figure 3 shows fatigue test case and field use condition load distribution comparison [5].

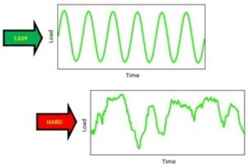


Figure-3Test and field usage loading history chart [4]

In 1967, Tatsuo Endo, suggested a method called “Rainflow Cycle Counting” to classify stress amplitude and mean values any load-time history into its constituent fatigue cycles [5].

The Rainflow algorithm step by step is as follows[6];

1. Reduce the time history to a sequence of (tensile) peaks and (compressive) troughs.
2. Imagine that the time history is a pagoda.
3. Turn the sheet clockwise 90°, so the starting time is at the top.
4. Each tensile peak is imagined as a source of water that "drips" down the pagoda.
5. Count the number of half-cycles by looking for terminations in the flow occurring when either:
a. It reaches the end of the time history
b. It merges with a flow that started at an earlier tensile peak; or
c. It encounters a trough of greater magnitude.
6. Repeat step 5 for compressive troughs.
7. Assign a magnitude to each half-cycle equal to the stress difference between its start and termination.
8. Pair up half-cycles of identical magnitude (but opposite sense) to count the number of complete cycles. Typically, there are some residual half-cycles.

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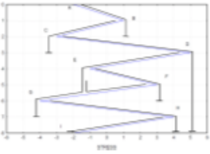

Table 1. Rainflow Cycles by Path		
Path	Cycles	Stress Range
A-B	0.5	3
B-C	0.5	4
C-D	0.5	8
D-G	0.5	9
E-F	1.0	4
G-H	0.5	8
H-I	0.5	6

Figure-4 Rainflow plot and cycles by path [6]

- An example of rainflow cycle identification results of a battery SOC profile shows in Figure 5. In this SOC curve, there are three half cycles, one charging half-cycle (the red one) is discontinuous in time. The green discharging half cycle and yellow charging half-cycle are of the same cycle depth [3].

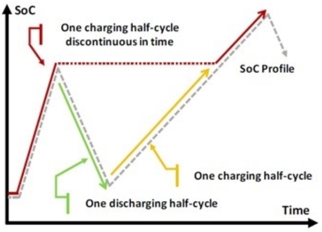

Figure-5 Rainflow Cycle Counting Example [3]

- Estimation of BESS Cycle Life Degradation; Once micro-cycles from the DOD (Depth of discharge) profile are identified, degradation of cycle-life can be estimated using the rated cycle-life curve, which is determined based on empirical methods. Degradation of cycle-life for each of the incurred cycles is then obtained and summed up to estimate the total degradation using following equation [7].

- $D_{CL} = \sum_{j=1}^{n} \frac{Cycle\ of\ R_j}{Ax\,(R_j)^B} x100\%$ (1)

- where, DCL is the degradation of cycle-life, Rj is the range of j-th micro-cycle in the DOD time history, n is the total number of cycles, A and B are empirical parameters to determine rated cycle-life at different DOD ranges [7].

A Case Study of Battery Cycle Life Degradation While Operating as Primer Frequency Controller

- In this paper, a daily real frequency measurement of the ENTSO-E System is used. The analyzes were carried out with the approach that the same frequency change occurs on other days of the year.

- Initially, frequency response of 10 MW battery has been analysed. Analyses were repeated for 5mHz, 10mHz and 15 mHz dead band values and increasing the frequency deviation and the battery SOC change was recorded.

- Deadband is one of the fundamental concepts in frequency control terminology. It is defined as the frequency deviation magnitude to which the unit participating in the control does not respond. . In battery systems, it is a necessity to apply a certain amount of dead band. If the dead band is not applied, the battery output power cannot be adjusted to the initial set point of 50% charge after the response due to frequency deviation. In order to solve this problem, it does not react to the frequency deviation of the battery at a certain dead band value and performs a charge or discharge process in order to reach the charge level to 50%.

- SOC graphic in 5 mHz dead band value of 10 MW battery is shown in Figure-7.

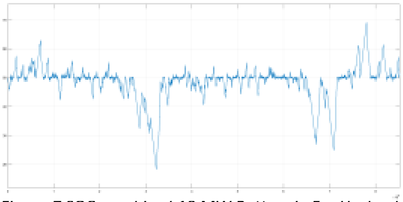

Figure-7 SOC graphic of 10 MW Battery in 5 mHz dead band

Conclusion

- In this study, degradation of battery which performs primary frequency control was evaluated by rain flow counting algorithm. The analyses were repeated at constant speed droop value with different dead band and different frequency deviation. Battery life is significantly increased under high deadband operating conditions. If the frequency deviation is increased by 3 times, the battery life is reduced by about half. Speed drop setting values are another important factor affecting battery life. While the outputs of the analysis give the expected results, it reveals the importance of performing a feasibility study on the measured actual frequency values of a battery to be used for primary frequency control.
- Calculating the battery life and determining the appropriate operating mode (peak shaving, arbitrage, etc.) will be the subject of future studies in case the battery is used for different purposes in the power system.