

Improving Power Quality and Reliability of Distribution Network by Battery Energy Storage Systems

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Abstract: In the last few decades, the power sector has evolved very significantly. While traditional systems relied minimally on electricity storage, the rise of RE Sources (Renewable Energy) and advancements in storage technologies have shifted the landscape. Energy storage now offers vital benefits like supply-demand flexibility, operational efficiency, and price arbitrage. Specifically, Battery Energy Storage Systems (BESS) have emerged as a leading solution for load following, peak shaving, frequency regulation, and enhancing grid reliability and provides many ancillary services. However, because BESS involves high capital costs, determining their optimal placement within a distribution system is critical. Since the ideal location often depends on the system's scale, placement and sizing must be addressed simultaneously. This paper presents a practical approach for siting BESS across multiple candidate locations, validated on IEEE 16-bus test distribution system.

Keywords: BESS, Power Quality, Reliability Indices, SAIDI, SAIFI.

1. INTRODUCTION

The Mumbai grid failure on 12th October 2020, caused a massive blackout that paralyzed the city's Commercial, Industrial and Residential sectors. This disruption halted critical services, including hospitals and train networks, causing widespread chaos. While power was restored in phases—prioritising essential services—the incident underscored the urgent need for a more resilient and robust power infrastructure.

In Mumbai's distribution network, industrial consumers requiring 24/7 power are particularly vulnerable; even minor fluctuations in power quality or reliability can result in catastrophic economic losses. A primary challenge in grid management is maintaining frequency stability, which is traditionally handled by large generators. However, these generators are often slow, inefficient, and expensive to operate.

Battery Energy Storage Systems (BESS) offer a superior alternative. Unlike traditional generators, BESS can provide both active and reactive power within milliseconds, smoothing frequency deviations and stabilizing the grid within narrow limits. Consequently, this paper proposes the optimal placement of BESS to enhance the reliability and performance of distribution system / networks.

2. ISSUES RELATED TO ELECTRICAL DISTRIBUTION SYSTEM

2.1 Power Quality

The IEEE defines the power quality (PQ) as the “concept of powering and grounding sensitive electronic equipment in a manner that is suitable to the operation of that equipment”. It encompasses voltage, current, and frequency deviations that can cause equipment malfunction, failure, or, in the case of sensitive equipment, poor performance.

For distribution utilities, equipment manufacturers, and consumers alike, power supply quality has become a critical deliverable. Driven by the use of non-linear power electronic loads, Power Quality (PQ) represents the integration of both voltage and current quality. Any deviation from ideal sinusoidal waveforms is classified as a PQ disturbance, encompassing issues such as harmonics, flicker, sags, swells, imbalances, and interruptions. To standardise these issues, the IEEE categorises PQ problems into specific terms, including over-voltages, under-voltages, transients, noise etc.

2.2 Reliability of Power Supply

Power system reliability refers to a grid's ability to provide a steady, uninterrupted energy supply while meeting strict quality standards. It measures the system's capacity to satisfy total load demand without compromising voltage or frequency stability. Ultimately, this reliability is essential for modern society, ensuring the operational integrity of all sectors and the resilience of vital infrastructure.

3. CASE STUDY

The solution was tested on IEEE 16 bus distribution network system. The standard schematic diagram is shown in Figure 1 This test distribution network system is modelled and simulated in CYMEDIST software for analysis.

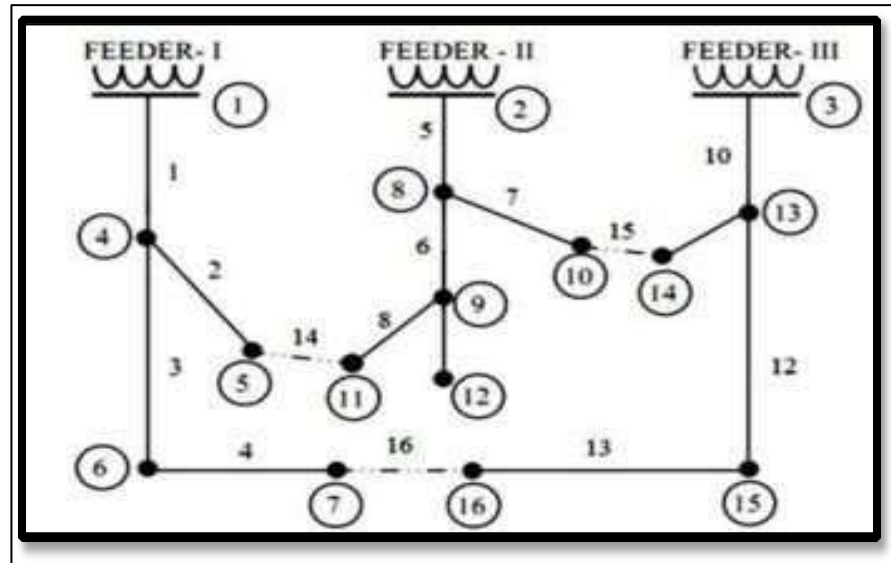


Figure 1. IEEE 16 Bus System

Table 1. Parameters of IEEE 16 Bus System

Line No	From Bus i	To Bus j	R (Ω) P.U	X (Ω) P.U	Receiving Bus j	
					P	Q
1	1	4	0.075	0.10	2.0	1.6
2	4	6	0.09	0.18	2.0	-0.4
3	4	5	0.08	0.11	3.0	0.4
4	5	11	0.04	0.04	-	-
5	6	7	0.04	0.04	1.5	1.2
6	9	11	0.11	0.11	0.6	-0.5
7	2	8	0.11	0.11	4.0	2.7
8	8	9	0.8	0.11	5.0	1.8
9	8	10	0.11	0.11	1.0	0.9
10	9	12	0.8	0.11	4.5	-1.7
11	7	16	0.12	0.12	-	-
12	15	16	0.4	0.4	2.1	-0.8
13	10	14	0.04	0.04	-	-
14	13	14	0.9	0.12	1.0	-1.1
15	3	13	0.11	0.11	1.0	0.9
16	13	15	0.8	0.11	1.0	0.9

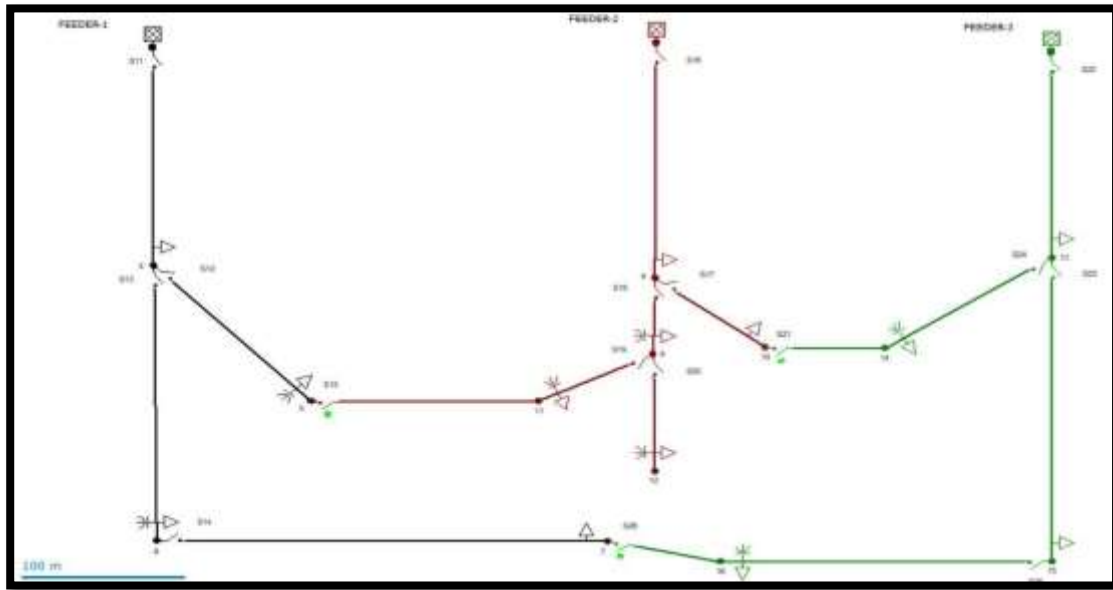


Figure 2. IEEE 16 BUS System as simulated in CYME software

Battery energy storage system (BESS) is applied to each feeder at strategic location. Figure 3. Shows the IEEE 16 bus system with BESS application.

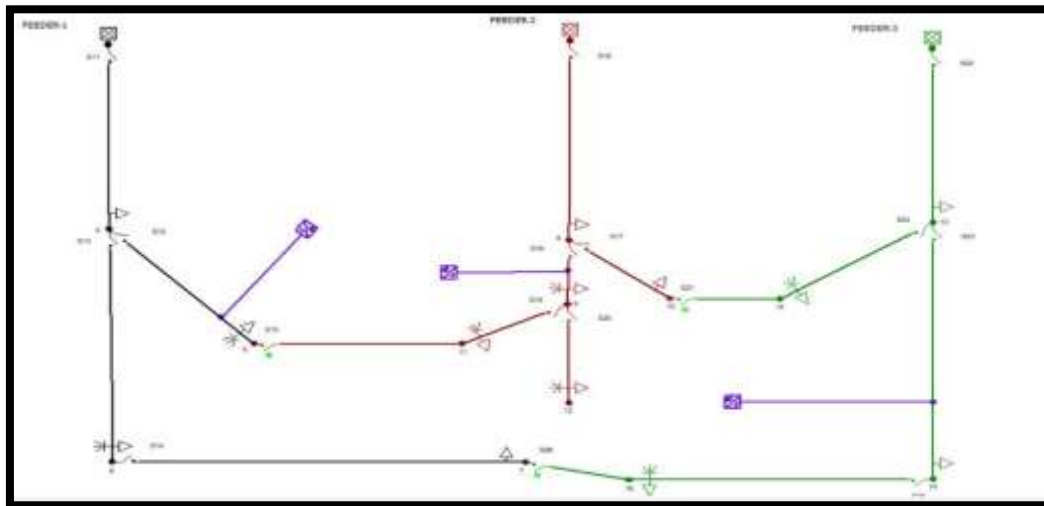


Figure 3. IEEE 16 BUS System with BESS as modelled in CYME software

BESS is applied to one of the feeder in Mumbai distribution network to check its power quality and reliability indices.

4. RESULTS

When the BESS is inactive, the reliability indices are recorded in Section A of Table 1. However, with the BESS connected, it immediately assumes the full load following a power supply failure. Consequently, the reliability indices drop to zero, as customers experience no interruption in service.

Table 2. Reliability Indices of Distribution System

	Without BESS (A)			With BESS (B)		
FEEDER	SAIFI	SAIDI	CAIDI	SAIFI	SAIDI	CAIDI
FEEDER 1	8.75	17.27	1.97	0	0	0
FEEDER 2	8.75	18.75	2.14	0	0	0

FEEDER 3	8.75	19.12	2.18	0	0	0
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When the battery's capacity is only sufficient to support a portion of the load, the resulting reliability indices are detailed in Section B of Table 3.

Table 3. Reliability Indices of Distribution System with partial BESS Capacity

	Without BESS (A)			BESS with partial capacity (B)		
FEEDER	SAIFI	SAIDI	CAIDI	SAIFI	SAIDI	CAIDI
FEEDER 1	8.75	17.27	1.97	6.55	16.37	2.50
FEEDER 2	8.75	18.75	2.14	6.55	16.21	2.48
FEEDER 3	8.75	19.12	2.18	6.55	16.57	2.53

Reliability indices are measured as follows: SAIFI in interruptions per customer-year, SAIDI in hours per customer-year, and CAIDI in hours per customer-interruption. Results indicate that integrating a BESS into the distribution system significantly enhances these reliability metrics.

As illustrated in the CYME power flow curves (Figures 4a, 4b, and 4c), the BESS automatically discharges during supply drops to bridge the generation-demand gap across various load profiles.

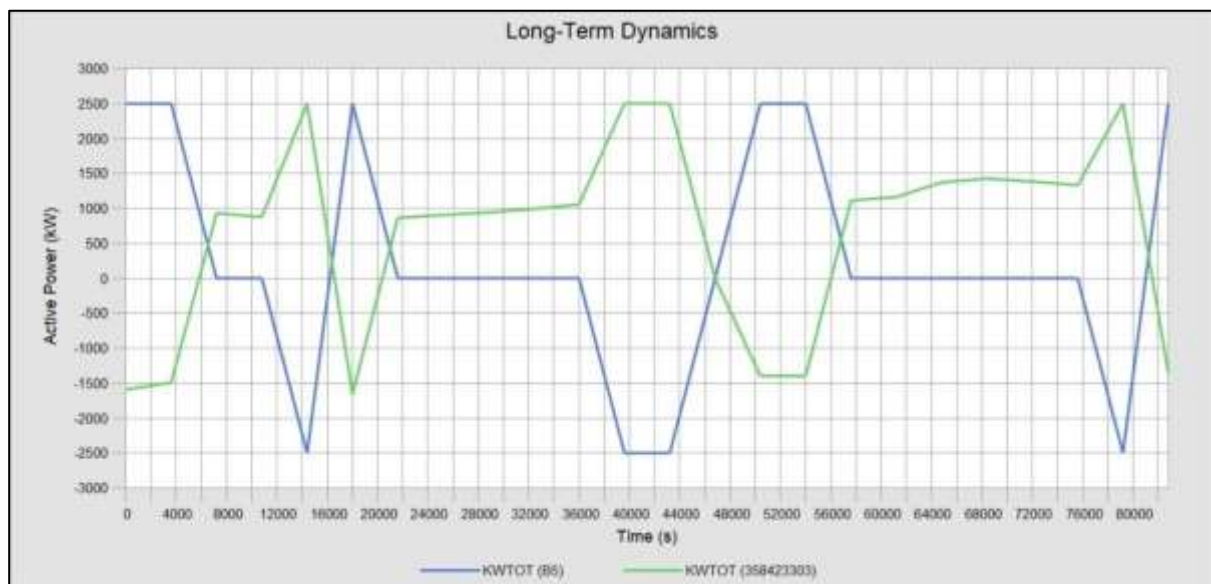


Figure 4a. Active Power Waveform for Battery-5 and Load 358423303 with scenario-1

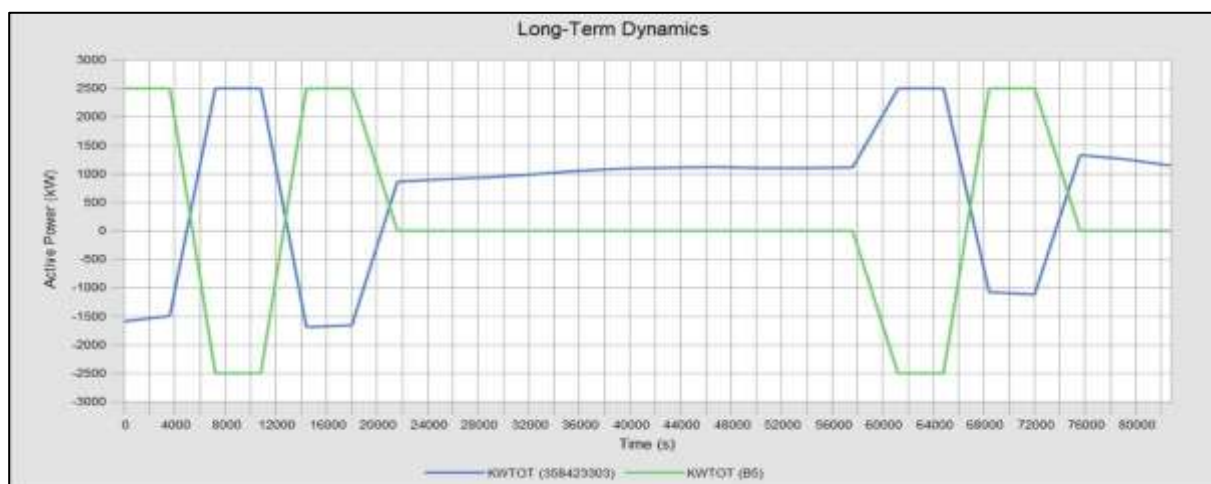


Figure 4b. Active Power Waveform for Battery-5 and Load 358423303 with scenario-2

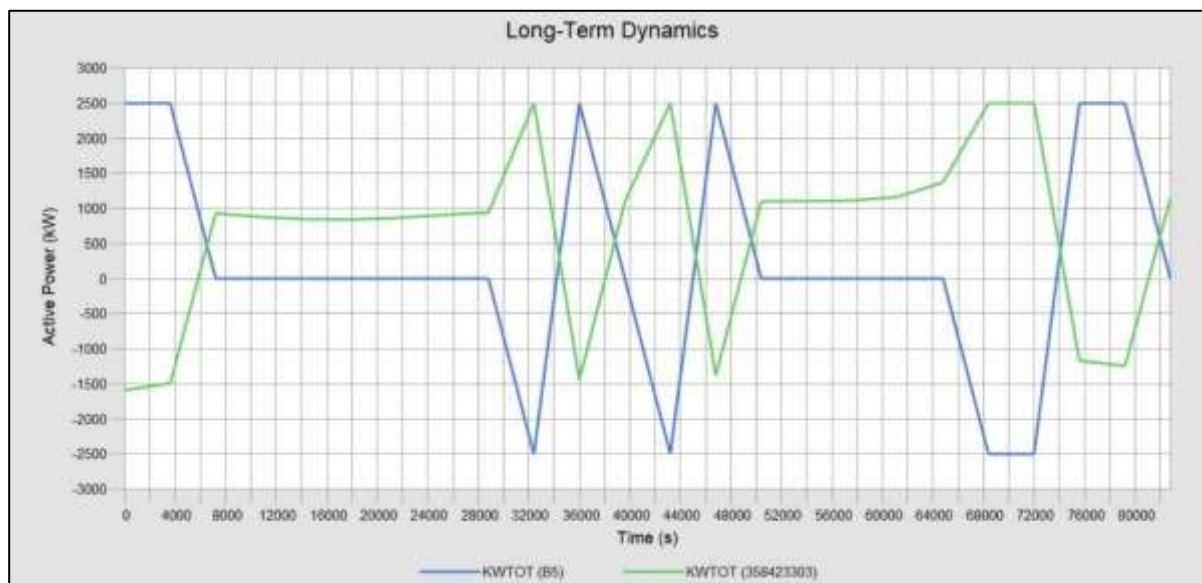


Figure 4c. Active Power Waveform for Battery-1 and Load 357296029 with scenario-3

6. DISCUSSION AND CONCLUSION

Strategic BESS deployment significantly enhances distribution network reliability by providing rapid responses to disturbances and ensuring an uninterrupted power supply. This effectively lowers both the frequency and duration of outages, as evidenced by improved reliability indices like SAIDI (System Average Interruption Duration Index) and SAIFI (System Average Interruption Frequency Index).

As shown in Figure 4, the BESS discharges power during voltage absences and automatically disconnects once the system voltage is restored. While BESS integration substantially boosts power quality and reliability, achieving these benefits depends on selecting a system with an appropriate capacity rating

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