Study Committee C1

Power System Development and Economics

Paper 10222_2022

STORAGE PLANNING – TEXTBOOK OR SECRET SAUCE?

Michael ABDELMALAK, Cedric BASSIL, Michele PASTORE, Aaron SNYDER*, Vadim ZHEGLOV

EnerNex

United States of America

Motivation

- With the advent of Distributed Energy Resources (DERs), there was a change in the typical distribution planning approach, from simple “design by the book” to more complex studies and simulations. Energy storage also gave planners new ways to solve energy delivery problems
- Aim of this paper is to proposes an assessment framework to evaluate the impacts of different battery energy storage system locations settings on the reliability of distribution system.

Approach

- The proposed framework compares three BESS location propositions in terms of reliability impact: feeder-centralized (1 BESS), sub-feeder centralized (3 BESS), and distributed (6 BESS)
- Reliability is measured by several indices that will help decision makers evaluate a system. SAIDI (System Average Interruption Duration Index) is a popular and widely used index.
- In this paper, a DC power flow and mixed integer linear programming are leveraged to formulate the objective function and network constraints considering the behavior of the BESSs.
- The proposed approach is applied to the IEEE 33-node distribution feeder for validation. The IEEE-33 node distribution system is characterized by 33 buses, 32 branches, 5 tie-lines, 3 laterals, and operating voltage of 12.66 kV. The total peak demand of the system is 3715 kW
- A Genetic Algorithm (GA) is used to investigate potential optimal location of BESS.
- Finally, a comparison between the optimal locations of BESS devices determined by GA and the predefined locations in this paper for the distributed BESS configuration is provided.

Objects of investigation

- Given a specific failure scenario, the status of each system component is obtained and injected into a DC optimal power flow to determine the amount of load curtailment and the number of unserved customers. Considering the role of the BESS, the value of load curtailment for a specific failure scenario will change. Also, the duration for supplying the impacted nodes depends on the state of charge of the BESS. In this paper, we have simulated centralized and distributed battery configurations. We have also compared two control strategies of BESS: back-up and normal operation. Fig. 1, 2, 3, and 4 show the flowcharts of reliability evaluation for different BESS topologies and control strategies.
- The effectiveness of the proposed method to evaluate the reliability level based on different BESSs topology is demonstrated through four different cases: 1) base case, 2) feeder centralized BESS, 3) sub-feeder centralized BESSs, and 4) distributed BESSs. The base case shows the system performance without BESS compared to the other cases. In the feeder-centralized BESS location, the BESS is installed at the head of the feeder. In the sub-feeder centralized topology, BESSs are installed at the start of each sub feeder as shown in Figure 5. Finally, the distributed topology shows installation of BESSs at randomly selected locations, as shown in Figure 6. Although the overall performance relies on the capacity of the installed BESS, we have selected the BESS size to supply the system nominal load demand for a 4-hour period.

Conclusion

- The results showed that the locations of BESS have a significant impact on the reliability of the distribution systems, no matter the placement methodology, providing distribution system planners with some comfort in their expertise while indicating a clear path to improvements using simulations. It also showed that distributed BESSs improves the reliability of the system because of the radial topology configuration of distribution systems.

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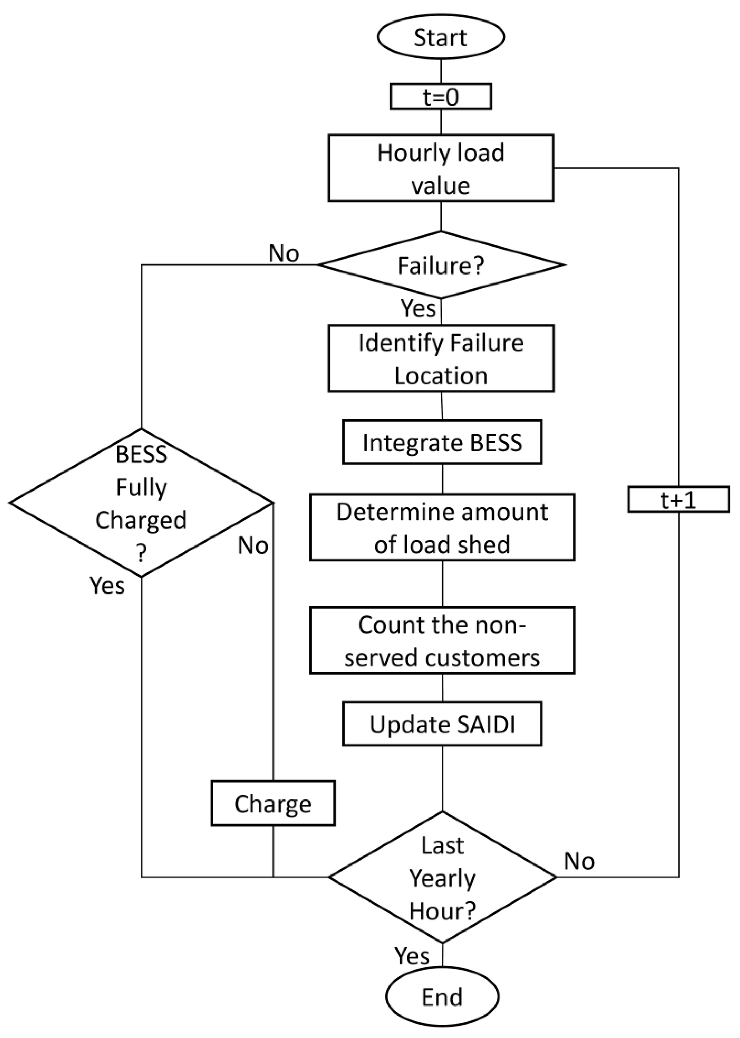

Figure 1. Flowchart for **centralized** back-up BESS

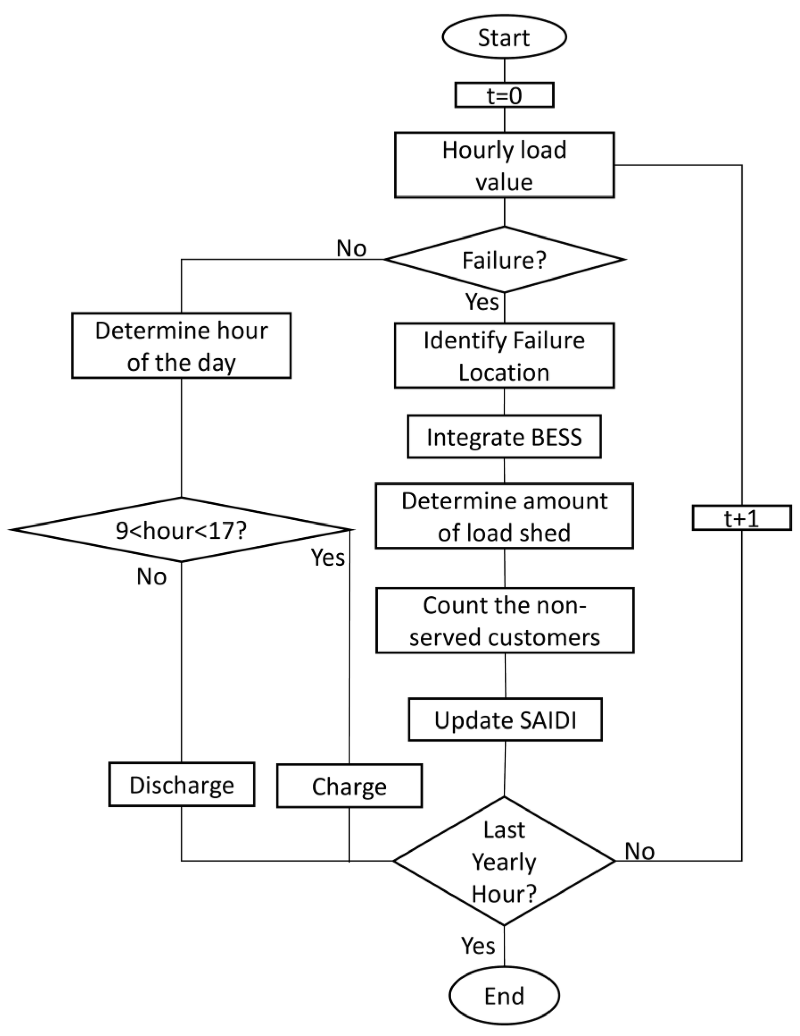

Figure 2. Flowchart for **centralized** normally operating BESS

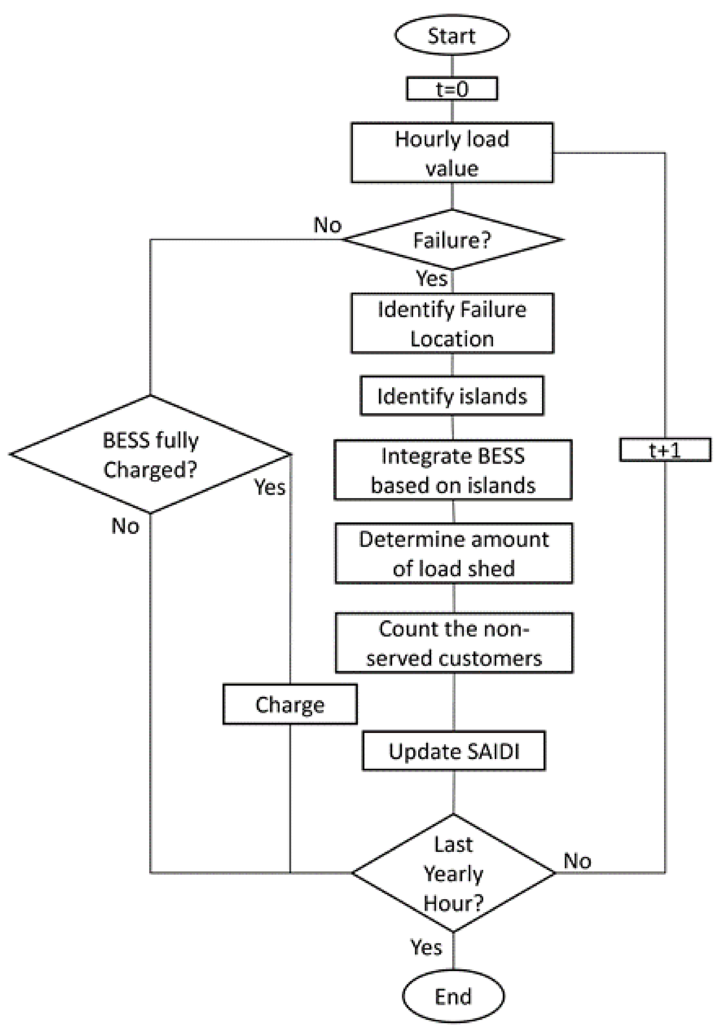

Figure 3. Flowchart for **distributed** back-up BESSs

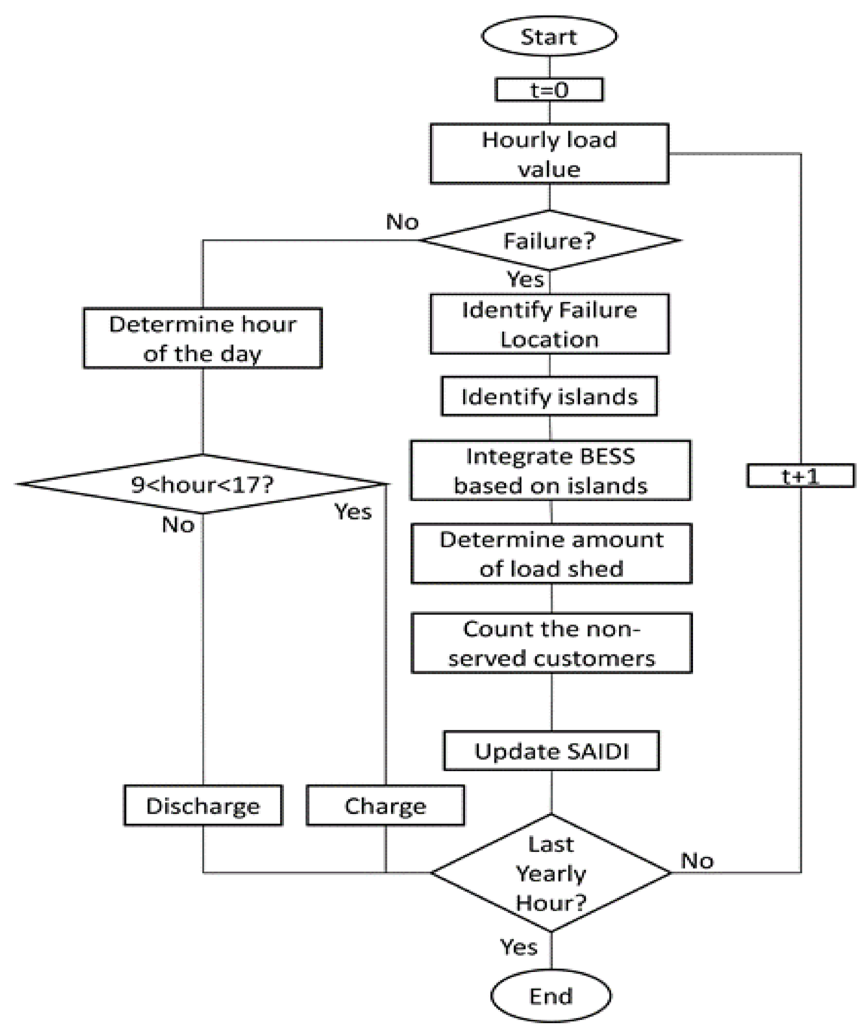

Figure 4. Flowchart for **distributed** normally operating BESSs

Experimental setup & test results

- The effectiveness of the proposed method to evaluate the reliability level based on different BESSs topology is demonstrated through four different cases: 1) base case (NO BESS), 2) feeder centralized BESS, 3) sub-feeder centralized BESSs, and 4) distributed BESSs.
- Although the overall performance relies on the capacity of the installed BESS, we have selected the BESS size to supply the system nominal load demand for a 4-hour period. The power rating of BESS depends on the case under study. The BESS power is 3.72MW and total energy of 14.88MWh. In sub-feeder centralized distribution, BESS1 (nodes 23,24,25) is 0.93MW/3.72MWH, BESS2 (nodes 19, 20, 21, 22) is 0.36MW/1.44MWH, and BESS3 (rest of the system) is 2.43MW/9.72MWH. In decentralized case, we have 6 BESS units, each is 1MW/4MWh.

Scenarios:

<u>1. BESS as back-up</u>

In this case, the BESS is assumed to be fully charged prior to the occurrence of failure. The simulations are run for the four topologies under the two failure scenarios.

<u>2. BESS normal operation</u>

In this case, the BESS is assumed to operate under normal conditions in a way that it charges during daytime and discharges during the night. The charge cycle starts at 9:00 and ends at 17:00; whereas the discharge cycle starts at 17:00 and ends when the BESS gets depleted. This scenario matches with using solar to charge the BESS during the day (or the grid when not possible), then using the BESS to alleviate the evening or after sundown peak. In this case, the results may vary based on the failure instance relative to the BESS charge state. For instance, if a failure takes place while BESS has enough charge, then this will improve the reliability of the system. The failure scenario used in case 1 is applied for this case as well. Table 2 summarizes the results.

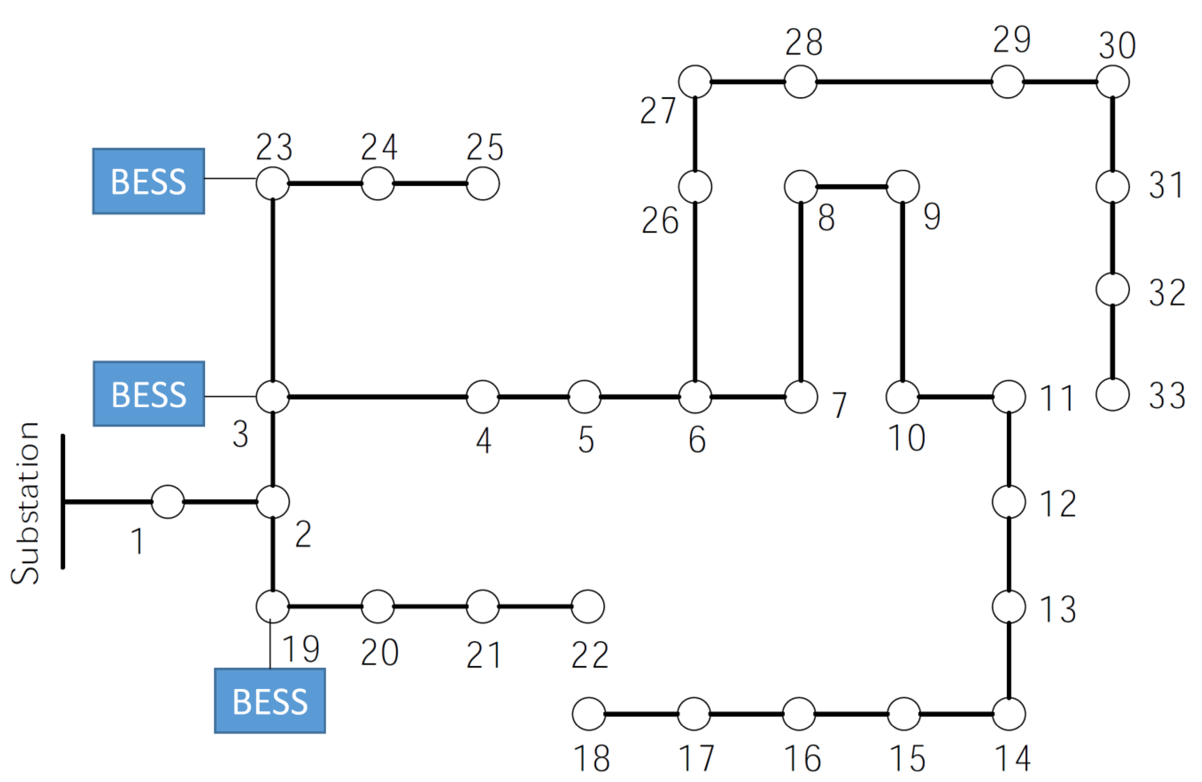

Figure 5. Sub-feeder centralized BESSs

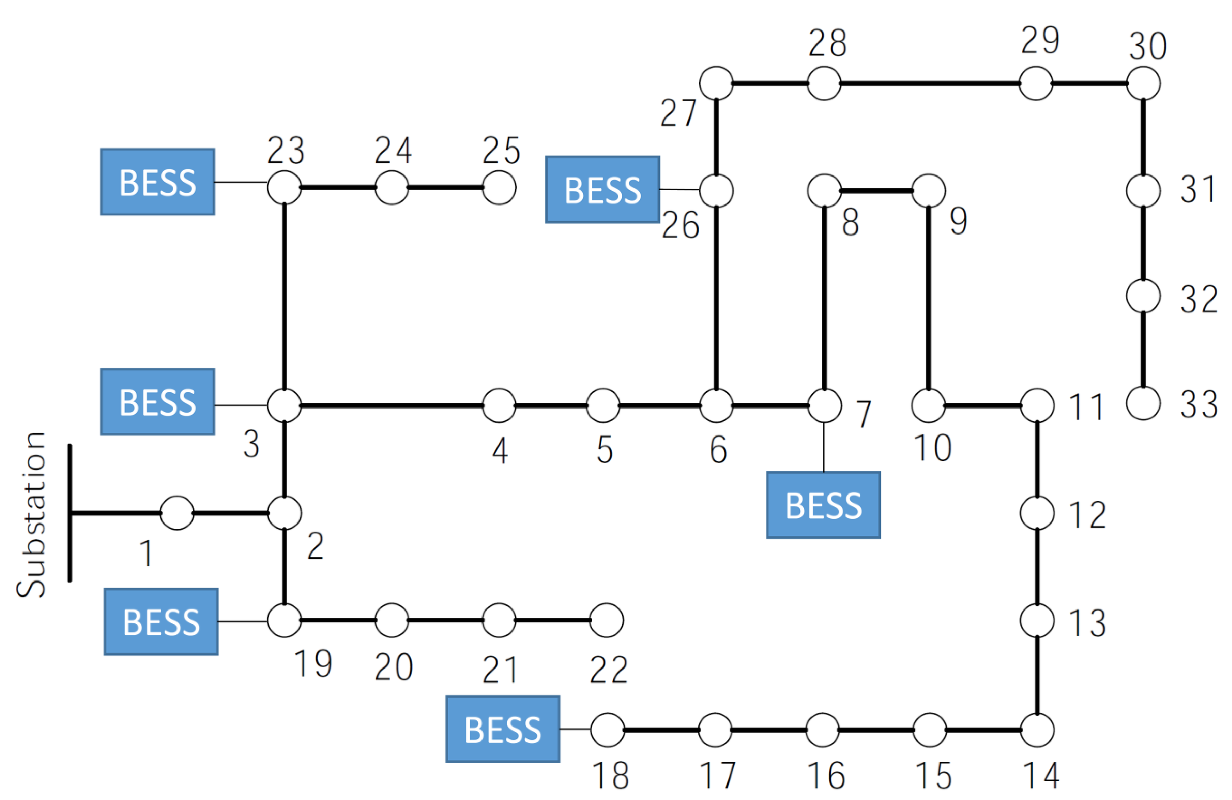

Figure 6. Distributed BESSs

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Discussion

As Table 1 shows, the SAIDI decreases by adopting distributed installation topology of BESSs. For the main feeder failure case, the SAIDI differs for various reasons. First, the BESS acts as a secondary generation source and supply load demand based on the available BESS charge. The sub-feeder centralized topology shows slightly lower SAIDI compared to the feeder centralized topology because the BESSs at each sub-feeder helps to have less system losses yielding longer power supply.

The distributed topology shows the lowest SAIDI value as more generation capacity by the BESSs are available. On the other hand, almost the same SAIDI value is observed for the random failure scenario except for the distributed topology. Due to the random failure locations, islanding will take place. The BESS will supply unserved nodes of islands as long as the BESS is installed at any of the unserved locations. Such nodes were completely disconnected in other BESS topologies.

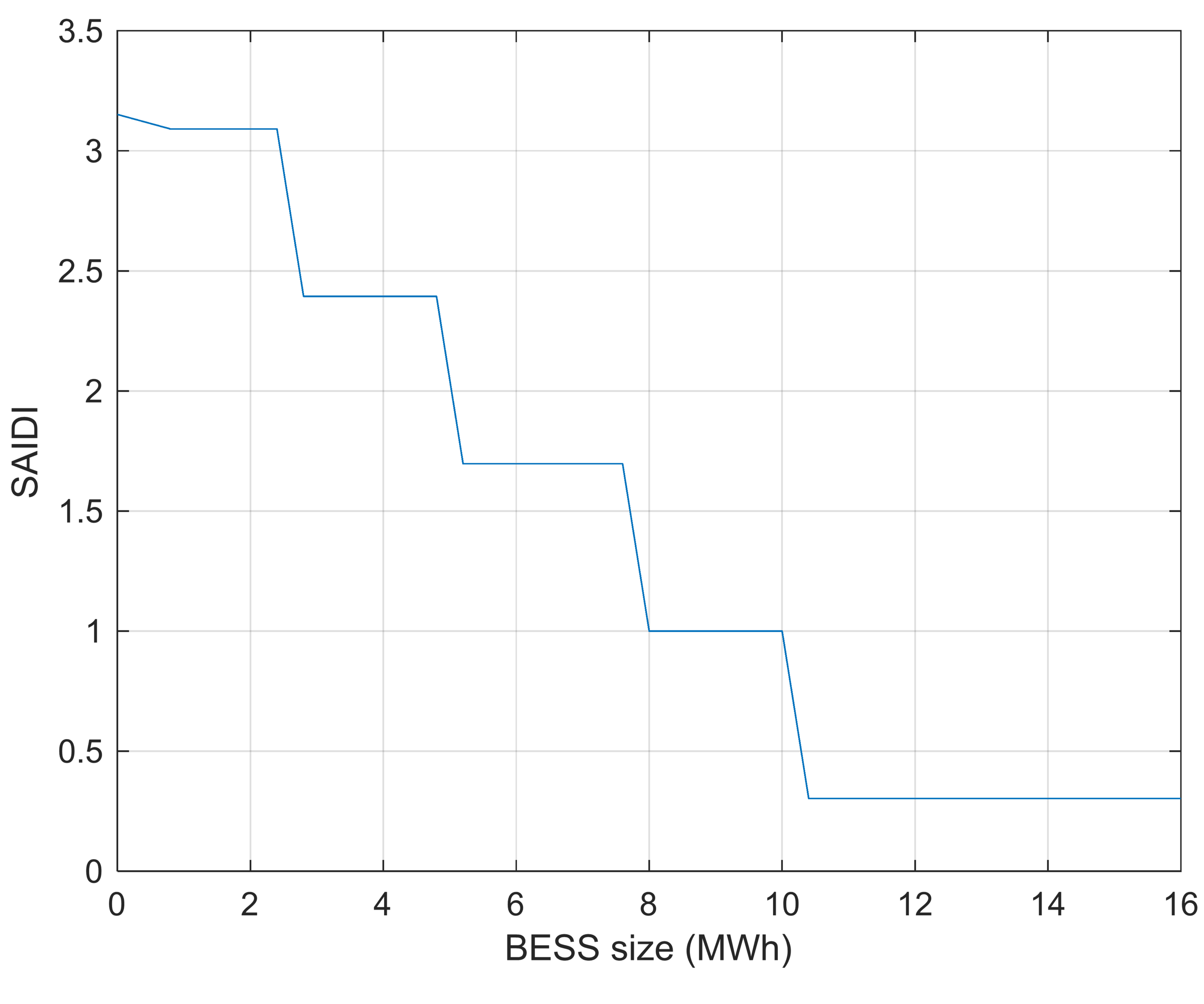
SAIDI (hour)	Scenario	Base case	Feeder centralized BESS	Sub-feeders centralized BESSs	Distributed BESSs
Main feeder failure	Back-up	12.61	0	0	0
Random failures		3.15	3.15	3.15	0.31
Main feeder failure	Normally operating	12.61	11.0	10.66	9.69
Random failures		3.15	3.15	3.15	1.06

To capture the stochastic behavior between failure instant and BESS charge state, we have simulated 1000 different failure scenarios. Each scenario has 5 failure instances randomly distributed over the period of one year with an average outage duration of 2 hours.

SAIDI (hour)	Base case	Feeder centralized BESS	Sub-feeders centralized BESSs	Distributed BESSs
Random 1000 failures	26.15	26.15	26.15	21.5

<u>3. Relationship between BESS size and SAIDI</u>

In this case, the distributed BESS topology is used to determine the correlation between their size and the reliability levels. As the size of BESS increases, the SAIDI decreases yielding better reliability. This is due to the higher available capacity of BESS in islanded portions of the system. However, for BESS more than 10 MWh, the reliability is maintained constant implying no further improvement.



<u>4. Comparison between optimal locations and determined locations of BESS</u>

In this case, a GA is used to determine the optimal location of six distributed BESSs. In the formulated GA problem, it is required to minimize the SAIDI value. The GA algorithm is run for 50 iterations with cross over probability of 0.9 and mutation probability of 0.05. A total of 40 chromosomes are selected as population size. To consider the stochastic failure behavior, 100 failure scenarios are generated with unique failure behavior. The solution of the GA is obtained and compared with the predefined distributed BESS locations case and base case (no storage) for the same failure scenarios as shown in the table below. The results show that reliability index is improved by integration of distributed BESS into distribution systems. Although the optimal BESS locations provide improved SAIDI value, the difference between the predefined and the optimal BESS locations is less than 10%. On the other hand, the complexity of modeling and formulating the GA increases dramatically by considering larger and more meshed systems.

	Base case	Predefined BESS locations	Optimal BESS locations
SAIDI (hour)	2.22	1.46	1.29

Conclusion

- The results showed that the locations of BESS have a significant impact on the reliability of the distribution systems, no matter the placement methodology, providing distribution system planners with some comfort in their expertise while indicating a clear path to improvements using simulations. It also showed that distributed BESSs improves the reliability of the system because of the radial topology configuration of distribution systems.