Data Article

Data on reducing carbon footprint in microgrids using distributed battery energy storage

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ABSTRACT

This data presented in this article was collected using simulations on a microgrid system to analyze reduction of carbon footprints using distributed battery storage devices. Analysis was performed over a 24-h period of operation of the microgrid system to reduce the CO₂ emissions from 0% to 100% using battery storage devices. The data can be used in designing efficient microgrid systems, understanding the potential of battery energy storage devices in future electricity generation, and sizing the microgrid systems depending of the CO₂ reduction goals in power systems.

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1. Data

Microgrids have become the most reliable sources of energy generation for future power systems [1]. The main structure of the test system is illustrated in Fig. 1. The microgrid system was simulated in MATLAB software, which included a 400 kW diesel generator, a variable 200–400 kW solar PV connected to the main AC bus using a DC/AC converter and a breaker, and 4 individual battery energy storage systems connected to the main AC bus through 4 standalone DC/AC bi-directional inverters. The fuel consumption or 24-h period is computed based on the percentage of the load from the generator’s data sheet. For example, for 400kW load support by the generator, referring to Ref. [2], the

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The system load was composed of fixed resistive load of 400 kW.

1.1. Case 1: No battery storage

Fig. 2 illustrates the 24-h generation profile of the microgrid system with no battery energy storage devices. As it can be observed, the batteries do not produce any active power and the diesel generator cooperates with solar PV to provide a fixed 400 kW power to the load over a 24-h period. As it can be confirmed in Fig. 2, the solar generation provides its maximum output power (200 kW) in a sunny day (assumption of the simulation) between 11 a.m. and 1 p.m. During this period, the generator’s power is at its minimum (200 kW), which reduces the CO₂ emissions significantly. The average fuel consumption rate (per gallon) for the 24-h operation of the system without any battery energy storage is illustrated in Fig. 3. As it is observed, the fuel consumption significantly reduces when the solar generation is at its maximum (11 a.m.–1 p.m.).

1.2. Case 2: with battery storage

In this case scenario, the system is enhanced with 4 individual battery energy storage systems, as was previously shown in Fig. 1. Each battery storage is rated at 50 kW and can support constant 50 kW over 24-h operation of the system.
Simulation data for this case are illustrated in Fig. 4. As it can be seen, the batteries (all four) support 50 kW of load power over the 24-h period of operation. Therefore, 200 kW of the load power is supported by the batteries. The remaining 200 kW of the load demand is shared between the generator and the solar PV. As it can be seen, during the 11–1 p.m. operating period of the system, the PV generation is at its maximum, and the overall load demand (400 kW) is supported by PV and batteries, therefore, the generator’s power drops to zero. Consequently, the amount of released CO₂ reduces.

Fig. 5 illustrates the average fuel consumption per gallon for the diesel generator in the system for the 24-h period of the operation when all the batteries are in operation. Compared to the first scenario (see Fig. 3), the average fuel consumption has significantly reduced due to the concurrent operation of distributed energy storage devise in the system. It is also observed that the fuel consumption or CO₂ emissions have significantly reduced during 11–1 p.m. period, as was anticipated in Fig. 4.

1.3. Case 3: nonlinear relationship between fuel consumption and output power of generators

Fig. 6 depicts the relationship between the average fuel consumption of diesel generators at gallon per hour rate versus percentage of the demand supplied by the generator. As it can be seen, a 400 kW
generator consumes about 27 gallons of fuel per hour to support a 400 kW load. However, this relationship is not linear, for example, the same generator consumes 10 gallons per hour to support 25% of the demand as illustrated by Fig. 6. Therefore, one should consider the nonlinear relationship of fuel consumption of generators versus the output power when designing a microgrid system.

Fig. 3. Average fuel consumption of the diesel generator during the 24-h period of operation.

Fig. 4. Daily generation profile of the system with batteries.

Fig. 5. Average fuel consumption for 24-h period of the operation for case 2.
1.4. Case 4: CO₂ emissions reduction

In this case, the amount of fuel needed for various CO₂ emission reduction levels for 24-h period of operation are considered in five scenarios. In the first case, the CO₂ reduction is set to 0%, where all the power is provided by the generator. For the second case, the fuel consumption will be reduced by 11.18%, in the third case, it is reduced to 23.69%, in the fourth case, it is reduced to 38.54% and finally, 55% fuel consumption reduction is achieved in case 5. Data is illustrated in Table 1; as it can be seen, the total gallons of fuel needed for 24-h operation of the system as well as total CO₂ emissions in kilogram (kg) are shown in Table 1. The CO₂ emission rate is considered as 11.36 kg CO₂ per gallon of fuel [3].

1.5. Case 5: energy storage capacity needed for CO₂ reduction levels

In this case, different CO₂ reduction levels are considered, and the amount of battery energy storage needed to achieve those reduction level with their respected capacity is elaborated. The data for this

| Table 1 | Total gallons needed for CO₂ reduction levels in 5 scenarios. |
|---------|-------------------------------------------------------------|
|         | Case 1          | Case 2         | Case 3         | Case 4         | Case 5         |
| Total gal fuel | 554.5076       | 492.482        | 423.1252       | 340.7912       | 249.1256       |
| Total kg CO₂ | 6,297           | 5,593          | 4,805          | 3,870          | 2,829          |
| Reduction    | 0%              | 11.18%         | 23.69%         | 38.54%         | 55.07%         |

| Table 2 | Total energy storage needed over 24 hours. |
|---------|-----------------------------------------------|
| CO₂ Reduction | Average (kW) | Capacity (MWh) |
| 0%        | 0                 | 0              |
| 10%       | 44.5874           | 1070.098       |
| 11.18%    | 50                | 1200           |
| 20%       | 85.2199           | 2045.278       |
| 23.69%    | 100               | 2400           |
| 30%       | 122.2934          | 2935.042       |
| 38.54%    | 150               | 3600           |
| 40%       | 155.8079          | 3739.39        |
| 50%       | 185.7634          | 4458.322       |
| 55.07%    | 200               | 4800           |
| 60%       | 212.1599          | 5091.838       |
| 70%       | 234.9974          | 5639.938       |
| 80%       | 254.2759          | 6102.622       |
| 90%       | 269.9954          | 6479.89        |
| 100%      | 282.1559          | 6771.742       |
Table 3
Cost analysis of various options in the microgrid system to reduce CO2 emissions.

| Case 1 | Case 2 | Case 3 | Case 4 |
|--------|--------|--------|--------|
| Solar: 200kW Generator: 400kW | Solar: 200kW Generator: 400kW 1 Battery: 50kW, 1,25 MWh each | Solar: 200kW Generator: 400kW 2 Batteries: 100kW, 1,25 MWh each | Solar: 200kW Generator: 400kW 3 Batteries: 150kW, 1,25 MWh each |
| Solar system | $427,000.00 | $427,000.00 | $427,000.00 |
| Diesel generator | $60,470.00 | $60,470.00 | $60,470.00 |
| Diesel fuel | $1,757.79 | $1,561.17 | $1,341.31 | $1,080.31 |
| Batteries | $0.00 | $260,832.00 | $521,664.00 | $782,496.00 |
| Total | $489,227.79 | $749,863.17 | $1,010,475.31 | $1,271,046.31 |

| Case 5 | Case 6 | Case 7 | Case 8 |
|--------|--------|--------|--------|
| Solar: 200kW Generator: 400kW 4 Batteries: 200kW, 1.25 MWh each | Solar: 200kW 4 Batteries: 1,99 MWh each | Solar: 300kW 4 Batteries: 1,73 MWh each | Solar: 400kW 4 Batteries: 1,46 MWh each |
| Solar system | $427,000.00 | $640,500.00 | $854,000.00 |
| Diesel generator | $0.00 | $0.00 | $0.00 |
| Diesel fuel | $789.73 | $0.00 | $0.00 |
| Batteries | $1,043,328.00 | $1,663,640.00 | $1,446,280.00 | $1,220,560.00 |
| Total | $1,531,587.73 | $2,090,640.00 | $2,086,780.00 | $2,074,560.00 |

Fig. 7. Simulated model in MATLAB software.
case is shown in Table 2. For example, as it can be seen, the 20% CO₂ reduction requires about 85 kW average storage rated at about 2-GW hour (GWh). Similarly, for a 50% CO₂ reduction in the test system, 185 kW storage at the capacity of 4.4 GWh is needed.

1.6. Case 6: cost analysis

The last scenario details a cost analysis of various options to reduce CO₂ emissions through various energy storage capacities and solar rated powers. The data is shown in Table 3. The cost for the entire solar PV system per kW was considered a $3,050 before 30% tax credit reduction [3], the diesel generator cost for a 400kW diesel generator was considered as $60,470 [4], the diesel generator fuel was considered $3.17 per gallon [5], and Lithium-ion energy storage battery cost was considered $209 per kWh [6]. The data can easily be updated for different costs on a yearly basis. It is observed that the most affordable case is when there is no battery energy storage in the system, however, as was discussed in previous scenarios, the CO₂ emissions are at their maximum when there is not battery energy storage in the system. However, once the battery is implemented (case 4 for example) the system cost would be double, however, the CO₂ emission reductions are significant (see previous scenarios).

2. Experimental design, materials, and methods

The simulated model was designed in MATLAB Simpower System toolbox, where a detailed tutorial for developing microgrids in MATLAB is included in Ref. [7]. The simulated model is illustrated in Fig. 7. The system is composed of a fixed 400 kW load, a solar array, which receives input irradiance and generates the output AC power using a DC/AC converter. The model was available in Microgrid library [7], and the input was generated using a probability distribution function (PDF) block in MATLAB library. The diesel generator was also available in the library and the inputs (voltage and frequency) was set to 1 per unit. The energy storage modules were also available in microgrid library [7] and their inputs were modified based on available power (mismatch between the load power and total generation (synchronous generator and solar PV)). The entire system was connected to the main grid (ideal voltage source) at the beginning and a breaker was used to isolate the system from the grid after 0.01 seconds.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.dib.2019.104679.

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