CHAPTER 3

Modeling and Design of DC Microgrid with HESS

Power management in a DC microgrid is a critical aspect of designing a reliable and efficient energy system. Calculating the capacity of the microgrid is fundamental to ensuring that energy generation, storage, and distribution components are optimally sized to meet dynamic power demands. Analyzing load requirements allows the microgrid to handle both peak and average demands efficiently, avoiding overloading or underutilization of resources. Precise sizing of energy storage systems, such as batteries and supercapacitors, is vital for maintaining system stability, ensuring adequate energy reserves, and managing rapid fluctuations in demand. Similarly, determining the photovoltaic (PV) model capacity enables the efficient use of renewable energy, ensuring sufficient power supply for both load demands and energy storage needs. Overall, capacity calculations and power management strategies facilitate a balanced, scalable, and sustainable microgrid system that meets current and future energy requirements.

3.1 Capacity of Proposed DC Microgrid (40KWh)

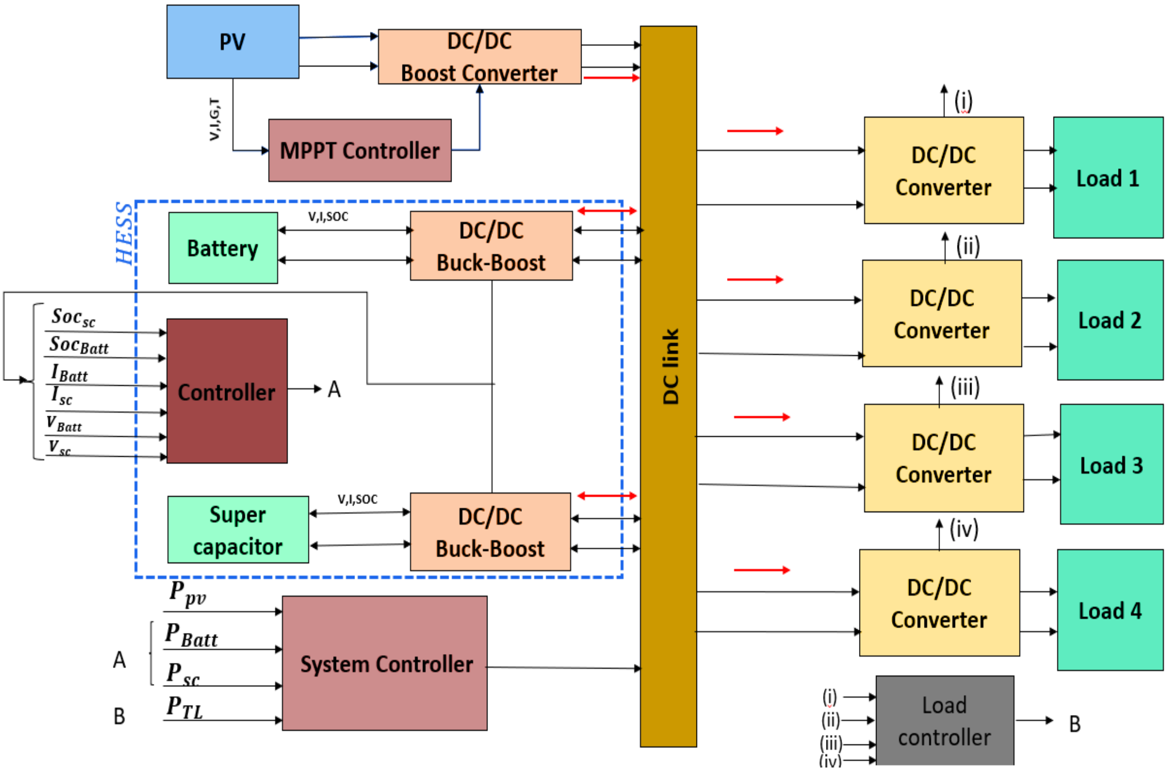

Figure 3. 1 Block diagram for DC Microgrid (40KWh)

Figure 3.1 illustrates a reliable power management system that integrates renewable energy generation with energy storage to meet varying load demands efficiently. The diagram represents a hybrid energy storage system (HESS) integrated with a photovoltaic (PV) system to supply power to various loads via a common DC link. The system begins with a PV module that converts solar energy into electrical power. The generated power from the PV module is regulated by a DC/DC boost converter, and the Maximum Power Point Tracking (MPPT) controller ensures that the PV system operates at its maximum efficiency.

The hybrid energy storage system consists of a battery and a supercapacitor, each connected to the DC link through separate DC/DC buck-boost converters. A controller manages the charging and discharging of both storage devices based on their state of charge (SOC), voltage, and current levels. The controller collects key parameters such as the state of charge of the battery, the state of charge of the supercapacitor, battery current, supercapacitor current, and their respective voltages. The system also includes a centralized system controller that manages the overall power flow within the network. It monitors the power generated by the PV system, the power from the battery, the power from the supercapacitor, and the total load demand. Based on these inputs, the system controller decides how much power to draw from the storage devices or the PV module to meet the load demand. On the load side, the DC link supplies power to four different loads through individual DC/DC converters. The load controller manages the distribution of power to these loads, ensuring that each load receives the required amount of power. The power outputs to the loads are labeled as (i), (ii), (iii), and (iv) in the diagram.

Overall, the system ensures continuous power supply by balancing generation, storage, and load requirements.

3.1.1 Load Analysis

The calculation of daily energy consumption is crucial for evaluating the energy requirements of a system. Understanding the total energy demand makes it possible to design and optimize energy storage systems, generation units, and overall energy management strategies. This approach ensures efficiency, reliability, and sustainability in meeting the energy needs of the system.

To determine the total daily energy consumption of the given loads, the energy consumption for each load is calculated by multiplying its power rating by the duration of its daily operation. The total daily energy consumption is then obtained by summing the energy consumption of all individual loads [161].

The energy consumption E for each load can be calculated using the formula:

$$\text{Energy Consumption}(E) = \text{Power}(P) * \text{Operating Hours}(t) \tag{3.1}$$

The load demands of the DC microgrid are specified as follows, where **P** represents the power in kilowatts (kW) and **t** denotes the operating hours:

Load 1 operates for 2 hours with a power consumption of 4 kW.

Load 2 operates for 4 hours with a power consumption of 4 kW.

Load 3 operates for 4 hours with a power consumption of 4 kW.

Load 4 operates continuously for 24 hours with a power consumption of 3 kW.

These values represent the operational profiles of the various loads, contributing to the overall power consumption and operational dynamics of the DC microgrid system.

Total Load demand = 15 KW

Calculations for Current and Resistance:

The load current [162] can be calculated as:

$$\text{Load current} = \frac{\text{The load demand}}{\text{Voltage}} \tag{3.2}$$

$$= \frac{15000\text{W}}{380\text{V}}$$

$$= 39.47\ \text{A}$$

The corresponding load resistance R is given by:

$$\text{Load Resistance(R)} = \frac{\text{Voltage}}{\text{Load current}} \tag{3.3}$$

$$= \frac{380}{39.47}$$

$$= 9.62\ \Omega$$

Energy consumption, load current and load resistor parameters are critical for system design and analysis, particularly for evaluating electrical losses, ensuring compatibility of components, and maintaining system stability. These calculations also serve as the foundation for assessing the performance and sizing of energy storage systems, ensuring that they can supply the required energy without exceeding operational limits. Moreover, understanding the total load demand, current, and resistance facilitates accurate modeling and simulation of the system, which is critical for predicting performance under various operating conditions.

3.1.2 Specification and Solar Capacity Calculation for Adani 530Wp Bifacial PV Modules

Module Details:

Adani 530Wp (ASB-M10-144-AAA) Bifacial PV modules Monocrystalline

Peak power P_{max} $(W_P) = 530\ W_P$ (Watt-Peak per unit area)

Maximum Voltage, $V_{mpp}(V)$ = 41.49 V

Maximum Current, $I_{mpp}(A)$ = 12.79 A

Open CKT Voltage, $V_{oc}(V)$ = 48.57 V

Short CKT current, $I_{sc}(A)$ = 13.70 A

Module efficiency (%) = 20.61 %

Temp. range: -40 ℃ to +85 ℃

Irradiation (G) = 1000 W/m^2

Cell Temp. = 25 ℃

Tolerance = $\pm$ 3%

Uncertainty = < 3%

To determine the optimal configuration of the solar PV system to meet the energy requirements. By considering the module specifications and load demands, the system is designed to achieve maximum efficiency while maintaining operational reliability.

Solar System Calculations:

- **Total Number of Panels Required:**

To determine the number of panels, the total load demand is divided by the power rating of each panel:

$$\text{Total No. of Panels required} = \frac{\text{Total load demand}}{\text{Power Rating of Each Panel}} = \frac{15000\text{W}}{530\text{w}} = 28.3 = 28$$

- **System Capacity:**

  The system capacity is the product of the total number of panels and the power rating of each panel:

$$\text{System capacity} = 28 * 530 = 14{,}840 \text{ W}$$

- **Number of Panels in Series:**

  The number of panels in series is calculated by dividing the system voltage by the voltage at maximum power (Vmpp)

$$\text{No. of Panels in Series} = \frac{\text{system voltage}}{V_{\text{mpp}}} = \frac{380}{41.49} = 9.16 = 9$$

- **Number of Panels in Parallel Strings:**

  The number of panels in parallel strings is the ratio of the total number of panels to the panels in series:

$$\text{No. of Panels in Parallel Strings} = \frac{\text{Total Panels}}{\text{No.of Panels in Series}} = \frac{28}{9} = 3.11 = 3$$

- **Voltage of PV Array (Vpv):**

  The total voltage of the PV array is determined by multiplying the number of panels in series by (Vmpp):

$$V_{\text{pv}} = 9 * 41.49 = 373.41 \text{ V}$$

- **Current of PV Array (Ipv):**

  The total current of the PV array is calculated by multiplying the number of panels in parallel strings by the current at maximum power (Impp):

$$I_{\text{pv}} = 3 * 12.79 = 38.37 = 40 \text{ A}$$

- Total Power of PV Array (Ppv):

  The total power of the PV array is the product of the total number of panels and the power rating of each panel:

$$P_{\text{pv}} = 27 * 530 = 14{,}310\ W$$

3.1.3 Battery Capacity Calculation

When designing a battery bank for energy storage, it is essential to calculate the required battery capacity based on the system's load and operating time. The following steps outline the process of determining the necessary number of batteries, their capacity, and their configuration to meet the energy requirements of the system.

Nickel-Metal Hydride (Ni-MH) Battery Specifications:

48 V, 10000mAh= 10Ah, 480 Wh, Discharge Current = 10 A, Efficiency: 60-80%

1. **Number of Batteries in Series:** To determine how many batteries need to be connected in series to achieve the required system voltage, we use the following formula.

$$\text{No. of battery in series} = \frac{\text{Systen Voltage}}{\text{Battery Voltage}} = \frac{380}{48} = 7.92 \approx 8$$

2. **Battery Bank Voltage:** The battery bank's total voltage is the product of the number of batteries in series and the voltage of each battery.

$$\text{Battery bank voltage} = 48 * 8 = 384\ \text{V}$$

3. **Ampere-hour (Ah) of the Battery:** The required battery capacity in Ah. depends on the load, the required backup time, and the depth of discharge (DoD). The formula is as follows.

$$\text{Ah of the battery} = \frac{15000\ \text{W(Load)} \times 6\ \text{hrs(t)}}{384\ \text{V(bat.V)} \times 0.8\text{(DOD)}} = 292.96 \approx 293\ \text{Ah}$$

4. **Number of Batteries in Parallel:** To determine the number of batteries in parallel, we divide the total number of batteries required by the number of batteries in series.

$$\text{No. of battery in Parallel} = \frac{\text{Total no.of battery}}{\text{No.of battery in series}} = \frac{32}{8} = 4$$

5. **Total Power Capacity of the Battery Bank:** The total power capacity of the battery bank is the product of the total number of batteries and the energy capacity of each battery.

$$\text{Total Power capacity of battery bank} = 32 * 480\ \text{Wh} = 15{,}360\ \text{Wh}$$

6. **Total Current of the Battery Bank:** The total current of the battery bank is calculated by multiplying the number of parallel strings by the discharge current of each battery.

$$\text{Total current of the battery bank} = 10 * 4 = 40\ \text{A}$$

Key Considerations:

Effect of Load Increase:

If the load increases, the battery capacity remains unchanged, but the operating time will be reduced. For instance, the battery will discharge faster with a higher load, decreasing the backup time available.

3.1.4 Supercapacitor Capacity Design for Transient Load Response

In high-power systems, rapid load variations can cause stability issues if the energy storage system is unable to respond swiftly. Supercapacitors, specifically Electrochemical Double-layer Capacitors (ELDCs), are well-suited for applications requiring fast energy delivery due to their high power density and rapid charge-discharge capabilities. The calculations below outline the design of the supercapacitor bank to meet a load demand of 5 kW for 1 second.

Specification:

ELDC (Electrochemical Double-layer Capacitor)

Capacitance = 3000 F, Voltage = 2.7 V

1. **Energy Storage in a Single Supercapacitor**

$$E = \frac{1}{2} cv^2 \tag{3.4}$$

$$= \frac{1}{2} \times 3000 \times (2.7)^2$$

$$= \frac{1}{2} \times 3000 \times 7.29$$

$$= 10.935 \text{ Joules}$$

2. **Load demand** = 5000 W = 5 kW (load suddenly - increases)
3. **Number of Supercapacitors in Series:** To achieve the required system voltage of 380 V, the number of supercapacitors connected in series is calculated as:

$$\text{Number of SC in series} = \frac{\text{System Voltage}}{\text{Voltage per SC}} = \frac{380 \text{ V}}{2.7 \text{ V}} \approx 141 \text{ N}_S$$

4. **Energy Requirement for Load Demand:** The total energy requirement to support a sudden load increase of 5 kW for 1 second is:

$$\text{Power demand in terms of energy requirement} = \text{Power(W)} \times \text{time(sec)} \tag{3.5}$$

$$= 5000 \times 1 \text{ sec}$$

$$= 5000 \text{ J}$$

5. **Number of Supercapacitors in Parallel**

$$\text{No. of SC in Parallel} = \frac{\text{Total Energy requirement}}{\text{Energy storage per SC}} = \frac{5000\ \text{F}}{10935\ \text{J/sec}} = 0.457 \approx 1\text{N}_\text{P}$$

6. **Total Voltage of the Supercapacitor Bank:** The total voltage of the supercapacitor bank, based on the number of capacitors in series, is:

$$\text{Total Voltage} = (\ 141 \times\ 1\ ) \times\ 2.7$$

$$= 141 \times\ 2.7 = 380.7 \approx\ 380\ \text{V}$$

7. **Power Delivery Capacity of the Supercapacitor Bank**

$$\text{Power delivery capacity} = \frac{\text{Energy Stored per SC}}{\text{Discharge Time}} = \frac{10935\ \text{J}}{1\ \text{sec}} = 10935\ \text{W} = 10\ \text{kW}$$

The designed supercapacitor bank, consisting of 141 units in series and a single parallel string, is capable of delivering 5 kW for 1 second at approximately 380 V. Its energy storage capacity of 10,935 J per unit and power delivery capability of 10 kW ensures reliable performance during transient conditions. The modular and scalable configuration makes it suitable for dynamic power systems and adaptable to future energy demands.

3.1.5 Total Capacity of the DC Microgrid

The total capacity of the DC microgrid is determined by summing the energy storage capacity and the power generation capacity.

Total Capacity of DC microgrid = Energy storage capacity + Power generation capacity

= 25 kWh + 14.8 kWh

= 39.8

= 40 KWh (Based on Application)

3.1.6 Fuel cell calculation

Specification:

PEMFC= Proton Exchange Membrane Fuel Cell

6 KW, 45 V_{dc}, 133.33 A,40-60% (Backup device)

The total load demand of 15 kW, the number of fuel cell units required is calculated as:

No. of units = 15000W/ 6000W = 2.5 =3 units

Total Capacity = 3 * 6000 = 18000 W

This configuration ensures sufficient backup power to support the system during outages or periods of high demand.

3.2 Design of Boost Converter

The boost converter is designed for a 530W solar panel system with panels connected in 9 series and 3 parallel strings, producing an output power of approximately 15,000W.

$\mathrm{V_{mpp}} = 41.49\,V$

$\mathrm{V_{oc}} = 49\,V$

$\mathrm{I_{mpp}} = 12.77\,A$

$\mathrm{I_{sc}} = 13.35\,A$

Panel in series = 9

Panel in parallel = 3

Maximum voltage of series connection:

$$\mathrm{V_{max}} = 9 \times \mathrm{V_{mpp}} = 9 \times 41.49 = 373.41\,V$$

Minimum operating voltage is around 70% of $\mathbf{V_{mpp}}$

$$\mathrm{V_{min/per\ panel}} = 0.7 \times \mathrm{V_{mpp}} = 0.7 \times 41.49 = 29.04\,V$$

$$\mathrm{V_{min}} = 9 \times \mathrm{V_{min/per\ panel}} = 9 \times 29.04 = 261.36\,V$$

Desired output voltage = 380 V

Output power = 27 × 530 = 14,310 ≈ 15,000 W

(Switching frequency = $\mathrm{f_s}$ = 50kHz) Based on application

Duty cycle:

For $V_{in_{min}} = 261.37\,V$

$$\mathrm{D} = 1 - \frac{V_{in}}{V_{out}} \tag{3.6}$$

$$= 1 - \frac{261.36}{380} = 0.313$$

For $V_{in_{max}} = 373.41\,V$

$$D = 1 - \frac{373.41}{380} = 0.017$$

Inductor:

$$I_{out} = \frac{P_{out}}{V_{out}} \tag{3.7}$$

$$= \frac{15{,}000W}{380} = 39.47\,A$$

[Ripple current $\Delta \boldsymbol{I_L} = \mathbf{20 - 30}\,\%\,\boldsymbol{I_L}$] [163],[164][165]

$$\Delta I_L = 0.3 \times I_{out} = 0.3 \times 39.47 = 11.84\,A$$

$$L = \frac{V_{in} \times D}{\Delta I_L \times f_s} \tag{3.8}$$

$$= \frac{261.36 \times 0.313}{11.84 \times 50kHz} = \frac{81.47}{592000} = 0.138mH$$

Capacitor:

$$[\Delta \boldsymbol{V_{out}} = \mathbf{1 - 2\%}\boldsymbol{V_{out}}]$$

$$\Delta V_{out} = 0.02 \times V_{out} = 0.02 \times 380 = 7.6\,V$$

$$C = \frac{\Delta I_L}{8 \times f_s \times \Delta V_{out}} \tag{3.9}$$

$$= \frac{11.84}{8 \times 50{,}000Hz \times 7.6} = \frac{11.84}{3{,}048{,}000} = 3.88\,\mu F$$

Design of Buck-Boost Converter

The buck-boost converter is designed based on a 48V Ni-MH battery to maintain a stable output of 380V.

Duty cycle:

$$D_{max} = \frac{V_{out}}{V_{in} + V_{out}} \tag{3.10}$$

$$= \frac{380}{48 + 380} = 0.888$$

$$\mathrm{V}_{\min} = 35\,V\,, V_{in_{max}} = 48\,V$$

$$D_{min} = \frac{380}{35 + 380} = \frac{380}{415} = 0.915$$

Inductor:

$$[\Delta \boldsymbol{I_L} = \mathbf{20 - 30}\,\%\, \boldsymbol{I_{out}}\,]$$

$$I_{out} = \frac{P_{out}}{V_{out}} = \frac{15{,}000}{380} = 39.47\,A$$

$$\Delta I_L = 0.3 \times I_{out} = 0.3 \times 39.47 = 11.84\,A$$

Capacitor:

$$[\Delta \boldsymbol{V_{out}} = \mathbf{2}\%\boldsymbol{V_{out}}]$$

$$\Delta V_{out} = 0.02 \times V_{out} = 0.02 \times 380 = 7.6\,V$$

$$C = \frac{\Delta I_L}{8 \times f_s \times \Delta V_{out}} = \frac{11.84}{8 \times 50{,}000Hz \times 7.6} = \frac{11.84}{3{,}048{,}000} = 3.88\,\mu F$$

- For minimum input voltage:

$$L = \frac{V_{in} \times (1 - D)}{\Delta I_L \times f_s} \tag{3.11}$$

$$= \frac{35 \times (1 - 0.95)}{11.84 \times 50kHz} = 5.03\,\mu H$$

- For maximum input voltage:

$$L = \frac{48 \times (1 - 0.888)}{11.84 \times 50kHz} = 9.08\,\mu H$$

Design parameters:

Table 3. 1 Design parameters of Buck-boost converter

D	0.888 to 0.915
$\boldsymbol{\Delta I_L}$	11.8 A
C	3.88 μF
L	5.03 μH to 9.08 μH

3.3 Case studies for power management in DC Microgrid

In a DC microgrid, maintaining stability and efficiency is crucial due to the intermittent nature of renewable energy sources and unpredictable load variations. Solar PV generation fluctuates based on environmental conditions, while sudden changes in load demand can impact system performance. To assess the effectiveness of the energy management strategy, two critical scenarios are analyzed: (1) variations in renewable energy availability during monsoon and nighttime, and (2) sudden load fluctuations in summer. Investigating these cases enables the development of a robust control approach to enhance system reliability, voltage stability, and overall operational efficiency.

Case:1 Variation in Renewable Energy Sources (G, T) [Monsoon and Night]

Renewable Energy Sources (RESs) such as solar photovoltaic (PV) systems are highly dependent on environmental factors like solar irradiance (G) and temperature (T). The variations in these factors significantly affect power generation, particularly during monsoon season and nighttime.

The power balance equation can be expressed as:

$$P_{PV} = P_{Load} \tag{3.12}$$

Case:2 Suddenly load increases or decreases [Summer]

1. $\boldsymbol{P_{pv} = 0\ or\ minimum\ ,\ P_{Bat\_} < P_{load}}$

In a DC microgrid system where solar power is unavailable or minimal (e.g., during cloudy weather or at night), the battery must supply power to meet the load demand. The following steps outline the calculation of the required battery capacity to ensure the system can handle sudden load variations.

Load Demand:

Peak load demand ($\boldsymbol{P_{load}}$): 15 kW

- Minimum load demand: 12 kW

Solar Generation Capacity:

- Solar generation capacity ($\boldsymbol{P_{pv}}$): 15 kW

Battery Capacity Calculation:

Battery efficiency (η): 90%

Calculate the Required Energy Capacity:

The required energy capacity of the battery is calculated as:

$$\mathrm{E_{req}} = \frac{\mathrm{P_{load}} \times \mathrm{t}}{\eta} \tag{3.13}$$

$$E_{req} = \frac{15\ kW \times 4\ hours}{0.90} = \frac{60\ kWh}{0.90} \approx 66.67\ kWh$$

Depth of Discharge (DoD):

$$\mathbf{E_{usable}} = \frac{\mathrm{E_{req}}}{\mathrm{DoD}} = \frac{66.67\ \mathrm{kWh}}{0.80} \approx 83.34\ \mathrm{kWh}$$

$$\mathbf{E_{final}} = \mathbf{E_{usable}} \times 1.10 = 83.34\ \mathrm{kWh} \times 1.10 \approx 91.67\ \mathrm{kWh}$$

Battery Capacity: Approximately 91.67 kWh

2. $\boldsymbol{P_{pv} = Minimum\ , P_{Bat\_} + P_{SC\_} < P_{load}}$

In this scenario, solar power is at a minimum or zero, and the power demand must be met by the battery and supercapacitor. The battery provides the base load, while the supercapacitor handles short-term high-power demands to reduce stress on the battery.

- DC Load: 12 to 15 kW

- Solar Power P_{pv} : Minimum or 0 ($P_{Bat\_} + P_{SC\_} < P_{load}$)

Total Energy Required (E_{total}):

$$\boldsymbol{E_{total} = P_{load} \times t}$$

$$= 15\mathrm{kW} \times 4\ \mathrm{hours} = 60\mathrm{kWh}$$

Battery Capacity ($\boldsymbol{E_{Bat}}$):

Assuming the battery handles 80% of the load and considering the battery efficiency:

$$\mathrm{E_{Bat}} = \frac{0.80 \ \times \mathrm{E_{total}}}{\eta_{\mathrm{Bat}}} = \frac{0.80 \ \times 60 \ \mathrm{kWh}}{0.90} \approx 53.33\mathrm{kWh}$$

Supercapacitor Capacity ($\boldsymbol{E_{SC}}$):

The supercapacitor handles 20% of the load and considering its efficiency:

$$\mathrm{E_{SC}} = \frac{0.20 \ \times \mathrm{E_{total}}}{\eta_{\mathrm{SC}}} = \frac{0.80 \ \times 60 \ \mathrm{kWh}}{0.95} \approx 12.63 \ \mathrm{kWh}$$

Battery Depth of Discharge (DOD):

- Assume a DoD of 80%.

$$\mathrm{E_{usable\_Bat}} = \frac{\mathrm{E_{Bat}}}{0.80} \approx \frac{53.33 \ \mathrm{kWh}}{0.80} \approx 66.67 \ \mathrm{kWh}$$

Supercapacitor DOD:

- Assuming a DoD of 95% for the supercapacitor:

$$E_{usable\_SC} = \frac{E_{SC}}{0.95} \approx \frac{12.63 \ kWh}{0.95} \approx 13.30 \ kWh$$

A 10% safety margin is added to both the battery and supercapacitor capacities to account for unexpected load increases or inefficiencies.

$$\mathrm{E_{final\_Bat}} = \mathrm{E_{usable\_Bat}} \times 1.10 \approx 66.67 \ \mathrm{kWh} \times 1.10 \approx 73.33 \ \mathrm{kWh}$$

$$E_{final\_SC} = E_{usable\_SC} \times 1.10 \approx 13.30 \ kWh \times 1.10 \approx 14.63 \ kWh$$

3.4 SOC Management for charging and discharging mode

SOC depends on whether it's charging or discharging. The direction of current flow is considered by using input/output power flow instead of a negative current.

3.4.1 SOC Management for the Battery

The state of Charge (SOC) for the battery is a crucial parameter in energy storage systems, representing the available energy relative to its total capacity. Effective SOC management ensures the battery operates within safe limits, preventing overcharging or deep discharging, which can degrade its lifespan and efficiency. The SOC of the battery is dynamically updated based on its charging and discharging states, as defined by the following equations.

Charging Mode (Battery is Receiving Power):

During the charging phase, the SOC increases as the battery stores energy. The SOC at any given time t is given by:

$$\mathrm{SOC_b(t)} = \mathrm{SOC_b}(t-1) + \frac{P_b(t)\cdot\Delta t}{C_b.\ Vdc} \tag{3.14}$$

Discharging Mode (Battery is Supplying Power):

During the discharging phase, the SOC decreases as the battery supplies power to the system. The SOC evolution in this mode is expressed as:

$$\mathrm{SOC_b(t)} = \mathrm{SOC_b}(t-1) - \frac{P_b(t)\cdot\Delta t}{C_b.\ Vdc} \tag{3.15}$$

where:

- $\mathrm{SOC_b}$(t) is the state of charge at time t.

- P_{bat}(t): Battery power at time t (in watts).
- $\mathrm{SOC_b}$(t-1) is the state of charge at the previous time step.

- Δt is the time step.

- C_b is the battery capacity (in ampere-hours)

These equations provide a quantitative framework for monitoring the battery's energy status, enabling optimized power management in a DC microgrid. Proper SOC regulation helps maintain system reliability, prolong battery life, and enhance overall energy efficiency.

3.4.2 SOC management for the Supercapacitor

Supercapacitors play a vital role in hybrid energy storage systems (HESS) by providing rapid response to transient power demands. Unlike batteries, supercapacitors have high power density and low energy density, making them suitable for short-term energy buffering. The SOC of the supercapacitor is dynamically updated based on its charging and discharging states, following similar principles as the battery but with a faster response time.

Charging Mode (Supercapacitor is Receiving Power):

When the supercapacitor is charging, its SOC increases as it stores energy, governed by:

$$\mathrm{SOC_{sc}(t)} = \mathrm{SOC_{sc}}(t-1) + \frac{P_{sc}(t)\cdot\Delta t}{C_{sc}.\ Vdc} \tag{3.16}$$

Discharging Mode (Supercapacitor is Supplying Power):

When the supercapacitor is discharging, its SOC decreases as it supplies power to the system, expressed as:

$$\mathrm{SOC_{sc}(t)} = \mathrm{SOC_{sc}}(t-1) - \frac{P_{sc}(t) \cdot \Delta t}{C_{sc}.\ Vdc} \tag{3.17}$$

Where:

- $P_{SC}(t)$: Supercapacitor power at time t (in watts).
- C_{SC}: Supercapacitor capacity (in ampere-hours).

Supercapacitors complement batteries by handling high-power transients and reducing the stress on the battery, thereby enhancing the overall efficiency and lifespan of the HESS. Their fast charge/discharge capability makes them essential for stabilizing voltage fluctuations and improving dynamic response in DC microgrid applications.

Summary

This chapter modeling and design for a 40 kW DC microgrid with HESS, focusing on the calculation of the system's capacity, which includes photovoltaic arrays, Ni-MH batteries, PEM fuel cells, and EDLC supercapacitors and calculation for case studies in DC microgrid. These modeling and design are integral to the optimization process, ensuring efficient power distribution and enhancing the overall performance and stability.