# DESIGN AND IMPLEMENTATION OF CUBESAT ELECTRICAL POWER SYSTEM


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# Contents

# Introduction

- Form factor of of 10 cm cube
- Cost-effective, timely and relatively easy to accomplish
- The Electrical Power System (EPS) is an electronic circuit board that is designed supply and manage energy to the Cubesat subsystems.

# Objective

To design and implement a fully autonomous power generation, storage and distribution system for a CubeSat

# Dynamic/Rheostatic Braking

- Works on the principle of reversibility of electrical machines
- Traction motors are switched into generator mode
- Power from braking is dissipated as heat in brake grid choppers or resistors
- Thus, the kinetic energy of the rolling stock is converted to heat energy

# Dynamic/Rheostatic Braking (Contd.)

Pros:

- Reduction of wear and tear of brake shoes and wheels
- Lesser chance of brake fade
- Speed control on downgrades
- Very short response time

Cons:

- Wasted power is about 10–30% of the total locomotive energy usage [4]
- Large cooling fans necessary for thermal protection
- Excessive heat may damage or disable the resistors
- Ineffective at very low speeds

# Commonly used Energy Storage Mechanisms

1. Electric: Regenerated energy is stored in electrical storage devices such as batteries and super capacitors
2. Hydraulic/Pneumatic: Energy is converted into internal energy of a liquid or compressed gas or a vacuum
3. Mechanical: Energy is stored in the form of mechanical energy of rotation or translational motion

# HESS Architecture

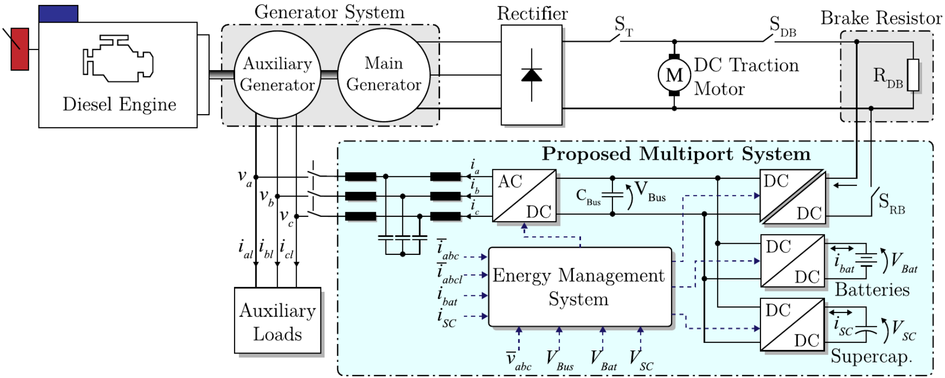
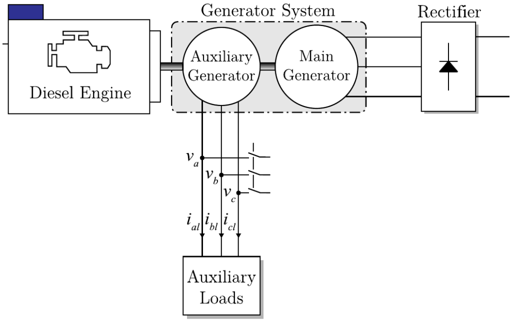



Figure 1: HESS Architecture (Source: Ref. [1])

# HESS Architecture: Power Generation System

- Main (MG) and Auxiliary generator (AG) coupled to diesel engine shaft
- MG output is rectified for powering DC Traction motors
- AG produces a 3-phase AC output
- AG output powers compressors, blowers, sanding systems, etc. (20% FL)



# HESS Architecture: Traction and Braking System

- DC motor is used for traction
- $R_{DB}$ - Dynamic Brake grid resistance
- $S_T$ - Traction Motor switch
- $S_{DB}$ - Dynamic Brake switch
- $S_{RB}$ - Regenerative Brake switch

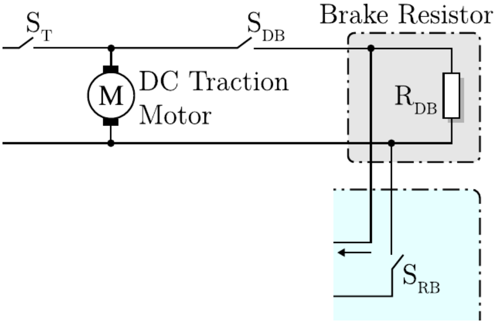



Figure 2: Traction and Braking diagram

# HESS Architecture: Energy Processing

- Li-ion batteries and super capacitors act as energy storage
- SCs take away all peak loads from the battery

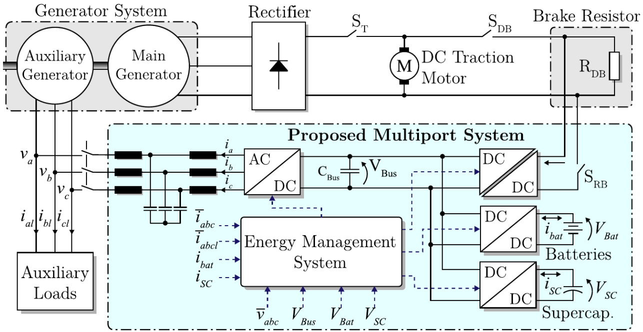



Figure 3: Energy Storage and Conversion[1]

[1]IEEE Transactions on Industrial Electronics, VOL. 68, NO. 10, OCTOBER 2021; pp. 9083 [1]

# HESS Architecture: Energy Processing (Contd.)

- Two DAB converters connected in input series output parallel fashion
- The DABs feeds regenerated energy into a common DC bus

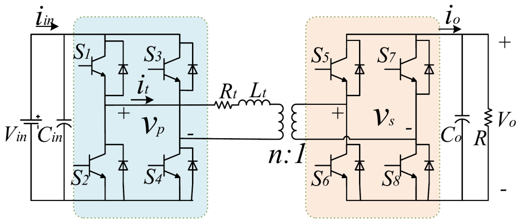



Figure 4: Dual Active Bridge (Source: Ref. [5])

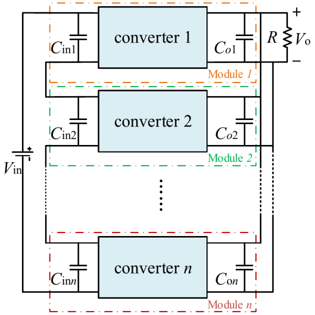



Figure 5: ISOP configuration (Source: Ref. [5])

# HESS Architecture: Energy Processing Contd.)

- Bidirectional non-isolated dc–dc converters are used to charge and discharge the batteries
- Decoupling between batteries, SCs, and the dc bus allows both storage devices to operate at a wider range of SoC[2]
- Volumetric efficiency of HESS is thus improved
- 3-$\Phi$ 2-level VSI with passively damped LCL filter is used to transfer power from DC bus to AC aux loads.

[2] State of Charge

# Power Flow

- Generated power must always be equal to the demanded power to ensure the system stability

## Power Flow Equation

On neglecting system losses,

$$P_{reg} + P_{gen} - P_L \pm P_{HESS} = 0 \tag{1}$$

- $P_{reg}$ - Power regenerated from dynamic braking
- $P_{gen}$ - Power supplied by the diesel generator
- $P_L$ - Power demanded by the locomotive auxiliary loads
- $P_{HESS}$ - Power available in the HESS

# Power Flow (Contd.)

- The regenerated power is used primarily by the loads during braking, while the surplus is stored
- If the HESS[3] is fully charged, the control strategy must reduce $P_{reg}$ until it matches the load demand
- If the HESS reaches its minimum SoC, the load is to be fed by the regenerated power or the diesel generator

[3] HESS: Hybrid Energy Storage System

# Modes of Operation

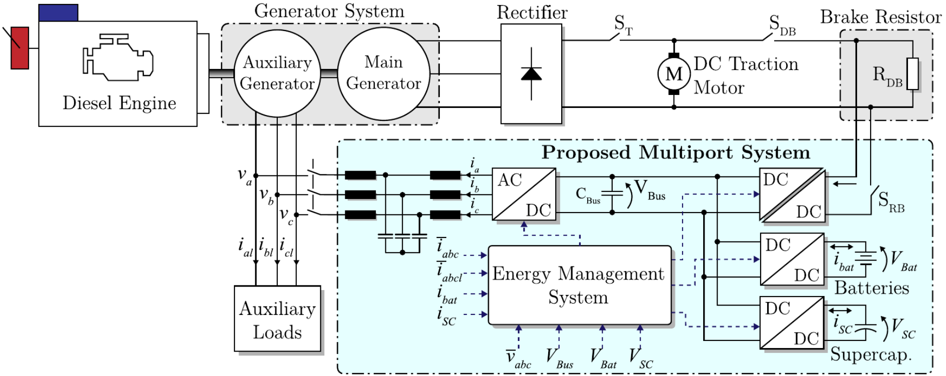



Figure 6: HESS Architecture (Source: Ref. [1])

1, 2, 3, 4, 5

# Modes of Operation: Mode 1 - Under-voltage Protection

- When the auxiliary load demand exceeds the discharge capacity of the batteries
- DAB ISOP converter does not regenerate power to the dc bus (not braking)

$$\therefore P_{gen} + P_{HESS} = P_L \tag{2}$$

# Modes of Operation: Mode 2 - Discharging

- Entire auxiliary load is supplied only by the HESS or with the aid of regenerated power
- Auxiliary generator provides the reactive power required by the load

$$\therefore P_{reg} + P_{HESS} = P_L \tag{3}$$

$$Or, P_{HESS} \geq P_L \tag{4}$$

# Modes of Operation: Mode 3 - Inverter

- Auxiliary loads absorb all the regenerated power
- HESS does not operate/charge
- The dc bus voltage is regulated by the discharging storage system
- A portion of this power is used to recharge only the SCs

$$\therefore P_{reg} = P_L + P_{SC} \tag{5}$$

$$Or, P_{reg} = P_L \tag{6}$$

# Modes of Operation: Mode 4 - HESS Charging

- The inverter supplies the entire load demand
- Batteries and SCs are recharged with excess regenerated power
- HESS regulates the dc bus voltage

$$\therefore P_{reg} = P_L + P_{HESS} \tag{7}$$

# Modes of Operation: Mode 5 - Over-voltage Protection

- Acts whenever the regenerated power exceeds all system demand
- The energy storage system is fully charged and auxiliary loads are off
- Regeneration is turned off

$$When, P_{reg} > P_L + P_{HESS} \tag{8}$$

# Advantages and Disadvantages

Advantages:

- Improved electric braking range and effectiveness
- Lesser load on auxiliary generator
- Non - intrusive system
- HESS can be modified to expand it's capability

Disadvantages:

- Lower lifespan of the batteries
- Maintenance cost

# Conclusion

- Focus on using the recovery energy to supply only auxiliary loads has reduced the cost and size of the system
- As the system presented is non-intrusive, it can be used to retrofit the existing systems
- There is potential for full hybridization of heavy haul locomotives.

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