MODEL PREDICTIVE CONTROL FOR OPTIMAL ENERGY MANAGEMENT OF HYBRID VANADIUM REDOX FLOW AND LITHIUM-ION BATTERY SYSTEMS IN PV-BASED STATIONARY APPLICATIONS.

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INTRODUCTION

The rising of the photovoltaic (PV) generation has created an increase on the investigation regarding the different storage systems used to support this type of energy generation.

One of the more interesting types is the hybrid energy storage system (HESS) which offer the combination of different type of storage technologies to maximize advantages. Lithium-ion (Li-ion) batteries and Vanadium Redox Flow batteries (VRFB) offer complementary characteristics, VRFB provide high energy capacity and low degradation for long-term storage while Li-ion provide high efficiency and fast dynamic response.

For this study, the idea is to combine a VRFB and a Li-ion battery combined with an Energy Management System (EMS) based in Model Predictive Control (MPC) with the idea of using the batteries at their higher potential.

The main objectives are:

- Increase the efficiency of the system.
- Offer a better flexibility of the system.

SYSTEM MODEL

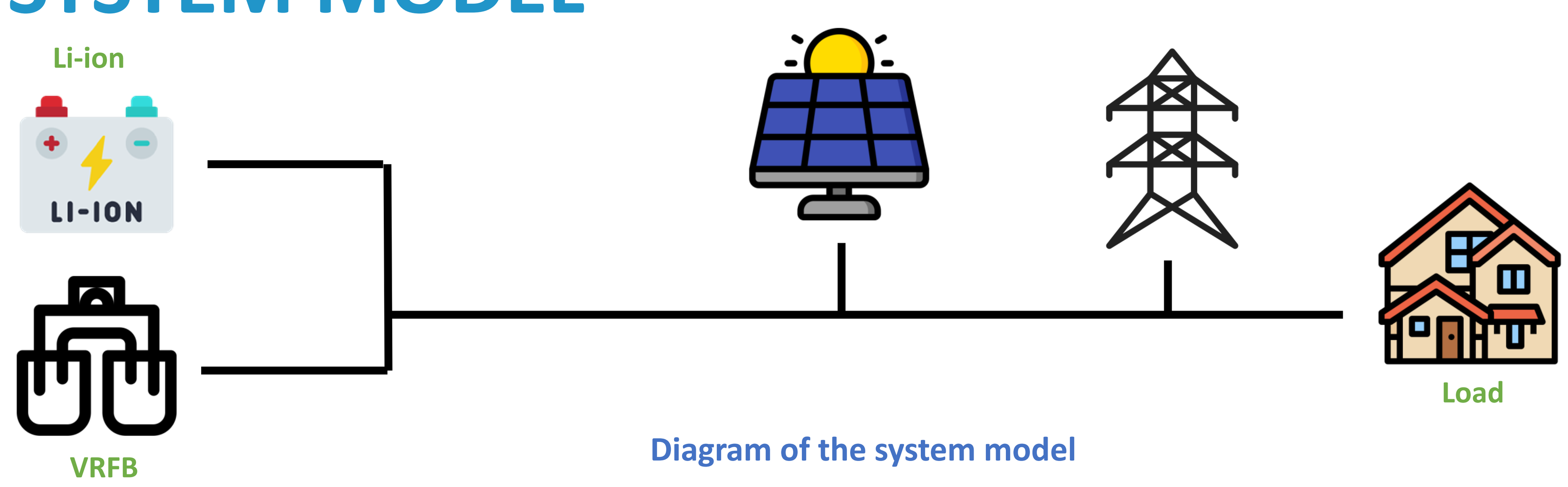


Diagram of the system model

Batteries Models

- **Lithium-ion battery**

The battery model for the Li-ion battery is an equivalent circuit model (ECM) based on real-life data from different characterization tests.

The battery model calculates the voltage from the Open Circuit Voltage (OCV) given by the tests for the different SOC values and the losses from the battery's resistance while the SOC is calculated with Coulomb counting

- **Vanadium Redox Flow Battery**

The battery model for the Redox Flow Battery is a mathematical model based on real-life data. The model considers the fact that 2 different reactions happen simultaneously on each side of the membranes with 4 different types of Vanadium species or oxidation states.

The voltage of all the stack is calculated from the Equilibrium Voltage, calculated by the Nerst equation, and the Losses Voltage while the SOC gets calculated from the minimum value of the Vanadium concentration of the tanks:

$$Vt = V_{eq} - V_{loss}$$

$$SOC_{tank\ A} = \frac{c_{v2+}}{c_{v2+} + c_{v3+}}$$

$$V_{eq} = n * \left(E_0 + \frac{RT}{F} \cdot \ln\left\{\left(\frac{c_{V5+} \cdot c_{H^+}^2}{c_{V4+}}\right) \cdot \left(\frac{c_{V2+}}{c_{V3+}}\right)\right\}\right)$$

$$SOC_{tank\ C} = \frac{c_{v5+}}{c_{v4+} + c_{v5+}}$$

$$V_{loss} = \mathrm{n} \cdot \left(R_{eq,\,(charge\ or\ discharge)} \cdot I\right)$$

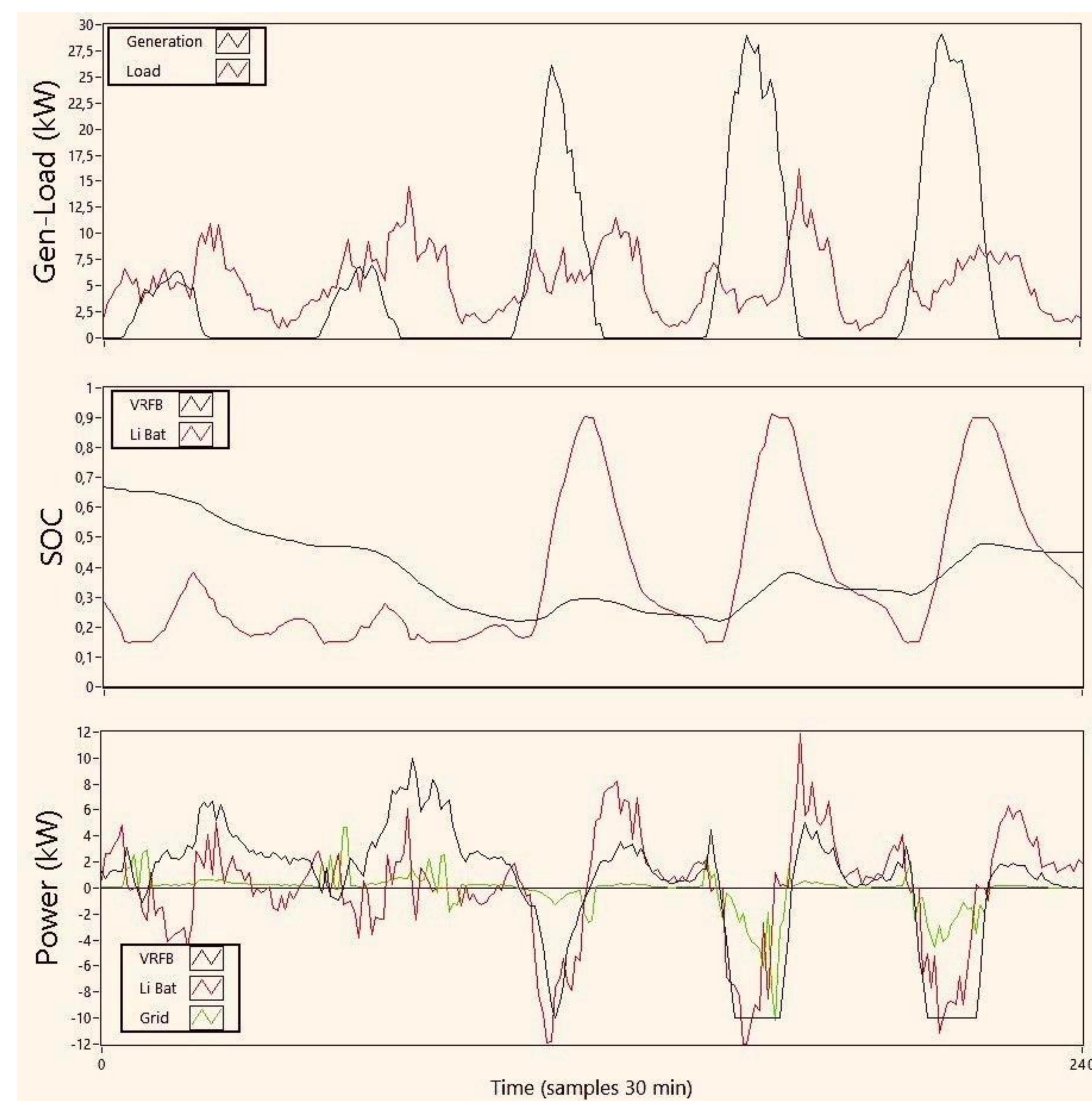
$$SOC = \min(SOC_{tank\ A}, SOC_{tank\ C})$$

RESULTS AND ANALYSIS

The model is used for a stationary Renewable energy system made by a photovoltaic plant (PV), the grid and the HESS. The power demand and PV generation has been obtained from the Ausgrid dataset, using the 14 households closer to the city of Newcastle to represent 5-day demand that need to be supplied as a microgrid. The model is created in MATLAB and the results are visualized by Labview.

The case presented for the model application considers for the Li-ion battery to be the main provider in case the energy storage is needed but it is protected by the moment its SOC is low. The grid is always considered the last option for the power.

The results show the VRBF being more used during the first 2 days as the Li-ion is discharged and the generation of PV is not enough to supply all the demand. By the time the generation becomes higher than the demand, the batteries can be charged and the Li-ion becomes the main provider when needed with the VRFB as a supporter.



Power and SOC results of the MPC

CONCLUSIONS

The Model Predictive Control (MPC) seems to be the perfect type of energy management system for hybrid storage systems as it can offer a better use of all the parts of the model:

→ The power requirements is met in all the demand, while maintaining safe operating limits for state of charge (SOC) and power.

→ The MPC offers flexibility allowing to change the model's strategy when the circumstances change, having a strategy that lasts for a long time.

Viability in real-world renewable energy systems contributing to:

→ Improved efficiency, extended battery lifespan, overall system sustainability.

Future research:

→ Exploring different types of demand and harder conditions.

→ Exploring this type of HESS with the addition of new different storage systems (Fuell Cell, other types of Lithium batteries, …).

Energy Management System

Model Predictive Control (MPC) is an optimization-based control method that offers the optimization of the system from an objective equation considering different constrained variables with a prediction of future steps in each time step, leading to a better informed and optimal decision on the minimization of the objective equation. For this study the objective function is:

$$min \sum_{i=k}^{k+N-1} Q_{grid}(i) + Q_{ESS}(i) + Q_{soft}(i)$$

$$Q_{ESS} = \lambda_{PVRFB} \cdot p_{VRFB}^2 + \lambda_{SOCVRFB} \cdot SOC_{VRFB}^2 + \lambda_{pLi} \cdot p_{Li}^2 + \lambda_{SOCLi} \cdot SOC_{Li}^2$$

$$Q_{grid} = \lambda_{grid} \cdot p_{grid}^2$$

$$Q_{soft} = \lambda_{soft,\beta} \cdot \epsilon_\beta(k)^2|_{\beta=\{VRFB,Li\}}$$

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