Using the nPM1300 Fuel Gauge

Application Note

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1 Introduction

This application note describes the seamless integration of the nPM1300 *Power Management Integrated Circuit (PMIC)* fuel gauge solution with a *System on Chip (SoC)* to ensure accurate and reliable monitoring of battery performance for low-power device applications.

State-of-charge estimation techniques based on open-circuit voltage methods often yield inconsistent results under fluctuating load and temperature conditions. The nPM1300 fuel gauge solution considers all these variations to provide a stable and accurate state-of-charge prediction.

nPM1300 has a comprehensive fuel gauge that uses integrated battery current, voltage, and temperature measurements. The advanced fuel gauge algorithm combines battery measurements with a battery model to provide stable and precise state-of-charge predictions, with a typical error of less than ±3%, under rated operating conditions of the battery. With temperature compensation, it ensures exceptional accuracy across the battery's operating temperature range.

The fuel gauge algorithm can be run on most Nordic host SoCs for a reliable estimation of the battery state of charge. The battery model is generated by a one-time battery profiling process in the nPM PowerUP computer app, by using the nPM1300 EK together with the nPM Fuel Gauge Board extension. The fuel gauge is also compatible with other non-Nordic SoCs. Contact your local Nordic sales representative for more information.

2 Minimum requirements

Before you start, check that you have the correct hardware and software.

Hardware requirements

- nPM1300 EK
- nPM Fuel Gauge Board
- Nordic *SoC* or *System in Package (SiP)*

The EK and the nPM Fuel Gauge Board are used to profile and generate the model. Once the battery model is extracted, you only need nPM1300 and the SoC (or SiP) in your application to do fuel gauging.

Software requirements

- nPM PowerUP app available in nRF Connect for Desktop

3 nPM1300 fuel gauge overview

The nPM1300 fuel gauge provides ultra-low power battery fuel gauging without compromising on accuracy.

The fully integrated design eliminates the need for additional external components, simplifying your design process and reducing board space and cost. The nPM1300 fuel gauge can be turned off to reduce quiescent current (Iq) during sleep and power-down of the device.

To predict the battery state of charge, the nPM1300 fuel gauge requires a battery model to give a mathematical representation of a battery's behavior. Battery modeling is made possible through the nPM PowerUP computer app available in nRF Connect for Desktop. The calculated state of charge is relative to the battery's present maximum capacity and always shows 100% when the battery is fully charged, even if the actual capacity has reduced due to aging.

The nPM PowerUP battery profiling solution allows you to independently develop a battery model tailored to your specific needs. A one-time profiling of the battery using the nPM PowerUP app together with the nPM1300 *Evaluation Kit (EK)* and nPM Fuel Gauge Board generates the battery model. The battery model can be further evaluated in the nPM PowerUP app before integrating it in your application. For more information, see the nRF Connect SDK samples at nPM1300 fuel gauge application samples.

The fuel gauge algorithm can run on Nordic host *SoC*s (nRF52, nRF53, nRF54, and nRF91 series) to ensure an accurate estimation of the battery state of charge by controlling and retrieving measurement information from nPM1300 through *Two-wire Interface (TWI)* communication. Other non-Nordic SoCs can also be used. Contact your local Nordic sales representative for more information.

To configure fuel gauge intervals for an optimal synchronization with different activity levels of a device, consider both the average and peak battery current consumption for a given activity level relative to the capacity of the selected battery. This ensures a balance between accurate state-of-charge estimation and low-power fuel gauging.

For a typical *Bluetooth*® low energy application, it is recommended to run the fuel gauge algorithm once every second in the active state and every five seconds in the idle state. The fuel gauge is not required to operate during host sleep intervals. For more information, see Fuel gauge example for a Bluetooth gaming mouse on page 8.

The following diagram shows an overview of the fuel gauge.

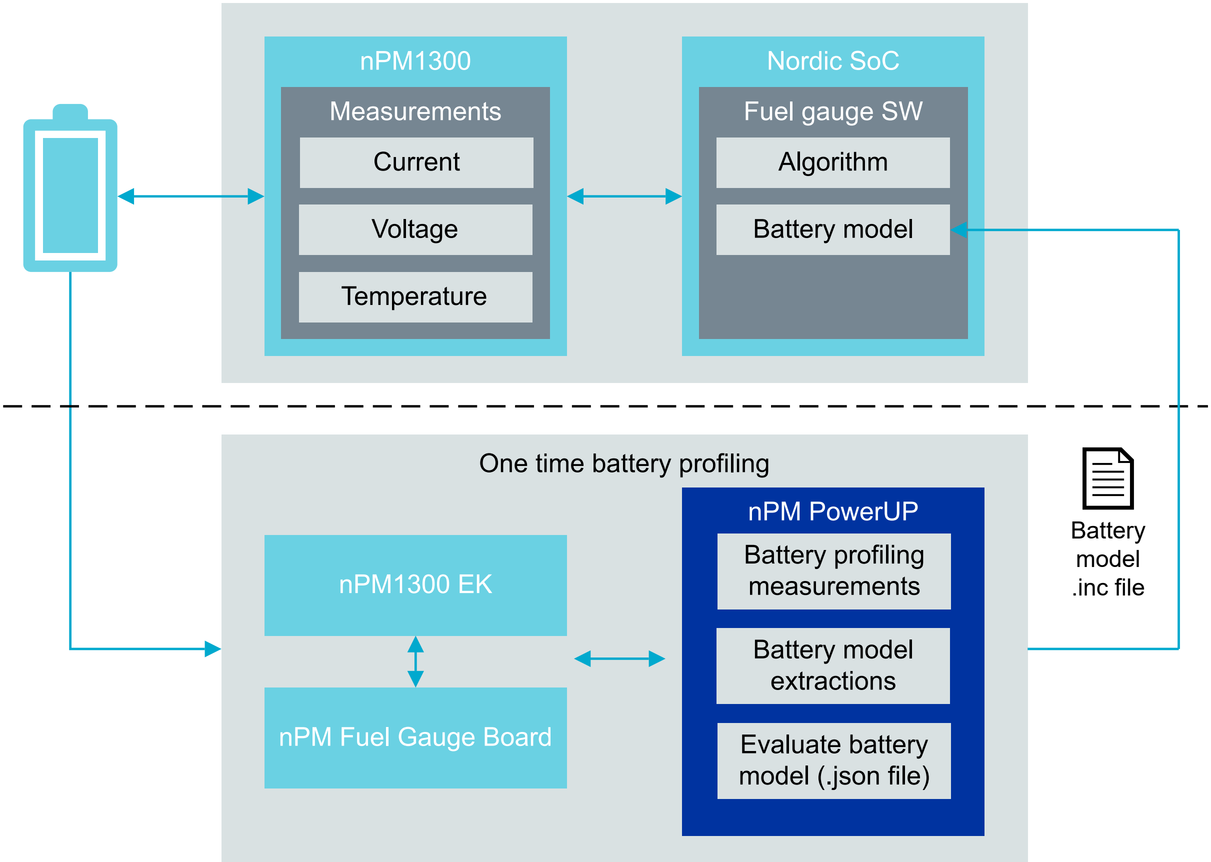


Figure 1: nPM1300 fuel gauge with battery profiling

3.1 Fuel gauge power consumption

The total current consumption of a battery fuel gauge is affected by several factors such as operating mode, measurement frequency, *TWI* communication, and CPU usage. nPM1300 delivers ultra-low power fuel gauging through an algorithm that is designed to operate exclusively during active periods of a device. This eliminates the need for system wake up during sleep intervals. Typical fuel gauge consumption is 8 µA to 10 µA in the active state when using a one-second fuel gauge iteration interval.

The following tables present examples for fuel gauge current consumption and resource usage when using the nRF5340 *SoC* as the host. All measurements are specified for a 3.7 V battery voltage at room temperature.

	CPU usage	TWI communication	Measurements
Time consumed (ms)	0.1	2.2	7.1
Average current (mA)	3.6	1.0	1.1
Charge per iteration (µC)	0.4	2.2	7.7
Total charge for each fuel gauge iteration (µC)	10.3		

Table 1: Fuel gauge example for a battery with NTC thermistor

	CPU usage	TWI communication	Measurements
Time consumed (ms)	0.1	1.5	5.6
Average current (mA)	3.6	1.0	1.1
Charge per iteration (µC)	0.4	1.5	6.0
Total charge for each fuel gauge iteration (µC)	7.9		

Table 2: Fuel gauge example for a battery without NTC thermistor

The average current values used in the tables are from laboratory measured values and the nRF5340 Product Specification:

- nRF5340 application CPU current, running CoreMark® from flash at 64 MHz clock
- nRF5340 current consumption for TWIM, transferring data at 400 kbps

3.1.1 Fuel gauge example for a Bluetooth gaming mouse

This example presents a typical load profile for a Bluetooth gaming mouse, including corresponding power consumption data for fuel gauging. The mouse operates in three distinct states: active, idle, and sleep.

The three states of the gaming mouse are shown in Figure 2: Typical load profile for a gaming mouse on page 9. In the active state, the gaming mouse is in a heightened operational mode, which responds to frequent and dynamic movements as the user interacts with it during gaming or similar activities.

In the idle state, the mouse enters a standby mode while remaining powered on. The mouse does not actively engage in user interaction but is ready for prompt responsiveness. The idle state has lower activity levels than the active state.

The sleep state is a low-power mode the mouse enters after being idle for a set period. This low-power mode significantly reduces the energy consumption during extended periods of inactivity.

By customizing the iteration interval of the fuel gauge to match the different activity levels of the gaming mouse, nPM1300 achieves a balance between accurate state-of-charge estimation and low-power fuel gauging.

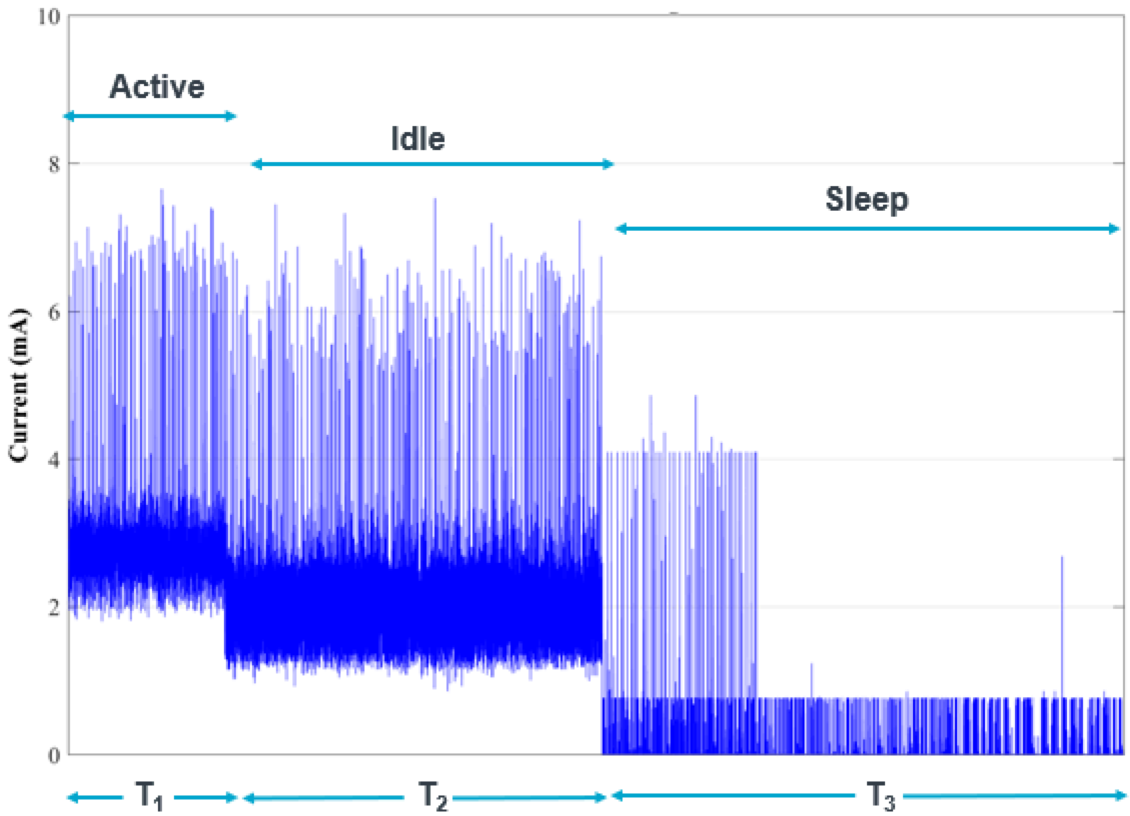


Figure 2: Typical load profile for a gaming mouse

The following table shows an examples of fuel gauging for a mouse that has medium activity level and is used for moderate periods. The mouse battery does not have an NTC thermistor.

Device state	Time (h)	Average current (mA)	Fuel gauge iteration interval (s)	Device total charge (C/day)	Device average load current (mA/day)	Fuel gauging total charge (C/day)	Fuel gauging average current (µA/day)
Active	3	2.80	1	77.6	0.9	0.12	1.0
Idle	6	2.07	5				
Sleep	15	0.05	0				

Table 3: Fuel gauging for mouse with medium activity, used for moderate periods

The following table shows an examples of fuel gauging for a mouse that has high activity level and is used for longer periods. The mouse battery does not have an NTC thermistor.

Device state	Time (h)	Average current (mA)	Fuel gauge iteration interval (s)	Device total charge (C/day)	Device average load current (mA/day)	Fuel gauging total charge (C/day)	Fuel gauging average current (µA/day)
Active	6	2.80	1	136.4	1.58	0.23	3.0
Idle	10	2.07	5				
Sleep	8	0.05	0				

Table 4: Fuel gauging for mouse with high activity, used for longer periods

4 Profiling a battery with nPM PowerUP

Use the nPM PowerUP app in nRF Connect for Desktop to profile your battery and generate a battery model.

4.1 nPM Fuel Gauge Board

The nPM Fuel Gauge Board is a cost-effective, plug-and-play extension board for profiling *Li-ion*, *Lithium-polymer (Li-Poly)*, and Lithium iron phosphate ($LiFePO_4$) batteries together with the nPM1300 *EK* and the nPM PowerUP app.

The board is specifically designed for the battery discharge and data collection needed for battery modeling, eliminating the need for expensive measurement equipment or specialized expertise. Plug the nPM Fuel Gauge Board into the nPM1300 EK and configure it using the nPM PowerUP app to allow easy and convenient battery profiling without complicated setup procedures.

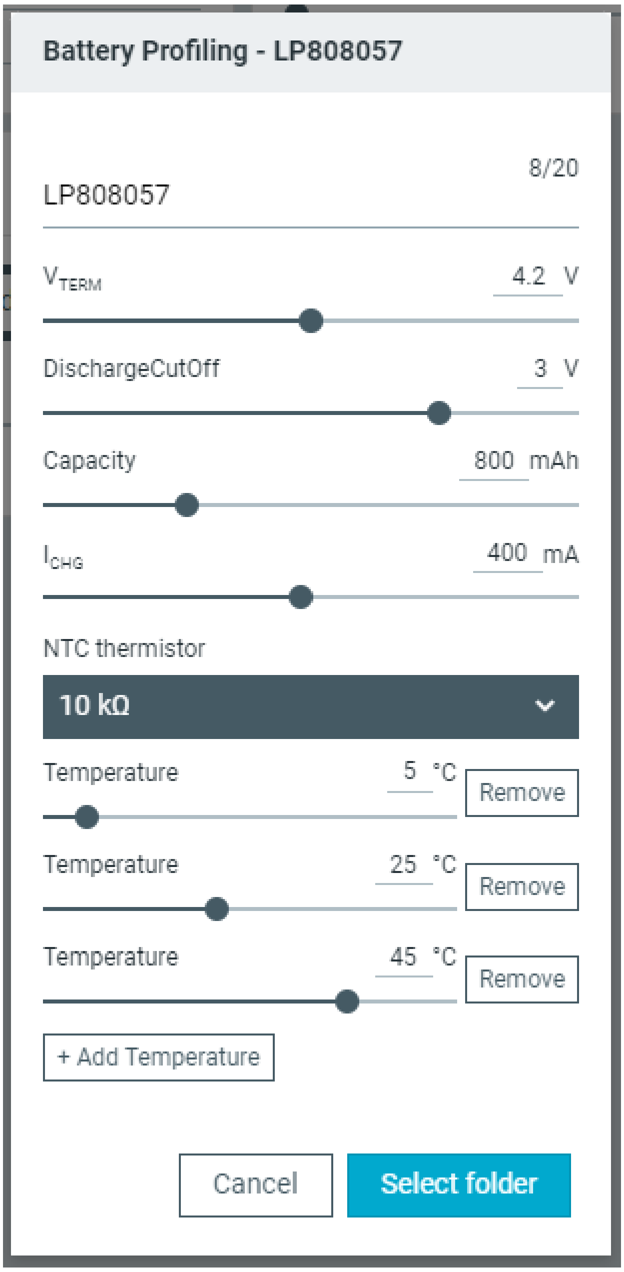
The nPM Fuel Gauge Board supports batteries with capacities up to 3000 mAh across the battery's operating voltage and temperature range. Larger batteries can be used, but profiling takes more time.

4.2 Generating a battery model

Follow the steps to profile a battery and use the generated battery model to initialize and run the nPM1300 fuel gauge in the nPM PowerUP app.

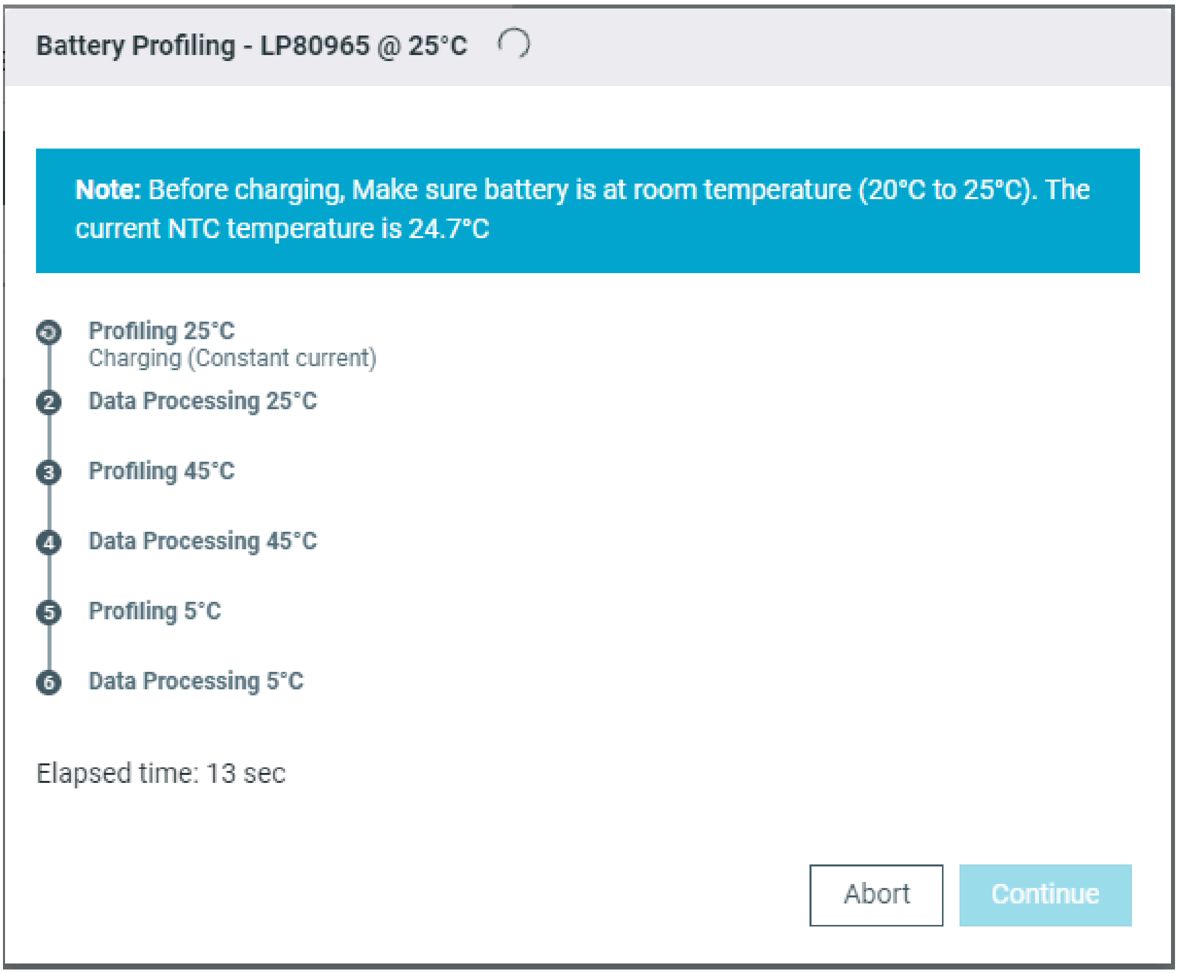
1. Connect the nPM Fuel Gauge Board to the nPM1300 *EK* at the edge connectors **P20** and **P21** (denoted as **EXT BOARD** on the EK).
2. Follow the instructions in Connect nPM1300 EK to nPM PowerUP to connect the nPM1300 EK and download the software.
3. Select **Profile Battery** on the left pane.
4. Enter the battery data and temperatures for the profiling test.

   Provide the generic information about the selected battery. Refer to the battery datasheet for information. For further information on profiling, see Guidelines for battery profiling on page 17.



5. Click **Select folder** to create a new project and store the battery model files.
6. Follow the instructions in the nPM PowerUP app to start battery profiling.

   The following text box is displayed during battery profiling.



The measurement data is automatically processed in the Nordic battery modeling software to make a single battery model file for each test temperature.

7. After the temperature profiling at a given temperature is complete, follow the instructions in the nPM PowerUP app to charge the battery at room temperature before profiling at the next test temperature.

   When all the individual temperature models have been completed, they will be merged to generate the final battery model file. The final battery model is automatically saved as a `.json` file.
8. Select **Load Battery Model** on the left pane in nPM PowerUP to load the generated `.json` battery model file to the host *SoC* of nPM1300 EK.
9. To start fuel gauge evaluations using the generated battery model, enable the **Fuel Gauge** on the **DASHBOARD** tab.

4.2.1 Evaluating a battery model

Use the nPM PowerUP app to evaluate the battery state-of-charge predictions.

After generating the battery model, you can use the **GRAPH** tab in the nPM PowerUP app to evaluate the battery state-of-charge predictions in real time. Make sure the battery fuel gauge on the **DASHBOARD** tab is enabled.

Figure 3: Evaluating the battery model in nPM PowerUP

To make changes to the generated battery model, upload the projects in the **PROFILES** tab of the nPM PowerUP app. You can then make edits, merge individual temperature profiles, or change the configuration settings of the generated battery model.

> **Note:** The battery model is automatically stored as `.json` and `.inc` file formats. Use the `.json` file for evaluations in nPM PowerUP and the `.inc` file when integrating the battery model to your final application with a Nordic *SoC*. Refer also to nPM1300 fuel gauge application samples.

5 Predicting a battery state of charge

The estimated state of charge (%) from the nPM1300 fuel gauge has been compared against measured data using an accurate coulomb counter-based state-of-charge test for a *Li-Poly* battery at room temperature.

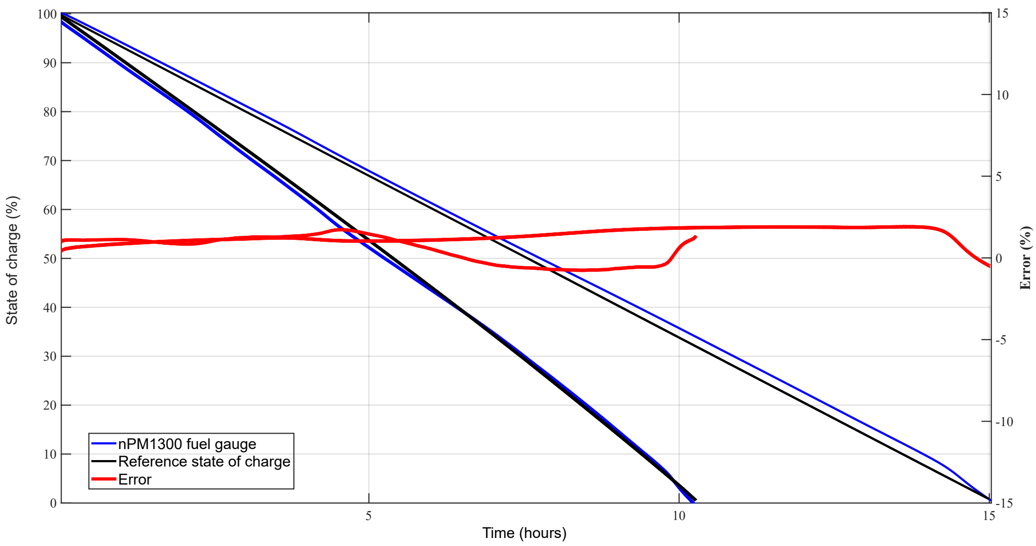


Figure 4: Estimated (nPM1300 fuel gauge) and measured state of charge (%) at different loads

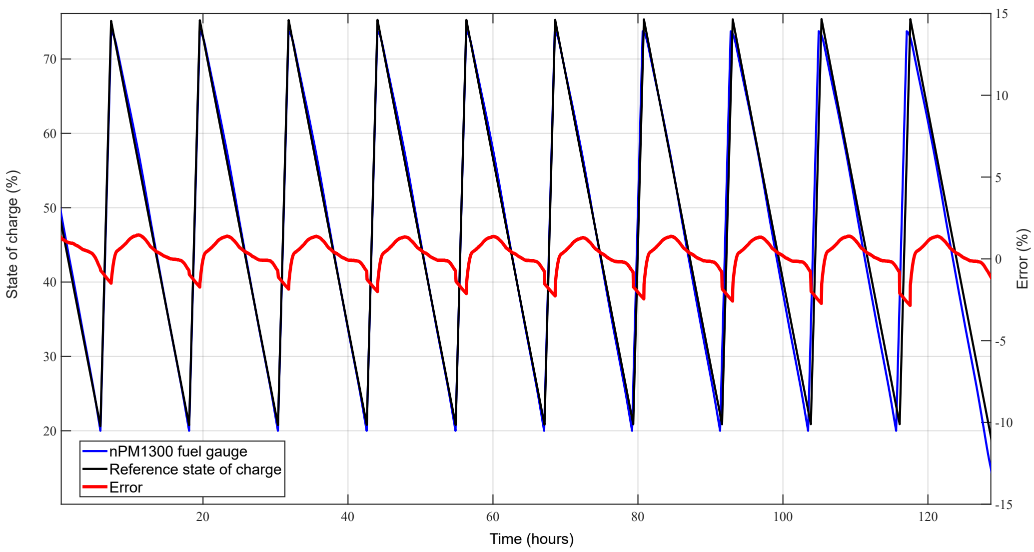


Figure 5: Estimated (nPM1300 fuel gauge) and measured state of charge (%) over several charge and discharge cycles

The following figure compares nPM1300 fuel gauge with a reference state of charge, compared to an Open-Circuit Voltage (OCV) based state-of-charge estimation method.

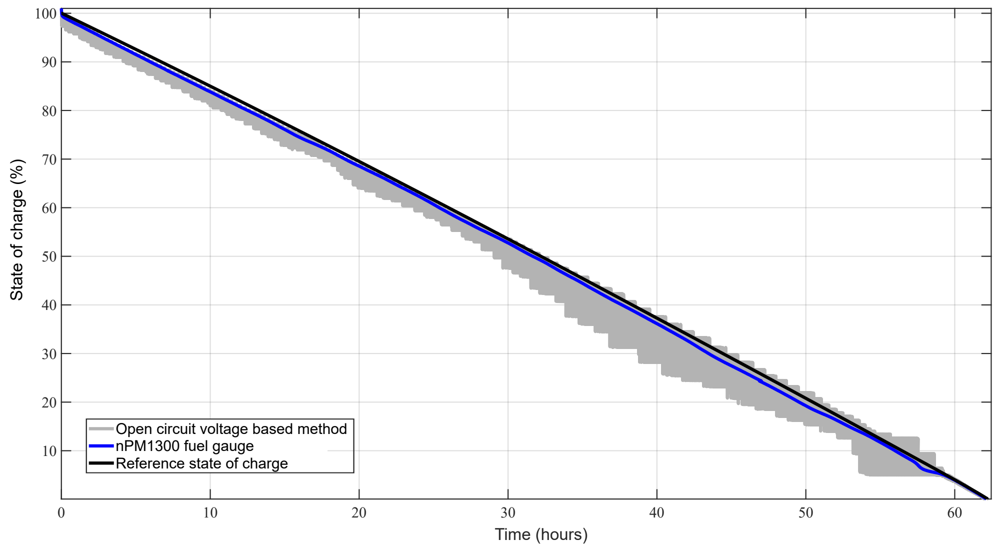


Figure 6: Comparing estimates from nPM1300 fuel gauge against OCV based look-up table method

6 Guidelines for battery profiling

The guidelines in this section optimizes the use of the nPM PowerUP app for battery profiling.

- Before starting battery profiling, refer to the battery datasheet and ensure that the parameters are set correctly. This includes specification of the battery capacity, termination voltages, and any other relevant parameters provided in the datasheet.
- Due to the increased non-linearities of batteries operating at temperatures below zero degrees Celsius, it is recommended to conduct battery profiling exclusively above zero degrees. Avoid profiling at temperatures below freezing or in extreme heat conditions.

  > **Note:** Even if the battery is profiled at temperatures above zero Celsius, the nPM1300 fuel gauge can still perform reliably below zero within the standard discharge conditions of the battery.

- To account for temperature variations and improve the accuracy of state-of-charge estimations, profile the battery at three different test temperatures. For example, if the operating temperature of the device ranges from -15°C to 45°C, you can profile the battery at 5°C, 25°C, and 45°C. The final battery model will be created by combining the individual temperature profiles.
- The time to profile the battery takes approximately 48 hours per temperature. Do not modify the device configuration during the profiling process as this causes the profiling to abort.
- Ensure that your computer does not go into sleep mode or hibernate during the profiling process.
- To avoid issues with computer restarting due to system updates, the computer can be put in flight mode during profiling.
- If necessary, you can choose to profile the battery at a single operating temperature. However, this method will not account for temperature effects during fuel gauging, which may result in reduced accuracy.
- Ensure that the battery test temperature stays constant throughout the profiling period, as fluctuations in temperature can affect the accuracy of the battery model. Use a temperature chamber to improve performance.
- The use of a battery with a *Negative Temperature Coefficient (NTC)* thermistor is recommended. Specify test temperatures for the profiling process for both type of batteries (with or without NTC).
  - If the battery NTC sensor is available, the battery temperature from the NTC measurement will be used for creating the battery model.
  - If the NTC sensor is not available, the specified test temperatures will be used for creating the battery model.
  - For NTC selection, refer to Battery temperature monitoring.
- The battery must be fully charged before profiling at a new temperature. Follow the instructions in nPM PowerUP to charge the battery at room temperature to ensure consistent and reliable results during the profiling process.
- The nPM1300 fuel gauge algorithm incorporates internal adjustments to correct any initialization errors resulting from an unrested battery and unexpected reset conditions. These errors typically have a minor impact, and the predictions will converge to the accurate value within a few minutes of normal operation.

For more information, or if you have any technical questions before, during, or after your development, contact our Technical Support team at Nordic DevZone.

Glossary

Evaluation Kit (EK)

A platform used to evaluate different development platforms.

Li-ion

Lithium-ion

Lithium-polymer (Li-Poly)

A rechargeable battery of lithium-ion technology using a polymer electrolyte instead of a liquid electrolyte.

Negative Temperature Coefficient (NTC)

A negative temperature coefficient refers to materials where there is a decrease in electrical resistance when their temperature is raised.

Power Management Integrated Circuit (PMIC)

A chip used for various functions related to power management.

System in Package (SiP)

Several integrated circuits, often from different technologies, enclosed in a single module that performs as a system or subsystem.

System on Chip (SoC)

A microchip that integrates all the necessary electronic circuits and components of a computer or other electronic systems on a single integrated circuit.

Two-wire Interface (TWI)

An I^2C compatible serial communication protocol that enables devices to exchange data by using a two-wire bus system, allowing multiple devices to be connected and controlled by a master device.

Recommended reading

In addition to the information in this document, you may need to consult other documents.

Nordic documentation

- nPM1300 Product Specification
- nPM1300 EK Hardware
- nPM Fuel Gauge Board Hardware
- nPM1300 EK product page
- nPM Fuel Gauge Board product page

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