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Battery State of Charge and Remaining Usage Time Estimation

Recognizing the state of charge (SOC) and the remaining usage time in a battery is as vital as knowing if your car has enough gas to reach its destination. This significance is especially pronounced in Electric Vehicles, where it equals or even surpasses the importance of monitoring gas levels in conventional cars, given the relatively less availability of charge stations compared to gas stations. In various applications such as notebook computers, eBikes, storage units, and power tools, precise estimates of remaining charge and time are indispensable. However, predicting these factors in batteries is inherently more intricate and prone to inaccuracies compared to estimating the remaining gas in a car and its range based on available fuel.

Those well-versed in power electronics recognize that achieving accurate current sensing is among the most challenging aspects of circuit design and implementation. In general power electronics, current sense circuits typically boast an accuracy of around 1% or even a fraction of that, a level often considered quite precise. The core of real State of Charge (SOC) estimation hinges on Coulomb counting, essentially likened to current sensing on steroids! Coulomb counting parallels the measurement of gas entering and leaving a tank. However, the intricacy arises from the fact that the charge and discharge profiles of a battery can be highly complex, unlike the straightforward process of refueling a gas tank and using it to power an engine. While a gas tank has a level sensor that can reasonably measure the remaining fuel, no equivalent exists for batteries. The closest approximation to a "level sensor" in a battery is its voltage, which serves as a somewhat imprecise indicator of the SOC.

While an accuracy of 1% or less may initially seem sufficient for estimating State of Charge (SOC), the truth is that even this seemingly small error can accumulate significantly, leading to inaccuracies in the estimation. In real-world scenarios, users typically don't fully charge or discharge the battery with each use. Often, charging starts and stops before reaching empty or full capacity. After several such cycles, even a minor error can magnify, becoming substantial and unacceptable.

To enhance accuracy, unlike typical current sensing, coulomb counting involves meticulously tallying every electron that enters or exits the battery during charge or discharge. This process significantly differs from merely sensing current for informational purposes. For example, a sampling circuit designed to take intermittent snapshots of the charge or discharge current is ill-suited for coulomb counting and the subsequent integration of these charges. The inherent issues with a sampling system contribute to decreased accuracy. Fluctuating currents present in most systems mean that the current between samples may differ substantially, introducing inaccuracies. Additionally, by introducing sampling, another variable—time—is added, creating challenges in achieving precise integration. To obtain an exact integration, both the magnitude of the current and the duration it persists must be precisely known, introducing another potential source of measurement error.

Ensuring an accurate ADC with impressive specifications may not be sufficient to guarantee a precise coulomb counting engine. The key lies in ensuring that the integration of charge is not only accurate but also repeatable. In fact, repeatability emerges as the cornerstone of effective coulomb counting, determining our ability to meticulously track and account for the charge going into the battery (charge) versus what is discharged out of it. While this concept has not been openly discussed in the past, obtaining an accurate rating for this function from datasheets poses a challenge.

It's evident that specifying ADC performance parameters such as low offset, gain linearity, INL, DNL and their stability over temperature forms the foundation for accuracy. However, merely stating these elements covers the basics but falls short of providing a comprehensive understanding of repeatability. Acknowledging that the most accurate representation of coulomb counting accuracy should include repeatability, the emphasis should be on specifying how reliably an identical amount of coulomb in the charge phase can be compared with the reading in the discharge phase. This ensures a thorough assessment of the repeatability factor. To get even more sophisticated, a system can be tested by forcing the same number of coulombs over different time periods, meaning perhaps fast charge, but slow discharge, and if the system is accurate, it should not be fooled by the difference in time variation.

Over the past few decades, with the advent of modern BMS ICs, a prevailing notion has persisted that coulomb counting faces challenges in achieving the accuracy necessary for robust SOC determination. Consequently, a multitude of algorithms has emerged, acting as metaphorical Band-Aids to mitigate this inherent issue. These approaches encompass battery modeling, various iterations of the Kalman filter, lookup tables, and several others, each designed to address perceived shortcomings in the accuracy and repeatability of coulomb counters. Many of these algorithms heavily rely on battery voltage as an indication of charge, essentially serving as a guardrail to maintain accuracy when coulomb counting goes way off.

In fact, published papers have asserted that a 3% accuracy in SOC is considered acceptable, striking a perceived balance between cost considerations and performance expectations.

We now understand that the inherent inaccuracy and imprecise estimation of SOC are not insurmountable challenges and can indeed be mitigated. A compelling showcase of effective SOC management is evident in Electric Vehicles (EVs). These systems are notably more sophisticated, benefitting from higher budgets and meticulous calibration. While a sudden shutdown during a Zoom call can be inconvenient, being stranded in the middle of nowhere due to SOC miscalculation is an entirely different scenario. The effectiveness of BMS in EVs underscores the principle that where there is a need, there is a viable solution. If the SOC accuracy in EVs were as imprecise as that in notebooks, the widespread adoption and success of electric vehicles today would likely be inconceivable.

Although coulomb counting is and should be the heart of any SOC estimation, that alone is not enough to do a complete job. The errors come about, as other factors come into play. Some of these errors are caused by energy loss as heat, battery capacity shift over temperature, again, self-leakage, BMS leakage, and the effect of aging on capacity. Assuming the coulomb counting can be accurate enough, the correction of these other elements should be used for finetuning, not a major course correction, as implemented today.

Nova's PureAveraging™ methodology represents a genuine approach to averaging that goes beyond conventional methods, such as sampling and digital filtering, which often introduce errors. PureAveraging™, our proprietary coulomb counting technique, achieves near-perfect repeatability with a minimal 0.02% error. This level of accuracy reestablishes coulomb counting as the core of SOC estimation, with voltage and temperature serving as supplementary fine-tuning guides as below:

1. Impact of Temperature:

Battery performance can be influenced by temperature, and understanding this impact is crucial for accurate SOC estimation. The relationship between temperature and battery characteristics includes:

Capacity Variation: Batteries exhibit temperature-dependent capacity changes. Lower temperatures can reduce the effective capacity, affecting the amount of charge a battery can store or deliver.

Internal Resistance: Temperature affects the internal resistance of a battery. Higher temperatures generally result in lower internal resistance, impacting the voltage response during charge and discharge.

Chemical Reactions: The chemical reactions within a battery are temperature-sensitive. Extreme temperatures can accelerate degradation processes, reducing the overall health of the battery.

To enhance SOC accuracy, advanced algorithms consider temperature compensation, adjusting SOC estimates based on the prevailing temperature conditions. Integrating temperature sensors into the battery management system allows real-time monitoring and adaptation to temperature variations. We should note that change of temperature by a few degrees should not create a large impart. The temperature range has high dependency on the application. As an example, we can safely assume a Notebook computer spends most of its time at room temperature and perhaps a bit elevated temperature when the system generates heat.

2. Integration of Energy Loss Factors:

Efficient SOC estimation requires addressing various factors contributing to energy loss. These factors include:

Heat Generation during Charge/Discharge: The charging and discharging processes in batteries are not perfectly efficient and result in heat generation. Efficient SOC estimation systems consider the energy lost as heat during these processes.

Self-Leakage and BMS Leakage: Some energy loss occurs due to self-leakage, where a battery discharges itself over time. Battery Management Systems (BMS) may also have a small continuous power draw. Integrating compensation for these leakage currents enhances the precision of SOC estimation.

Aging Effects: Battery aging, a natural process over time, can result in reduced capacity. Advanced SOC algorithms consider the age-related changes in capacity to provide more accurate predictions of remaining energy.

By comprehensively addressing these energy loss factors, SOC estimation systems can ensure that the calculated state of charge aligns closely with the actual energy content of the battery, even in the presence of various inefficiencies and losses. This nuanced approach improves the reliability of SOC estimates across diverse operating conditions and battery lifetimes.

Another crucial factor influencing remaining usage time estimation is the measurement of average usage. In certain car models, users may have encountered fluctuating estimates of remaining miles, largely attributed to the short averaging time of current usage. Without a sufficiently extended averaging period to smooth out variations, factors like ascending and descending hills can impact projected remaining miles. Achieving a long average discharge rate, especially in the order of many seconds, proves challenging. Analog filtering requires substantial values for R and C, while digital filtering at such durations introduces complexities and demands considerable resources.

PureAveraging™ comes to the rescue by delivering an accurate average of usage over extended periods without introducing errors. The combination of a prolonged averaging duration and precise coulomb counting significantly enhances the accuracy of remaining usage time estimation.

With these improvements, the remaining usage time estimation for a notebook computer can rival the accuracy of remaining miles in Electric Vehicles (EVs). Importantly, EVs can also benefit from these enhancements, potentially streamlining system complexity, reducing costs, and eliminating lengthy and expensive calibration steps in manufacturing.

Conclusion:

In the realm of battery management, the accuracy of State of Charge (SOC) estimation is paramount. Nova's PureAveraging™, with its exceptional repeatability at 0.02% error, revolutionizes coulomb counting. By addressing temperature variations and mitigating energy loss factors like heat, self-leakage, BMS leakage, and aging, PureAveraging™ ensures precise SOC estimation.

Extended averaging periods facilitated by PureAveraging™ enhance the accuracy of remaining usage time estimation, rivaling that of Electric Vehicles. This not only benefits notebook computers but also holds promise for simplifying Electric Vehicle systems, reducing costs, and eliminating extensive calibration processes.

In the intricate dance of electrons and aging components, PureAveraging™ emerges as a beacon, propelling us toward a future where battery charge prediction becomes as reliable as Electric Vehicle mileage, marking a significant stride in the convergence of accuracy and efficiency in energy management.

Saving our planet, one battery pack at a time!

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