CeLLife EFP™ vs Traditional Electrical Parameters

White paper: module unbalance and state-of-health evaluation

This paper shows why CeLLife Electrical Fingerprint (EFP™) can outperform traditional scalar checks such as ACIR and DCIR in two practical use cases: module unbalance screening and SoH evaluation. The key reason is simple: EFP™ keeps a broader electrical signature instead of reducing the battery to one number. At the same time, familiar outputs such as OCV, ACIR and DCIR can also be extracted from the EFP™ measurement.

Imbalance signal	SoH signal	OCV reality
In the imbalance case, EFP™ indicators were ranked above DCIR and ACIR. This is a strong sign that imbalance is easier to detect from a richer electrical fingerprint than from one resistance number.	In the SoH case, the top-ranked predictors were EFP™-derived. DCIR still carried some signal, but ACIR was clearly weaker.	OCV carries some signal but it is strongly affected by usage history. That makes OCV a weak stand-alone parameter, when full history of the module is not available.

Study basis

This paper is based on an internal study note covering 22 used battery modules from a well-known EV brand. Each module was 8S3P - NMC. The set covered SoH from about 20% to 98% of original or nominal capacity and unbalance from about 10 mV to 1.8 V, defined as the max-min cell voltage spread inside the module. Ten parameters were studied: traditional ACIR and DCIR together with eight EFP™-enabled indicators that capture broader electrical behavior across the module. OCV was also available from the same EFP™ measurement, but it was treated separately because voltage is strongly affected by charge/discharge history. The evidence presented in this white paper is strongest for screening, bucketing and anomaly detection.

Why is consensus ranking used

Feature importance is based on a consensus ranking across multiple methods - Lasso, Random Forest, Gradient Boosting, SHAP, and permutation importance. This gives a robust and model-independent view of which parameters repeatedly carry predictive information. In practice, it reduces bias from any one model and highlights the signals that stay useful across different analysis methods.

In simple terms, the ranking shows which signals stay important no matter which method is used. Across both case studies, several EFP™ indicators rank above the traditional single-number checks. DCIR still helps, especially for SoH, while ACIR is weak in both studies.

1. Module unbalance screening

Module unbalance is not a simple good/bad fault. It is a continuous condition that ranges from small cell-to-cell differences to severe weak-cell or dead-cell behavior. For real screening work, the important question is which electrical measurements most consistently separate normal modules from abnormal ones.

The figure shows that several EFP™-enabled indicators rank ahead of the traditional scalar checks. Both DCIR and ACIR were the weakest two of the studied ten parameters. This supports the practical value of EFP™ for early screening, because it captures electrical behavior more broadly than a single resistance values.

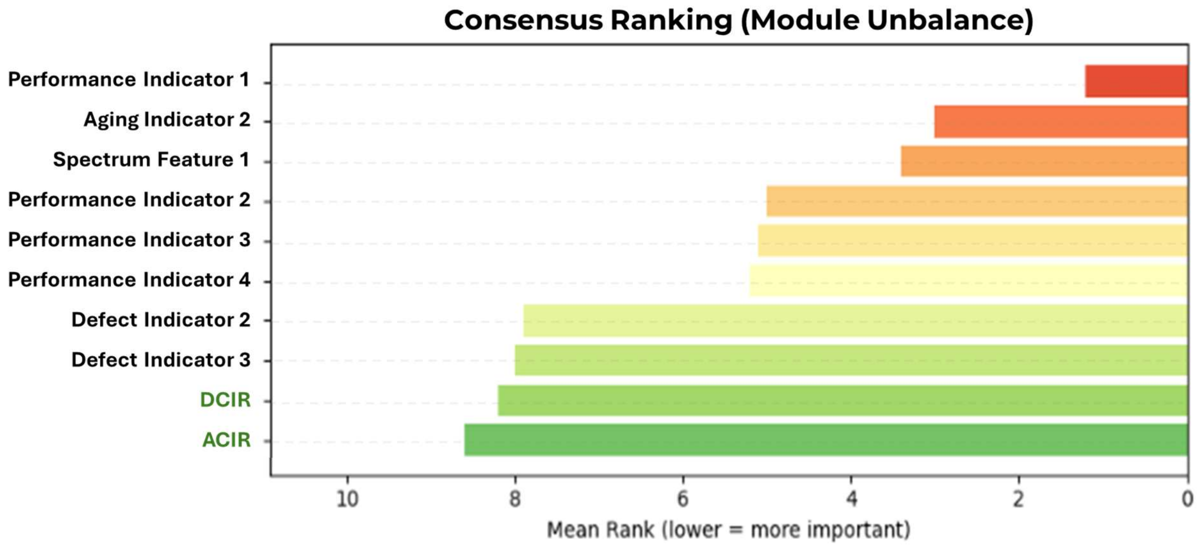

Figure 1. Consensus Ranking (Module Unbalance). Lower mean rank means higher importance.

2. State-of-health (SoH) evaluation

For SoH, the practical goal is not only to explain the past, but to estimate health from one electrical measurement when the usage history of the module is incomplete. That reflects real operations, especially when used modules are handled individually.

The same pattern appears in the SoH case. EFP™-enabled indicators occupy the strongest positions. DCIR remains somewhat useful, but ACIR stays at the bottom. OCV is not treated here as a strong standalone quality parameter, because it can change with recent charging and discharging history. In many practical cases, such as recycling operations, that history is unknown.

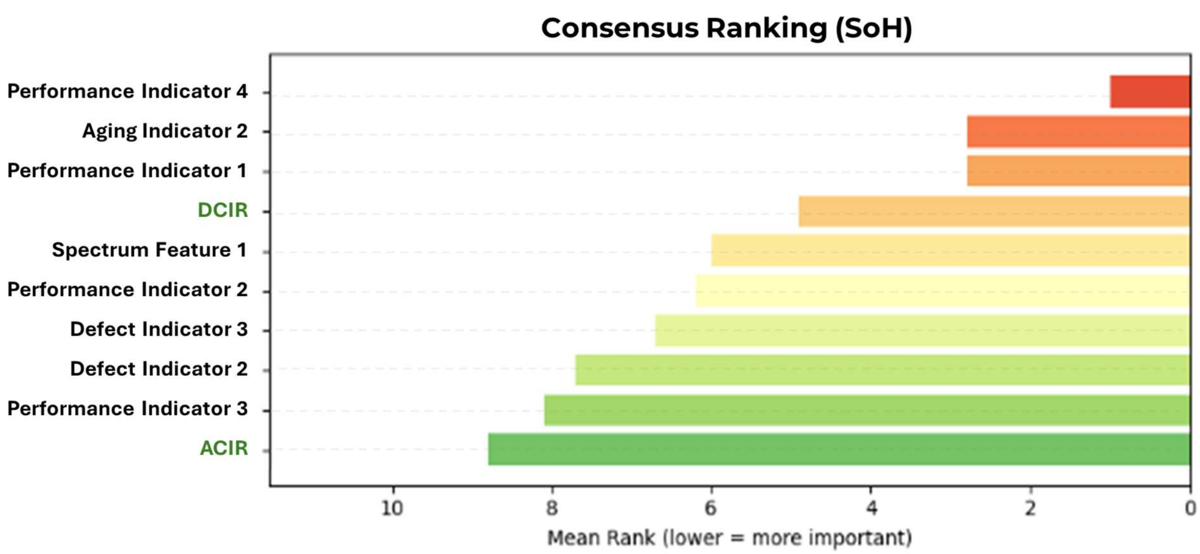

Figure 2. Consensus Ranking (SoH). Lower mean rank means higher importance.

3. Studied parameter set

In this study, 10 electrical parameters were compared: the traditional ACIR and DCIR measurements, plus 8 EFP™-enabled indicators that describe widely full electrical behavior of the battery. The table below shows the used indicator names in the consensus rankings figures together with a plain-language technical and practical description.

Indicator Name	Technical Description	Practical Description
ACIR (Defect Indicator 1)	AC-resistance (1 kHz)	Traditional ACIR measurement
Defect Indicator 2	Lowest internal resistance point	Lowest resistance point observed in the measured electrical response
Defect Indicator 3	High-frequency inductive response	Behavior of the high-frequency electrical response
Performance Indicator 1	Electrical response speed	Indicates how quickly the electrical system responds
Performance Indicator 2	Charge-transfer resistance	Reflects electrochemical charge-transfer and reaction kinetics difficulty
Performance Indicator 3	Pure internal resistance (ESR)	Resistive part of the internal electrical behavior
Performance Indicator 4	Overall current-path impedance	Describes the total impedance seen along the current path / electrical response
DCIR (Aging Indicator 1)	DC-resistance (0.5 Hz)	Traditional DCIR measurement
Aging Indicator 2	Ion transport limitation	Indicates limitations in ion transport behavior
Spectrum Feature 1	Resistive vs reactive balance	Describes the balance between resistive and reactive behavior of the electrical response

Note. *OCV is not part of the 10-parameter ranking set shown above, because voltage can be strongly affected by recent charge and discharge history. Still, OCV, ACIR and DCIR can all be extracted from EFP™ when needed.*

4. Interpretation for CeLLife

The practical message is not that traditional parameters are useless. The message is that they are incomplete. ACIR and DCIR each summarize the battery with one number, while EFP™ keeps a richer electrical picture. This richer information creates stronger inputs for anomaly detection, unbalance screening and SoH models.

In other words, EFP™ can become the main electrical measurement, while still delivering the familiar outputs that customers already know. That makes it easier to replace separate OCV, ACIR and DCIR measurements with one richer measurement workflow.

Conclusion

Across both case studies, the same conclusion appears: the most informative signals come from the EFP™-enabled indicators, not from ACIR alone and not from DCIR alone. Traditional parameters remain understandable and useful, but EFP™ adds broader electrical behavior and therefore better diagnostic value. For CeLLife, this supports the case for using EFP™ as the primary measurement layer for used-module screening and health evaluation.