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DC BUFFERING AND FLOATING CURRENT FOR A HIGH VOLTAGE IMB APPLICATION

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Abstract

An interface technique for the latest generation of the Impedance Measurement Box (IMB) has been conceived to enable measurement of impedance spectra for battery modules up to 300V. A 300V capable or higher IMB is an enabling technology for in-situ diagnostics within electric vehicle charging stations or battery back-ups within power distribution sub-stations. It is possible that the existing IMB can be adapted via a 300V interface module to a test battery with voltage significantly greater than 50V. Recently a new concept was conceived for the calibration, algorithm and electronics of the IMB. That algorithm and calibration for that concept have been physically validated. The principal feature of the new electronics is the floating current source excitation of the battery under test. The single ended current excitation of the battery under test, used in the 50V IMB, requires that the negative terminal of the test battery must be the analog ground for the IMB. The new floating current technique allows the test battery to be fully high impedance isolated for a measurement. That isolation will improve IMB noise immunity and enable interrogation of cells internal to a battery module. All these techniques still use the same rapid concept for impedance measurement with the IMB. The purpose of this disclosure is to provide an overview of the analytical validation for three concepts to interface the floating current excitation to a high voltage battery. Recursive simulation models were used in different test scenarios to validate the various new concepts. The analysis will show that it is possible to interface the floating signal current to obtain an impedance measurement on a high voltage test battery. Additionally, the analysis will investigate stress seen by electronics while testing a 300V battery.

Introduction

An interface technique for the latest generation of the Impedance Measurement Box (IMB) [1,2, 3] has been conceived and analytically validated to enable measurement of impedance spectra for battery modules up to 300V. Recently a new concept was conceived for the calibration, algorithm and electronics of the IMB. That algorithm and calibration for that concept have been physically validated. The principal feature of the new electronics is the floating current excitation of the battery under test and that feature has been analytically validated. The single ended current excitation of the battery under test, used in the 50V IMB [3], requires that the negative terminal of the test battery must be the analog ground for the IMB. The new floating current technique allows the test battery to be fully high impedance isolated for a measurement and this feature will greatly improve noise immunity. All these techniques still use the same rapid concept for impedance measurement with the IMB, that of exciting the test battery with a Sum of Sines (SOS), a parallel concurrent sum of those sine waves for all the frequencies of interest for the impedance spectrum (typically an octave harmonic frequency spread). The purpose of this disclosure is to provide an overview of the analytical validation for three concepts to interface the floating current excitation to a high voltage battery. This will allow high impedance isolation from a high voltage battery under test. Two of these three concepts enable the high voltage IMB to excite the test battery with the same high level SOS current as the 50V IMB, this greatly improves signal to noise ratio and allows the high voltage IMB to acquire credible spectra from a very low impedance automotive type battery module. The analytical validation will show that it is possible to interface the floating signal current to obtain an impedance measurement on a high voltage test battery.

Progress

A double and a single buffer concept for coupling the floating current source to a high voltage battery were conceived and analyzed. A schematic block diagram of the measurement concept with the dual high voltage buffer is shown in Figure 1.

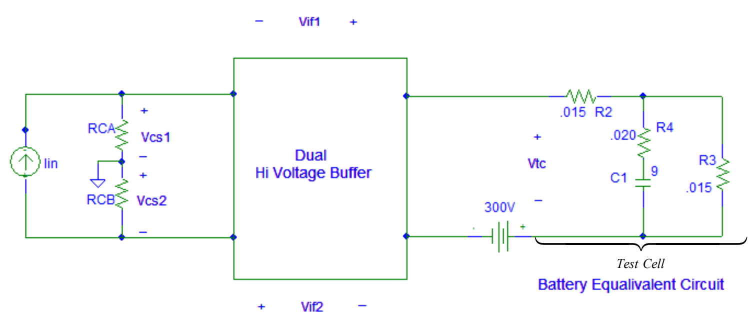

Figure 1 Dual high voltage buffer floating current IMB

Also shown in Figure 1 all the desired analysis outputs: the Test Cell voltage, V_{TC};, the upper buffer voltage, V_{IF1}; the lower buffer voltage V_{IF2}; the current source outlet voltage, V_{CS1} and, the current source inlet voltage, V_{CS2}. The 300V battery is modeled as a perfect battery in series with the equivalent circuit of a Test Cell (TC) as source impedance [3]. The TC was used because its frequency characteristics of its impedance are very similar to a typical battery except that it lacks the Warburg low frequency tail [3]. The resistors $R_{CA,B}$ associated with the floating current source are added source impedance to provide balance to the analog ground. The components of the TC: R_2 , R_3 , R_4 & C_1 are typical values for a TC used in IMB development. The attractive feature of this circuit is that there is balanced buffering from the test battery and the buffers must tolerate only half of the battery voltage. However, since the buffering circuits are effectively in series, their impact will double any IMB algorithm error introduced by buffering. The single buffering block diagram is exactly like Figure 1 except the voltage V_{IF2} is not present. It provides only single ended buffering but is still high impedance isolated by the floating current source. However, the single buffer must now sustain the total battery voltage. Additionally, because of the single buffer, the IMB algorithm error is halved. A Spice circuit simulation model (A commonly used computer program for circuit simulation in EE electronic design) was configured for both circuits and excited with a waveform of characteristics comparable to the SOS RMS signal current. The voltage developed at the input and output of the floating current source was computed. The excitation was trimmed until the stress voltages developed at the floating current source were within+/-30V. The +/-30V limit means that the electronics design can be scaled from the 50V IMB design and the power supply needed won't have to be offset (+55V/-5V) as was done for the 50V IMB. The excitation current that reached that limit for the double buffer was 60mA. For the single buffer the signal current that just reaches the 30V limit was 120mA. Based upon the results of the Spice analysis yielding the low current limit for the dual buffer concept, the single buffer with the higher current limit for a 300V IMB was selected and evaluated with a recursive model [4] to simulate an IMB measurement for a TC.

The single buffer was analyzed modeled and excited with a SOS signal current for the purpose of identifying the impedance of the Test Cell (TC). The recursive model was derived starting with a Laplace circuit analysis. Then a Laplace to Z transformation [4] was performed to obtain a transfer function in terms of Z. Finally a discrete state variable description of the Z transform transfer function [4] was implemented to become the recursive model. An analysis time step was selected to be used that was compatible with the system time constants. Using this recursive model, the time response of the Test Cell, V_{TC}, to SOS current was captured and processed via the HCSD algorithm and the estimated impedance compared with the ideal, $j\omega$ impedance. Additionally, the stress voltages at the outlet and inlet of the floating current source V_{CS1} & V_{CS2} and battery voltage buffer, V_{if1} were also computed. For the buffer a 300V blocking battery voltage was assumed. The recursive model was validated by using it to compute the pulse response for the TC and compare it to the Spice model pulse response. The recursive model and Spice model responses to the identical pulse gave very good agreement and thus the recursive model was validated.

The recursive model was excited with a SOS current of 120mA RMS, 15 frequencies starting at 0.1 Hz. The captured time response de-convolved via the HCSD algorithm into the test cell impedance spectrum and plotted with the theoretical test cell impedance spectrum (computed via $j\omega$ analysis).
Figure 2 plots the recursive spectrum with the true spectrum for HCSD. The mismatch error was very slight and was probably caused by the buffer and the floating current source impedance bypassing a small amount of SOS current around the TC. The recursive model estimated the stress response for the current source outlet voltage and the current source inlet (voltage must be within +/-30V). Parameter tolerance values were set to worst case by 0.4%, an SOS current of 120mA RMS and a HCSD frequency spectrum of 0.1 Hz with 15 frequencies was run. With the 0.4% parameter tolerance error the current source was at the 30V limit and there was insignificant change in the spectrum resolution. Thus the single buffer concept has been analytically validated for an SOS current up to 120mA RMS. The 120mA SOS current barrier limits impedance spectrum resolution because of signal to noise issues. However, this concept allows the existing 50V IMB hardware and software to be easily scaled for this application.

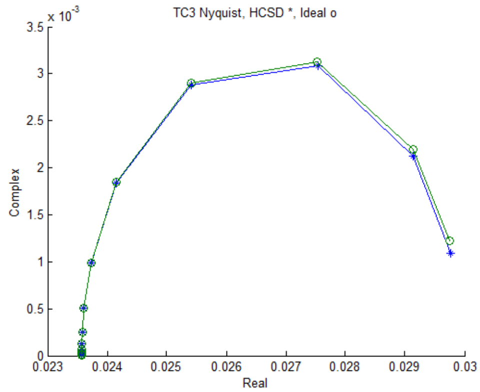

Figure 2 HCSD Impedance spectrum

A different approach must be taken to go to higher SOS current. The basic assumption of all generations of IMB is that the SOS current to the test device is constant thus the voltage time record from the test device can be acquired and calibrated to yield an impedance spectrum. This measurement concept has worked well. However, in order to source higher levels of SOS current a small amount of current must bypass the test battery and this will degrade the assumption resulting in corrupted spectra. However, if that current is known then the spectrum can be obtained.

Since most of the bypassed current is from the current source impedance, which is known, measuring the current source voltage drop gets the current, thus the test device current is known and a spectrum can be obtained. Using an SOS of 500mA RMS and a worst case parameter tolerance of 0.4% the spectrum is obtained but there is a slight error caused by the buffer bypass current. That error is in the form of an offset in the real part of the impedance and can likely be addressed by calibration. The next concept fixes that with a current shunt in series with the test battery and measures the actual current to the test battery. Figure 3 illustrates the final results. Clearly, measuring the actual current yields a perfect match. For approaches an extra measurement channel is needed and a different calibration will be needed. Never the less, with a 500mA SOS current the resulting signal to noise ratio will yield a resolution of impedance compatible with that of battery modules use in electric vehicle applications.

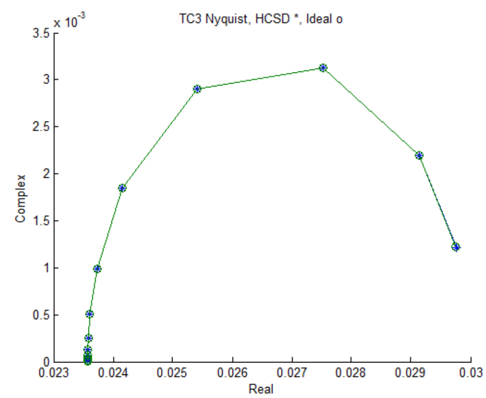

Figure 3 spectrum via the actual current

Future work

The concept of buffer connected floating current for a 300V IMB has been analytically validated and is ready for physical design testing of the various concept features and then full prototype development. A buffer circuit control and safety monitoring system must be developed and tested. Its conceptual approach is simple but its performance for function and safety is critical. The battery voltage differential amplifier must reject 300V or more and focus its resolution on acquiring the voltage response to the SOS current. The same technique used for the 50V IMB will be adapted and refined to work here. If the test device is expected to have extremely low impedance higher SOS current will be needed and the limited SOS current of method one may not be applicable. The demand for higher resolution may drive increased bits of resolution from 16 to 24. Additionally, with the increasing demand for sensitivity the issue of switching power supply noise may need to be revisited and enhanced techniques implemented to suppress it much more than what was done for the 50V IMB. The electronic development will be a challenge indeed.

Impact on Laboratory or National Missions

The enhancements to the IMB that allow the rapid acquisition of impedance spectra from high voltage battery modules will facilitate real time diagnostics for battery backup systems used in mission critical applications as in electrical utility substations. Additionally, a high voltage IMB could be integrated into an electric vehicle charging station and thus capture an impedance spectrum for the specific battery pack being charged to track its health and predict its future performance. Insuring the availability of critical battery backup for energy storage and advancing the technology of electric vehicle power are missions of the National Laboratories.

Conclusions

Three measurement techniques, using the floating current source and a single buffer, were evaluated with positive results. The first technique used the conventional IMB measurement approach of known SOS current exciting the test device, capturing the time record, processing with the HCSD algorithm and then applying a calibration to identify the device impedance. This method will work if the floating current source SOS current is below 120mA. The attractive feature of this method is that data processing and calibration are exactly like the 50V IMB. The second method can source SOS current to 500mA and will provide an impedance spectrum with some minor error that could likely. The third method is exactly like the second method except that a shunt in series with the current path to the test device will measure the actual test device SOS current. It will yield a perfect spectrum with no error. The disadvantages of methods two and three are the need for an additional concurrent measurement channel and the uncertainty of how to handle calibration. Never the less these are minor development issues. The clear advantage of these two methods over method one is their much improved resolution for application to very low impedance batteries.

References

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Appendix:

Paticipants:

Name	Institution	Activity
J. L. Morrison	Montana Tech	Concept inventor performed detailed analysis
W.H. Morrison	Montana Tech	Co-inventor, generated custom code for analysis
J. P. Christophersen	INL	Co-inventor, oversight and review
T.Mcjunkin	INL	Oversight and review
C. Rieger	INL	Oversight and review

Scientific Facilities

Battery Research Lab at Building Main Hall, Montana Tech

Notable Outcomes

INL Invention Disclosure: XXXXX

300V IMB, single shunt calibration and Harmonic Orthogonal Synchronous Transformation algorithm

Research Vibrancy

The concept of a high voltage IMB is enabling for in-situ diagnostics applied to a wide range of energy storage battery applications. One such perfect application for this technology is for an EV charging station. INL is presently doing research in quantifying the shift of impedance spectra over life to the health of a battery. Additionally, SNL is doing research to identify unique characteristics of impedance spectra that are precursors to failures. Rapid impedance measurements performed during the EV charge cycle could ensure safety by early identification of failures and a spectrum obtained at some finite levels of charge would be archived for that specific battery and used to estimate overall health and remaining useful life. Another possibility could be for critical battery backup systems such as in Electrical Utility Substations.

Connection to Programs at Home Academic Institution

Montana Tech will use these concepts with further development via research for a MSEE thesis that will prototype a 300V IMB in a manner similar to what was done for the 50V IMB.