A Measuring Method about the Bus Insulation Resistance of Power Battery Pack

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For the shortcomings of insulation resistance detection method about battery pack, a novel detection method is introduced. This method can effectively realize the real-time measurement for the insulation resistance of the positive and negative bus, relative to the ground. In the dynamic conditions, improved the positive and negative bus insulation resistance measurement accuracy, more suitable for applications in integrated battery pack monitoring unit, It has a simple circuit, low power consumption, low cost hardware.

1. Introduction

In electric vehicles, because the working voltage of power battery is higher (generally in the 300 v to 600 v), when the battery power bus cable insulation aged or affected by damp environment factors, which can lead to high voltage circuit and the insulation performance is degraded, resulting in leakage current between the positive and negative bus and the environment, which is the threat to personal safety and vehicle safety (Lei et al., 2010). Therefore, accurate real-time monitoring of battery power bus insulation resistance and safety are of great significance to ensure that vehicles and personnel (Huang et al., 2005).

Currently, the measuring methods of battery bus insulation resistance include auxiliary power method, current sensing method, the positive and negative bus on the Environment and the partial pressure of the asymmetric method and bridge method (Wang, 2011). Due to the asymmetric bridge measurement is relatively simple, currently received more applications. The basic principle is to connect the parallel connection between the positive bus-to-ground insulation resistance Rp and the negative bus-to-ground insulation resistance Rn, respectively, and the two known positive and negative bus parallel resistors R + and R-. By measuring the positive and negative bus-to-ground voltages Vp, Vn and the battery voltage V, according to the loop equation, Since this method is done by switching R + and R- times to complete sampling and measurement of Vp, Vn, and V , therefore, in sampling measurement, when the battery voltage V is steady state value, the measurement error approach mainly from the dividing resistor, an operational amplifier A1, A2 and an error of the ADC. However, when the battery is in a dynamic state of working conditions, due to the drastic changes in the battery voltage V,Vp, Vn and V sampling measurement time is not synchronized, the measured value Rn and Rp will produce large errors (Zhou et al., 2013).

This article provides a battery powered bus insulation resistance measurement apparatus and method which can reduce the measurement error bus insulation resistance in dynamic conditions (Cheng et al., 2012; Luo et al., 2013; Wu, 2015; Zhang and Wen, 2013).

2. Bus insulation resistance measurement method

Measurement of power batteries bus insulation resistance, comprising: these shown in Figure 2, 3, 4.
2.1 Bus insulation resistance calculation method

\[
\frac{R_{+,IR}}{R_{-}} = \frac{V_{+}}{V_{-}} = K_{+} \tag{1}
\]

\[
R_{-} = \frac{R_{+,R}}{K_{+}(R_{+,R}+R)} \tag{2}
\]

\[
\frac{R_{-,IR}}{R_{+}} = \frac{V_{-}}{V_{+}} = K_{-} \tag{3}
\]

\[
R_{+} = \frac{R_{-,R}}{K_{-}(R_{-,R}+R)} \tag{4}
\]

Take equation (2) into equation (3)

\[
R_{+} = \frac{(1-K_{+,R})R}{K_{+}(1+R_{+,R})} \tag{5}
\]

Take equation (4) into equation (1)

\[
R_{-} = \frac{(1-K_{-,R})R}{K_{-}(1+R_{-,R})} \tag{6}
\]

2.2 Improvement bus insulation resistance calculation method

Above is calculated on the assumption that V is constant deduced conclusions. The practical application of V is within a certain range, and if unable to V, V+, V- strictly simultaneous measurement, when the change rate V is larger, since the measurement process will not synchronize V+, V- of deviation from the measured value of V sampling time of the actual value of the insulation resistance caused by a calculation error (Wang et al., 2012).

To do this, use the following measurement and compensation:

1. \(\Delta T\) cycle, sequentially V, V+, V-, V sampling, measurement values were obtained V0s, V+s, V-, V3s;
2. V increment calculation of \(\Delta V = V3s-V0s\);
3. The V in the sampling period (0.0-3 \(\Delta T\)) can be approximated by a linear change, and V+, V- and V has a linear relationship, that is, V+, V- and V have the same \(K_{\Delta V}\). Thus, in the sampling period, with \(K_{\Delta V}\) at the same time point to V+, V- and V were estimated.
4. Click the estimated time in $3\Delta T/2$, the computing $V_+, V_-, V$ in $3\Delta T/2$ time estimates $V_{+ES}$, $V_{-ES}$, $V_{ES}$.

$$V_{ES} = V_0 + K\Delta V (3\Delta T/2)$$

$$V_{+ES} = V_{+ES} + K\Delta V (3\Delta T/2)$$

$$V_{-ES} = V_{-ES} - K\Delta V (3\Delta T/2)$$

5. The $V_{+ES}$, $V_{-ES}$, $V_{ES}$ as (1), (2), (5), (6) where $V$, $V_+$, $V_-$ calculated.

S1: the following order cycle sampling: First, the battery voltage is sampled; then on the positive bus voltage is sampled on the ground; and then the battery voltage is sampled; and negative-ground voltage sampling;

S2: Calculation positive bus to ground voltage sampling value, twice the measured battery voltage difference as a first increment coefficient, calculated in negative ground voltage value, twice the measured battery voltage difference as a gain in the second, and respectively positive bus and negative bus voltage to ground-to-ground voltage estimates at the time of sampling the battery voltage based on the first and second incremental increase coefficient;

S3: According to the sampled battery voltage and the battery voltage sampling time is positive, negative ground voltage estimation value obtained in the sampling time positive bus and negative bus insulation resistance.

![Image](image-url)

**Figure 4:** The actual value and the measured value of the voltage

![Image](image-url)

**Figure 5:** Voltage sampling process of traditional methods
Loop sampling process in particular:
S11: initialization of the loop sampling counter \( i = 0 \);
S12: positive bus and negative bus communication, measuring the battery voltage \( V \) \((4i \cdot \Delta t)\), where \( \Delta t \) is the sampling period;
S13: positive bus communication, disconnect the negative bus, measuring positive bus to ground voltage \( V_p \) \(((4i + 1) \cdot \Delta t)\);
S14: communicating positive bus and negative bus, measure battery voltage \( V \) \(((4i + 2) \cdot \Delta t)\);
S15: negative bus communication, disconnect the positive bus, measure negative ground voltage \( V_n \) \(((4i + 3) \cdot \Delta t)\);
S16: loop sampling counter \( i = i + 1 \), go to step S12.
Voltage sampling process is shown in Figure 6.

In practice sampling period \( \Delta t = 10\text{ms} \) or \( 20\text{ms} \).
Since the insulation performance degradation is a slow process, the insulation resistance \( R_p \) positive bus and negative bus insulation resistance \( R_n \) in a sampling cycle time can be approximated as a constant by the formula (1), (2) and (3) can be seen, when incremental coefficient \( R_+ = R_- = N \), the positive bus to ground voltage \( V_p \) in \( 4N\Delta t \): \( (4N + 2) \Delta t \) sampling time has a first gain in battery voltage \( V \) of the same \( kp \) \((N)\), which is
\[
kp \(N) = \frac{\Delta V_p}{V_p} = \frac{[V ((4N + 2) \Delta t) - V ((4N\Delta t))]}{V ((4N\Delta t))}
\]
Similarly, negative ground voltage \( V_n \) at \( (4N + 2) \Delta t \): \( (4N + 4) \Delta t \) having an inner \( \Delta t \) sampling time and battery voltage of the second gain in the same incremental coefficient \( kn \) \((N)\), that is,
\[
kn \(N) = \frac{\Delta V_n}{V_n} = \frac{[V ((4N + 4) \Delta t) - V ((4N + 2) \Delta t)]}{V ((4N + 2) \Delta t)}
\]
Accordingly, by the positive bus to ground voltage \( V_p \) at \( (4N + 1) \Delta t \) time and negative bus to ground voltage \( V_n \) at \( (4N + 3) \Delta t \) time measurement \( V_p \) \(((4N + 1) \cdot \Delta t)\) and \( V_n \) \(((4N + 3) \cdot \Delta t)\) calculate the estimated value of the bus to the positive and negative voltages \( V_p \) and \( V_n \) in the \((4N + 2) \Delta t \) time:
\[
V_p \((4N + 2) \cdot \Delta t) = V_p \((4N + 1) \cdot \Delta t) \left[1 + \frac{kp \(N \)}{2}\right]
\]
\[
V_n \((4N + 2) \cdot \Delta t) = V_n \((4N + 3) \cdot \Delta t) \left[1 - \frac{kn \(N \)}{2}\right]
\]
The battery pack voltage \((4N + 2) \Delta t\) time measurement values \(V\) \((4N + 2) \Delta t\) and known \(R +, R-\), the use of (1) - (5), we can calculate the positive negative insulation resistance \(R_p\) and \(R_n\) at \((4N + 2) \Delta t\) measured value \(\Delta t\) time.

When the next sampling cycle, that is, \(i = N + 1\), the positive and negative moments in \(4N \Delta t\) ground voltage \(V_p\) and \(V_n\) can be calculated:

\[
\begin{align*}
kp (N) &= \frac{\Delta Vp}{Vp} = \frac{[V ((4N + 2 \Delta t) - V (4N \Delta t)) / V (4N \Delta t)]}{1 - kp (N) / 2} \\
Vp ((4N + 2) \Delta t) &= Vp ((4N + 1) \Delta t) [1 - kp (N) / 2] \\
Vn ((4N-1+2) \Delta t) &= Vn ((4N-1+3) \Delta t) [1 + kn (N-1) / 2]
\end{align*}
\]

The battery pack voltage measurements \(V\) in \(4N \Delta t\) time \((4N \Delta t)\) and known \(R +, R-\), the use of (1) - (5), we can calculate the positive and negative insulation resistance \(R_p\) and \(R_n\) measurements in \(4N \Delta t\) time, as shown in picture 7.

**Figure 7:** The positive and negative bus voltage to ground to the schematic diagram of estimate measurement

### 3. Measurement Embodiment

This measure can effectively achieve the insulation resistance of the positive, negative battery voltage and the bus in real time measurement, improve the dynamic conditions of positive and negative bus to ground insulation resistance measurement accuracy, with a simple circuit, low power consumption, low cost hardware, it is more suitable for integration in the power battery monitoring unit (Guo et al., 2011).

When used, the basic principle of asymmetric bridge method, measuring means circuit has three inputs, i.e. positive bus input terminal, a negative input bus bar and vehicle ground through a first resistor \(R1\) and the second resistor \(R2\), the third resistor \(R3\) and the fourth \(R4\) as a voltage divider resistors constituting the first and second voltage divider circuits 5, 6, Measuring device provide positive \(V_p\), negative bus voltage to ground. \(V_n\) and \(V\) battery voltage measurement signal for high impedance differential operational amplifier A1 in-phase side and reverse side.

In this embodiment \(R1 = R3, R2 = R4, kf = R1 / R2 = R3 / R4\) ratio of the partial pressure. After the signal the operational amplifier A1 is amplified to ADC input AD conversion of the microprocessor CPU via isolation amplifier A2 ADC. Measurements:

1. When the first gate switch \(J+\) and the second gate switch \(J-\) conducting at the same time, Battery voltage \(V\) via the first to fourth resistor \(R1, R2, R3\) and \(R4\), bleeder circuit amplifier A1 provide partial pressure signal \(V/kf\) of battery voltage operational \(V\), realized measurement of battery voltage \(V\).

2. When the first gate switch \(J+\) and the second gate switch \(J-\) turned off at the same time, voltage \(V_p\) of positive bus opposite ground is divide after the resistors \(R1\) and \(R2\), which provide with the partial pressure signal \(Vp/kf\) for amplifier A1 to achieve measurement of the positive bus to ground voltage \(Vp\) (Ding, 2016).

Because the amplifier A1 input has \(G\) the level of input impedance, Thus, \(R1 + R2\) can be regarded as parallel resistance \(R\) between the positive bus and ground, used to calculate the insulation resistance \(R_p\) of positive bus and insulation resistance \(R_n\) of negative bus (Li et al., 2015).

When the second gate switch \(J-\) turned on, the first gate switch \(J+\) turn-off, the voltage \(Vn\) of the negative bus opposite ground is divide after the resistors \(R3\) and \(R4\), which provide with the partial pressure signal \(Vn/kf\) for amplifier A1 to achieve measurement of the negative bus to ground voltage \(Vn\). Because the input of amplifier
A1 has G ohms the level of input impedance, Thus, R3 + R4 can be regarded as parallel resistance R−
between the positive bus and ground, Used to calculate the insulation resistance Rp of positive bus and
insulation resistance Rn of negative bus. To give positive and negative bus insulation resistance value via the
specific formulas (1) to (5).

4. Conclusion
This design reduces the measurement error of the positive bus insulation resistance Rp and the negative bus
insulation resistance Rn , dueing to the non-synchronization measurement of the battery voltage V for the
positive bus-to-ground voltage Vp and the negative bus-to-ground voltage Vn in the rapid change of the
battery voltage, improved the measurement accuracy of the insulation resistance of the bus to ground,
reduced the complexity of the measurement circuit, making the measurement circuit more simple and reliable.
To achieve an integrated measurement of bus insulation resistance and battery voltage.

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