EVS24
Stavanger, Norway, May 13 - 16, 2009

The New Electric Leakage Sensor

Hiroatsu Tokuda[1] , Masaaki Yoshikawa[2]

[1]*PUES Corporation Chief Engineer 1516 Aiko,Atsugi,Kanagawa 243-0035 JAPAN E-mail:tokuda@pues.co.jp*

[2]*PUES Corporation Deputy Director 1516 Aiko,Atsugi,Kanagawa 243-0035 JAPAN E-mail:m.yoshikawa@pues.co.jp*

Abstract

This paper describes a new Insulation Failure Warning Device.

High voltage direct current power supplies for Electric Vehicles (EV) are insulated from the chassis to prevent electrocution. The Insulation Failure Warning Device continuously monitors the insulation resistance between the high voltage direct current power supply and the chassis, issuing an alarm signal when the insulation resistance decreases below the specified value. A new Insulation Failure Warning Device was developed that realizes rapid high precision measurement with a simple circuit.

Keywords: Insulation Failure Warning Device, Current alternated circuit, Insulating Capacitance

1 Introduction

The Insulation Failure Warning Device is a device that has the function of continuously monitoring the insulation resistance between the chassis of a vehicle and the high voltage circuit, producing a Warning Signal and an Alarm Signal when the insulation resistance decreases below the specified value.

The high voltage direct current power source mounted on EVs or HEVs (Hybrid Electric Vehicles) stores high voltage energy by stacking several Lithium Ion battery cells or super capacitor cells. The voltage varies greatly depending on whether charging or discharging. Insulation Failure Warning Devices must have the ability to endure high voltages, the capacity to track large voltage variations, and the capability to provide continuous detection.

When the insulating condition is good, the insulation resistance has a value equal to or greater than several tens of Mega Ohms (MΩ). Stray capacitance of several tens of nano Farads (nF) to several hundreds of nF exists between the high voltage circuit and the chassis. Accordingly, the time constant (=insulation resistance x stray capacitance) becomes very large (=several seconds to several tens of seconds). For this reason, the measurement of insulation resistance requires a long time, which causes a problem at vehicle start up. Rapid judging capability regardless of the value of insulation resistance and stray capacitance is an essential element for an Insulation Failure Warning Device.

The high voltage circuit is divided into the direct current region between the high voltage direct current power source consisting of the battery and the inverter/converter, and the alternating current region between the inverter/converter and the motor/generator. When a drop in insulation resistance occurs in the alternating current region, the zero phase current caused by distorted wave flows and high frequency noise superimposes on the current in the Insulation Failure Warning

Device—which means the judgment may take longer. Therefore, Insulation Failure Warning Devices also require the capability to provide rapid judgments regardless of the point where the insulation resistance drop occurred.
The Insulation Failure Warning Device developed by our company (herein after called the EL sensor) has the capability to provide continuously detection with a simple circuit, and can provide rapid, highly precise judgments, regardless of the insulation resistance and of the point where the drop of the insulation resistance occurred. The remainder of this article describes the details of this development.

2 System Configuration

Fig.1 shows the system configuration including the high voltage circuit of the EV and the measurement circuit (EL sensor). Rx is the insulation resistance between the high voltage circuit and the chassis, while Cx is the stray capacitance between the high voltage circuit and the chassis. There is no difference in the sensor's operation whether the insulation resistance Rx and the stray capacitance Cx are distributed or concentrated in the high voltage circuit.
The high voltage circuit and the EL sensor are connected by only one electric wire, and if it is connected to the direct current region of the high voltage circuit, the location of the connection point does not affect the sensor's operation.
The insulation capacitor Ci is contained in the EL sensor circuit and has the role of DC insulation of the EL sensor from the high voltage circuit. Because of this, the component must be able to endure high voltages. The capacitance of insulating capacitor Ci is 10 times that of estimated stray capacitance Cx.
The EL sensor operates with a normal battery voltage of 12 V. It provides the following outputs: Warning Signal, Alarm Signal, and Valid Signal, all of which are open collector outputs. The Warning and Alarm Signals are issued when the insulation resistance drops to the specified value or lower. The Valid Signal is issued when the Warning and Alarm Signals are valid.
The sensor starts operating when the 12 V terminal is connected to the 12 V battery voltage. The insulation resistance Rx of the high voltage circuit is continuously monitored and when a drop in the voltage is judged according to the specified value, either a Warning Signal or an Alarm Signal is issued.
The specified value of the resistance for issuing the Warning or Alarm Signal is 0 to 400 kΩ and the design assumes a stray capacitance Cx of 0 to 0.4 μF.

3 Method of Measurement

There are two methods for measuring resistance value: (1) Apply the voltage and measure the current value, (2) Force the current flow and measure the voltage value. This EL sensor adopted the latter, method employing current.
Concretely, this device adopts a Constant Current Alternated Method that switches the direction of

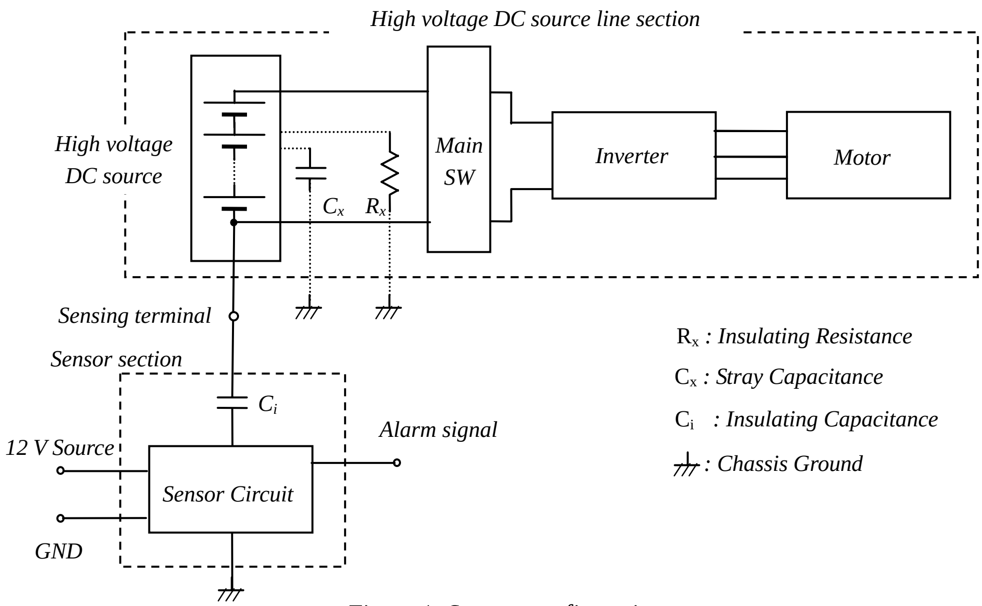

Figure 1: System configuration

the constant current every sampling period.

Fig.2 shows a circuit diagram explaining the principle behind the Constant Current Alternated Method. The operation is described for a case in which the voltage Vci of the insulation capacitor and the voltage VB of the high voltage circuit are balanced. Fig.3 shows the output voltage when the current direction alternates every sampling period Ts. The output voltage V out (Ts) and V out (2Ts) in alternation is expressed as follows.

$$V_{out}(T_s) = V_{ci}(T_s) + V_{cx}(T_s) = \frac{I_0}{C_i}T_s + R_x I_0\left(1 - \varepsilon^{-T_s/\tau_x}\right) \quad (1)$$

$$V_{out}(2T_s) = V_{ci}(2T_s) + V_{cx}(2T_s) = -R_x I_0\left(1 - \varepsilon^{-T_s/\tau_x}\right) \quad (2)$$

Where the time constant $\tau_x = C_x R_x$
and the difference of both becomes

$$V_{out}PP = V_{out}(T_s) - V_{out}(2T_s) = \frac{I_0}{C_i} + 2R_x I_0\left(1 - \varepsilon^{-T_s/\tau_x}\right) \quad (3)$$

Here, when the sampling period TS is set at four or more times the time constant $\tau_x = C_x R_x$, the exponential term need not be considered.

$$V_{out}PP \approx \frac{I_0}{C_i} + 2R_x I_0 \quad (4)$$

From this Equation (4), the insulation resistance Rx is obtained as follows.

$$R_x = \frac{V_{out}PP}{2I_0} - \frac{T_S}{C_i} \quad (5)$$

Supposing the sampling period Ts calculated using the maximum value of the estimated insulation resistance Rx of 0 to 400 kΩ and a system stray capacitance Cx of 0 to 0.4 μF,

$$(T_S)_{max} = 4 \times \tau_x = 4 \times (400\text{k}\Omega \times 0.4\mu\text{F}) = 0.64\,\text{sec} = 640\text{ms} \quad (6)$$

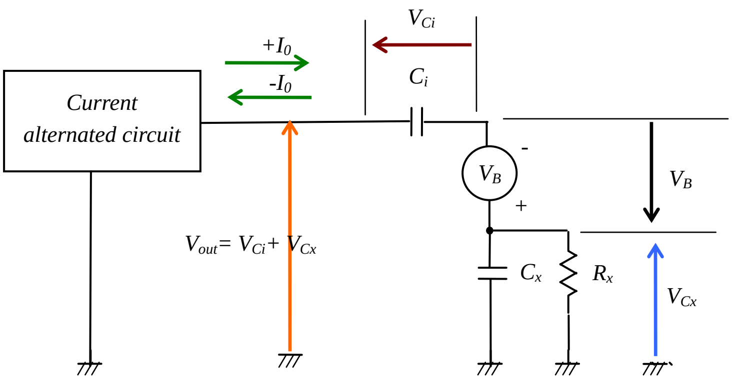

Figure 2: Circuit to explain the principle behind the constant current alternated method

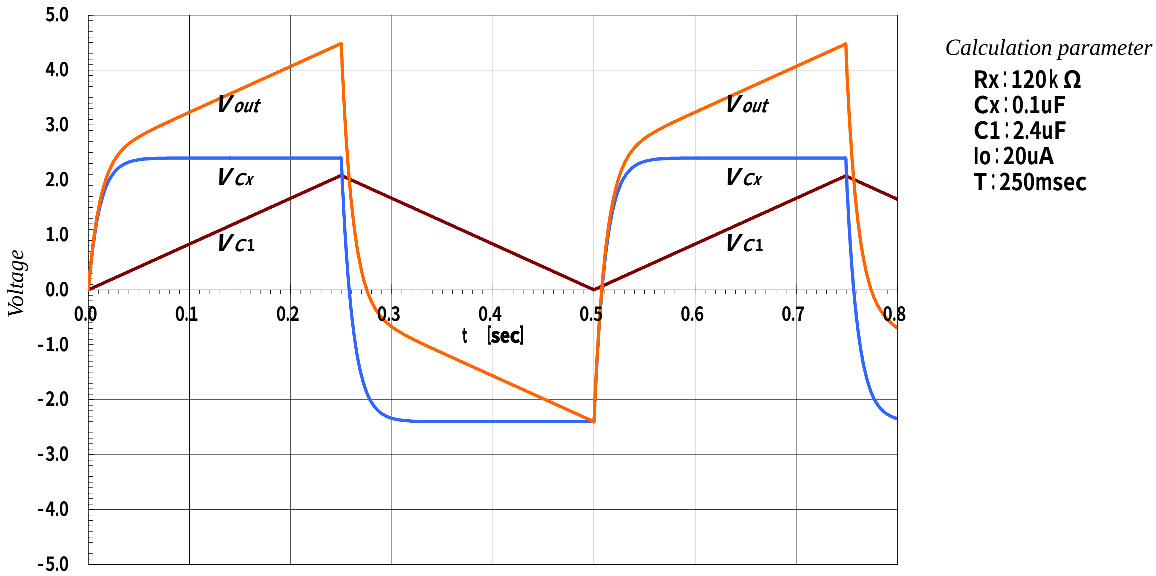

Figure 3: Output Voltage

The insulation resistance is calculated with a precision of 98.2% in the assumed region.
When the stray capacitance Cx of the high voltage circuit is less than 0.4 μF, the same precision can be obtained even with a shorter sampling period. Thus, the sampling period is set in four steps (80 ms, 160 ms, 320 ms and 640 ms) and the minimum sampling period of Ts=80 ms is set at start up. When the calculated insulation resistance value Rx drops to 400 kΩ or less, the sampling period Ts is prolonged successively. A difference in the calculated insulation resistance of no more than 1.8% between the current sampling period Ts(n) and the next sampling period Ts(n+1) is taken as evidence that the calculation is already in the convergence region for the current sampling period Ts(n). The sampling period Ts(n) is thus defined.
With this operation, the most suitable sampling period Ts was obtained for the stray capacitance of the high voltage circuit, thus enabling rapid judgment.

The operation principle is as described above. However, when the insulation resistance is normal in the constant current circuit (i.e. when the insulation resistance Rx is several tens of MΩ and the stray capacitance Cx is low) there is one weakness in that the output voltage V out becomes large and the driving power source (voltage) of the constant current circuit cannot force a constant current.
To solve this problem, a current limiting mechanism in proportion to the output voltage V out is adopted in the real circuit in order to keep the maximum output voltage to the driving voltage or less.
Fig.4 shows the relationship between the insulation resistance Rx and the output voltage V outPP. It becomes apparent that when the insulation resistance is 400 kΩ or less, highly precise high resolution measurement is possible, and with greater insulation resistance, the resolution deteriorates.
When a drop in insulation resistance in the alternated current region occurs, a zero phase current caused by the distorted-wave current flows and high frequency noise is superposed in the current of the Insulation Failure Warning Device. This non signal wave form noise component is removed by the powerful Digital Soft Filter built into the EL sensor.

4 Hardware Configuration

Fig.5 shows the hardware configuration. Parts with general specifications (voltage endurance of equal to or less than 60 V) can be used apart from the capacitor, which assures the insulation between the measurement circuit and the high voltage direct current power source. Thus, the sensor does not incorporate expensive parts with special specifications.
The hardware comprises an analog part and a digital part. The analog part comprises the power source and the constant current circuit. The digital

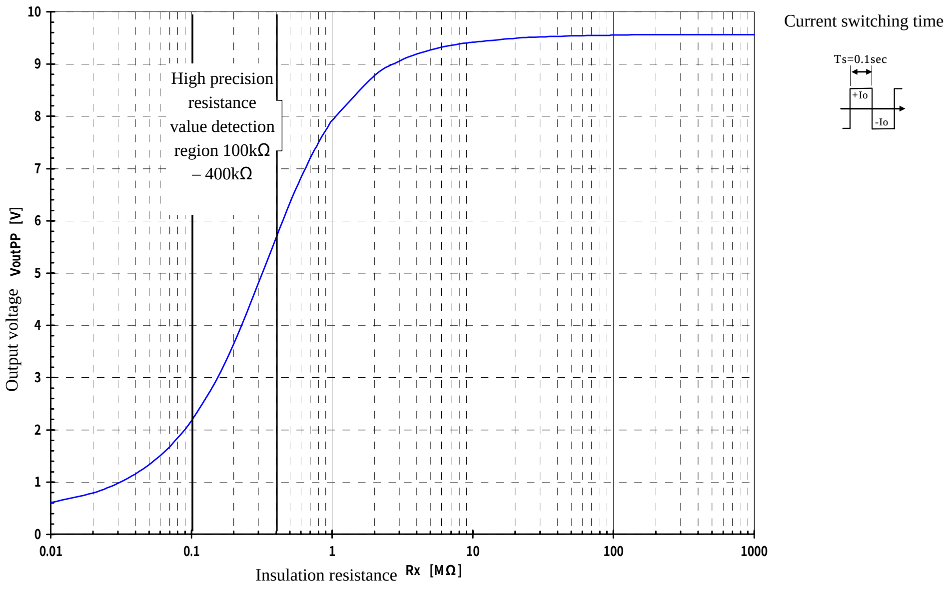

Figure 4: Relationship between insulation resistance Rx and output voltage VoutPP

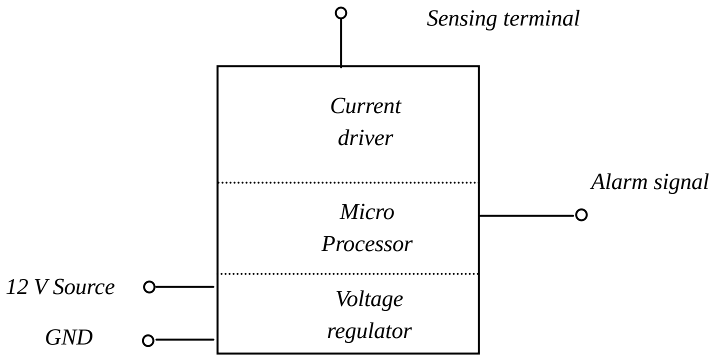

Figure 5: Hardware configuration

part uses a single chip microprocessor with an integrated 10 bit AD converter.
The power consumption of the sensor's power supply source is very low, at DC 8 to 16 V and current consumption of 150 mA or less.

5 EL Sensor Characteristics

The main characteristics of the EL sensor is are as follows.
Electrical
  Operating Voltage DC 8 – 16 V
  Maximum Current 150 mA
Operating
  Isolation resistance 0 – ∞Ω
  Stray Capacitance 0 – 0.4 μF
  Setting resistance 0 – 400 kΩ
  Allowable high voltage 1,000 V (max)
  Response
    0.28 sec at stray capacitance 0 – 0.1 μF
    0.46 sec at stray capacitance 0.1 μF – 0.2 μF
    0.64 sec at stray capacitance 0.1 μF – 0.2 μF
    0.38 sec at stray capacitance 0.3 μF – 0.4 μF

6 Conclusion

The high voltage direct current power source for EV or HEV has a configuration whereby multiple cells (lithium battery cell, super capacitance cell) are stacked. This creates high voltage which results in a high degree of stray capacitance between the power source and the chassis, thus interfering with the rapid measurement of the insulation resistance. This EL sensor can provide an Insulation Failure Warning Device that can rapidly detect the leakage of the high voltage direct current power source of an EV or HEV. It can also rapidly detect insulation resistance and issue an alarm when the insulation resistance has decreased but not to the level of a leakage.

References

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Authors

Hiroatsu Tokuda was Chief Engineer of Manufacturing Engineering, PUES Corporation.

Masaaki Yoshikawa was Deputy director of Engineering, PUES Corporation. He joined Tokyo R&D Co., Ltd. in 1984.