Ground Fault Detection by Differential Monitoring of the Float Current

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Abstract - **The safety requirements for battery ground fault detection were recognised by UPS industry from its infancy. Detection of leak to ground as low as 4mA is a standard feature in UPS battery installations. In Telco applications one of the battery busses is usually grounded, therefore ground fault detection appears to be redundant.**

Placement of the battery in closed cabinet initially removed the requirements of ground detection. However, the issue of serious failure of the system in the case of ground failure initiated the search not so much for ground detection as for leakage of current to ground. In some instances it is possible to use the same technique as for the "floating" battery [2].

In this paper the Authors will discuss specifics of the leak detection when the battery is intentionally grounded or connected directly to the AC.

INTRODUCTION

Traditionally, when batteries were positioned on racks, UPS designers were forced to put an isolation transformer on the charger and the inverter, for safety of the battery service personnel. With the battery totally insulated from the AC power source, there was no safety issue as long as the batteries remained "floating". Connection of any point of the battery string to the ground possessed no safety hazards and no danger of a large current path incidentally created in the system However if such a path was created and was not detected, part of the battery string would become "live" and create safety issues for the personnel by virtue of its own voltage.

Various ground detection methods were developed [2] and successfully used in the "floating "battery installation. Well documented tests of the laboratory controlled leak to the battery ground were conducted by H.K.Giess [3]. Ed P. Rafter [2] describes techniques used by leading UPS manufacturers (AC input sensing, shunt and Hall effects). Those techniques will not be discussed here; just their disadvantages will be briefly mentioned. Although ground detection started to gain recognition [2,3,4] there is no known (to the Author) study of the situation where the battery ground fault is not at the string terminals but in some place within the string. In this paper, the Author analyses such an event and proves that if the battery monitoring system is in place and capable of monitoring a float current and/or individual cell voltages, mostly there is no need for any additional equipment. In some cases, the ground fault can be detected just by the proper data interpretation of the existing monitoring system already on-line. Finally, the application of the float current monitoring equipment as a ground detection tool will be presented as the ultimate ground detection solution for UPS and Telco applications.

SPECIFICS OF THE NONISOLATED BATTERY INSTALLATIONS

Elimination of the input transformer would cause the battery to be momentarily "grounded" to the incoming line in the sequence of the semiconductor switches firing. The voltage of the battery in this configuration in respect to ground was no longer safe.

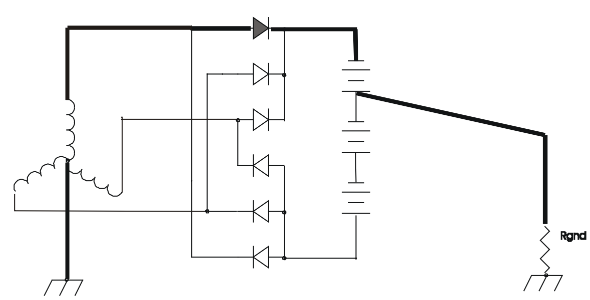

Fig.1 Ground fault path for a transformerless UPS.

Fig.1 represents the familiar UPS configuration with an indication of the ground fault path. With an input voltage of 600V, the AC common voltage may reach as much as 1kV. [1].

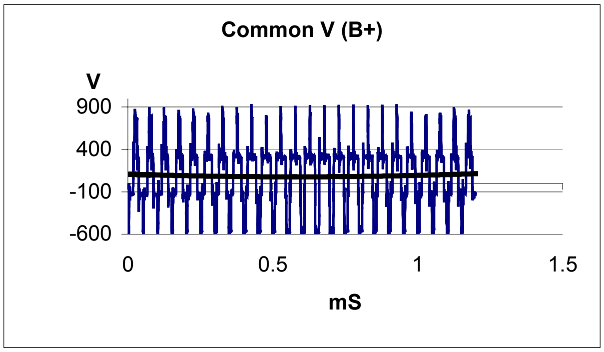

Fig.2. Common Voltage (positive bus).

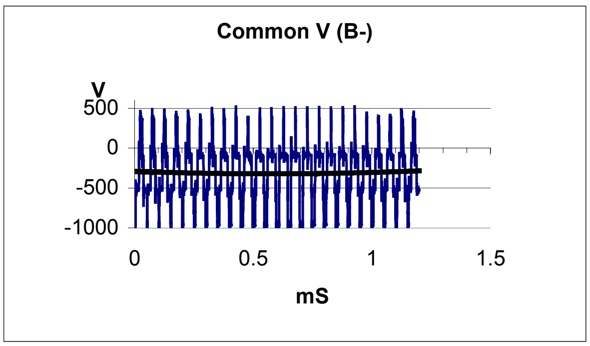

Fig.3 Common Voltage negative bus

The fundamental frequency of 20KHz can be observed superimposed on the DC component (solid line on Fig.2 and 3). The waveform is asymmetrical. The value and direction of this asymmetry depends upon the position of the scope probe. (Compare Fig.2 to Fig.3). It is evident that incidental connection if any battery post to ground, will produce high AC and DC current limited only by the resistance to ground.

The situation is not much different in the Telco application in which one battery post is grounded. The only difference is the absence of AC voltage between battery and ground. In both situations, sudden ground connections will result in instantaneous catastrophic failure. No ground detection equipment can prevent this. However, in cases where one cell develops an electrical leak to ground, detection of such situation may prevent catastrophic failure from occurring. Below we briefly examine possible techniques of ground fault detection in such situations.

CURRENT TRANSFORMER

Since in nonisolated UPS installation there is plenty of AC voltage, even high ground resistance can initiate destructive chain events. Fortunately, the presence of AC inherently offers a means of early detection.

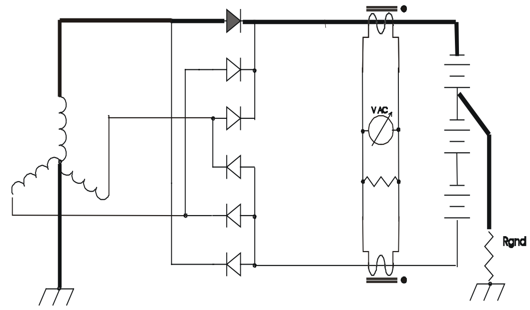

Fig.4 AC current sensing

As shown in Fig.4, such early detection may be implemented by two current transformers, located on the positive and negative battery bus. When they are connected in reverse/parallel configuration, the output voltage from them is proportional to the difference between AC current existing in the positive and negative bus. In the ideal case, this would be equal to the current flowing to ground.

Unfortunately, in practice, the DC current flowing to or from battery due to charge /discharge or float current is not detectable using this method. Additionally, the presence of DC (float) current in order of few Amps will push the magnetic core of the current transformer (CT) into a non-linear region of operation. Consequently, the sensor function may produce a false indication of a ground fault or, no indication at all.

Note that this method cannot be used in Telco applications due to the absence of AC common mode voltage.

VOLTAGE UNBALANCE SENSING

Referring to Fig.2 and 3, the reader may observe that DC component of the leakage current will depend on the total voltage, the resistance to ground, and its polarity will depend on the physical position of the fault.

Armed with this information one can design a simple circuit consisting of a voltage divider and a DC sensor as presented on Fig.5, known as 'Middle point monitoring'.

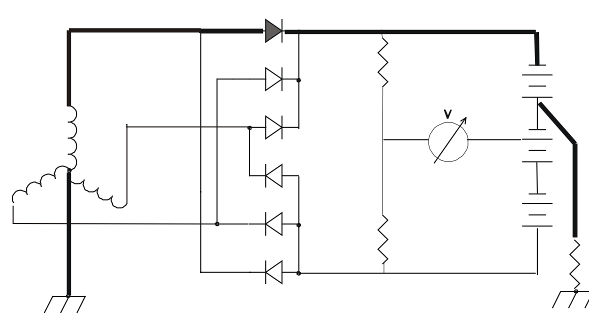

Fig.5. Middle point monitoring.

Middle point monitoring was used in the past [4] to monitor battery imbalance due to individual cells failure.

Application of such circuitry for ground fault detection was not published or discussed (to the best of the Author's knowledge).

The circuit works as follows:

String terminals will follow the AC waveform as discussed before, but the DC component of the AC waveform will be distributed along individual cells of the string. Any individual battery post voltage can be matched by an external voltage divider. Voltage difference between battery post and voltage divider would remain close to zero regardless of the status of the battery (Charging, discharging, float). Additionally, any ground path will produce an additional DC current flowing to or from the battery grounded segment to the string terminal.

This difference produces additional float current for some cells while starving others. With time, the voltage difference between battery segments and voltage divider increases, eventually triggering an alarm.

The main advantage of this circuitry lays it its simplicity and low cost.

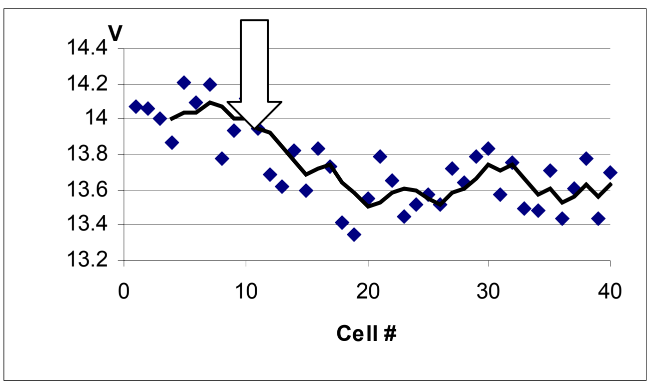

Fig.6 Segment voltage difference

When the battery is monitored at individual cell level, this method can be used without a voltage divider. All what is required in such a case is the proper interpretation of the data collected by monitoring equipment. Fig.6 displays the result of application of 100K Ohms from cell #13 to Ground. Cells 1-13 are scattered along 14V, while cells 14 to 40 are floating around 13.6V. (trend line was inserted to help locate the difference). The concept works with UPS and Telco applications.

A major disadvantage is the long response time (it may take weeks to see the voltage unbalance) and lack of ability to detect fault current of the DC bus.

Some other techniques capable of detecting fault at the post level were discussed by E.P.Rafter [2]. Disadvantages of them are listed below:

- -AC sensing of incoming feeders- -will detect AC not the DC produced by the and they are affected by DC current.
- Double shunt- low resolution, requirement of electronics
- Double Hall effect- low resolution and/or memory effect. unsteady zero.

FLOAT CURRENT MONITORING

The previously mentioned monitoring techniques, despite being able to detect faults at a battery post level, lack the resolution to be widely useful, particularly for identifying a weak ground leakage.

The main obstacle seems to be a lack of current sensing instruments capable of measuring mA while withstanding discharge currents in the kA range without a detrimental effect on accuracy or zero stability.

However, devices with such capability are in fact available off the shelf. They are designed for Float Current measurement but can be used to detect pending Ground problems. With the resolution of DC in the mA range, immunity to large currents and steady zeros such float current monitors are an ideal candidate for ground detection applications. These devices consist of saturable donuts or splitable cores (DCT) and relatively simple control electronics. In most installations, observation and interpretation of the float current would be sufficient to identify a small leakage to ground.

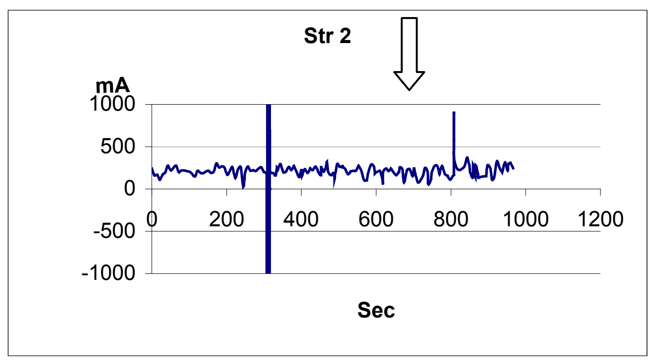

Fig.7 Float current rise due to 100 mA ground current

Fig.7 shows a sudden rise of the float current. While there are many possible sources of such a sudden rise, a ground failure is one of them. Further investigation is necessary in any case. Utilizing a segment voltage monitoring option may help to zoom in on the problem much further.

For more accurate solution one device with two DCT's may be used to detect and measure the float current of the positive and negative battery bus. See Fig.8.

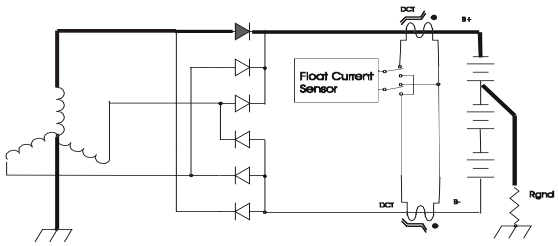

Fig.8 Float current device monitoring positive and negative bus

One DCT is positioned on positive and the other one on the negative battery bus. Additionally, the DCT are positioned in opposite directions to each other. An external three-position switch periodically connects one DCT, then another and then connects them back-to-back.

This scheme records float current in three states: positive battery bus, negative bus and the differential float current (connecting DCT back to back will cancel common components similar to the widely used AC transformers).

Standard Float current device will close contacts when Float Current is not detected (Open String Alarm).

Therefore, contact will close every time DCT are parallel unless the Ground Fault was detected. This is reverse logic but it can be sufficient in some applications. Alternatively, the device can be periodically visited over the Internet and pending ground fault detected by the supervisory logic.

Utilizing the segment battery voltages, monitoring provides additional information about the status of some cells within the battery string.

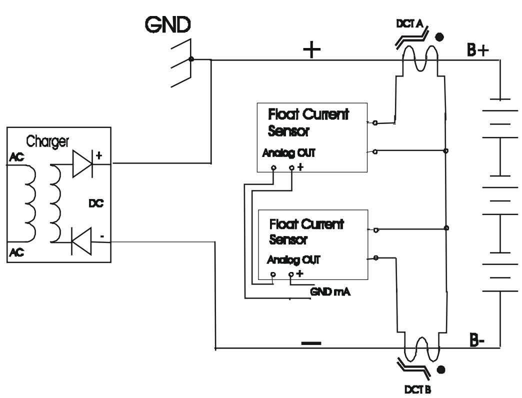

Fig.9. Two Float Current Monitors form a GND fault detector for typical Telco installation

For Telco application, it is desirable to install 2 float current monitors to form a GND fault detector. One float current DCT may be placed on the positive and another on the negative bus. (Fig.9). The voltage output from both devices can be connected serially in opposite directions, resulting in a signal directly proportional to the ground fault current (1). In this configuration, ground fault current can be detected when the battery is either floating or open. No detection is possible during discharging or charging.

Battery is floating:

$$Vout \sim I$$
$$V1_{OUT} \sim I_{FLT} + I_{GND}$$
$$V2_{OUT} \sim I_{FLT}$$
$$V1 - V2 \sim I_{FLT} + I_{GND} - I_{FLT} = I_{GND} \quad (1)$$

Battery is open:

$$Vout \sim I$$
$$V1_{OUT} \sim 0 \text{ (no current from charger)}$$
$$V2_{OUT} \sim -I_{GND}$$
$$V1 - V2 \sim -I_{GND} \quad (2)$$

This is shown on Fig.10A and Fig. 10B. These figures also explain why the arrangement still works regardless of position of ground leak.

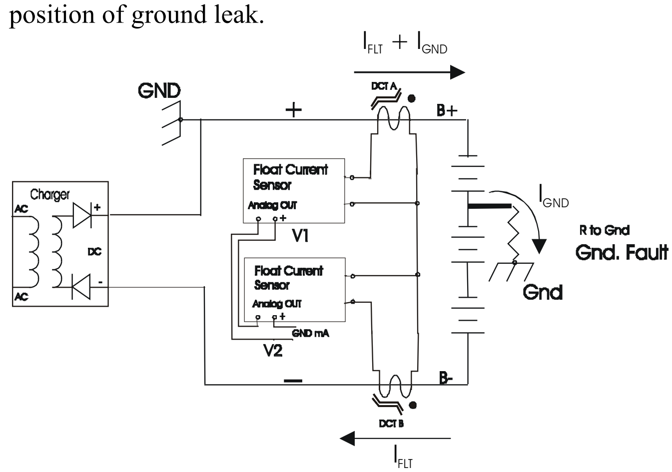

Fig.10A. Ground Fault current appears as positive voltage value when battery is floating.

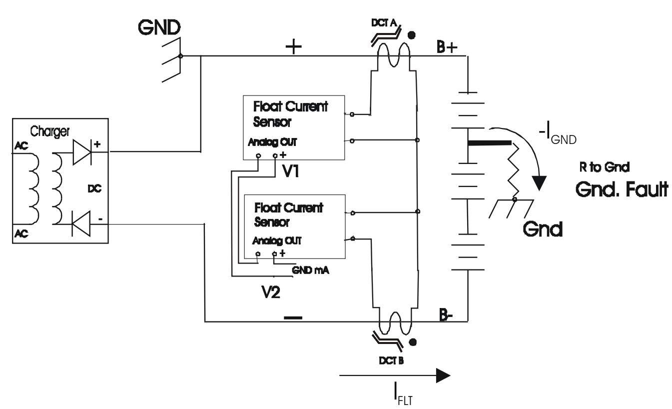

Fig.10B. Ground Fault current appears as negative voltage value when battery is open.

The ground fault detector sensitivity is defined by the floating current monitor sensitivity and can easily reach a fraction of mA levels. Since two DCTs are working simultaneously, good noise and AC-ripple current rejection ratio is achieved, resulting in more accurate detection and a commensurate false alarms reduction. Conveniently, such a system also provides information about battery floating current, which often can be used as an indicator of overall battery health..

CONCLUSION

In most applications detection of the ground fault current is possible by utilizing AC Common Voltage present in all transformerless UPS systems by the placement of two AC sensing CT (one on each buss) and connecting them back to back. Output voltage from such arrangements is proportional to the ground fault current. Saturation of the cores by DC float current limits this application to the small UPS application.

Another simple solution is to monitor individual cells or segments voltages and comparing it to each other, or to the voltage obtained from the resistive voltage divider.

Finally the full utilization of the Float Current Monitoring devices allows user of such device not only to monitor float current of each battery bus but also by observation of the difference between positive and negative bus to derive the current to ground. The proposed solution is possible by the application of the single or double float current monitoring devices which in fact operates as a two DC rated current transformer (DCT)

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4) Glad Arto at all; “Middle Point Voltage Comparison as a Simple and Practical gut Effective Way to Ensure Battery Systems Capacity to Perform” Intelec 1991