Protection Against Transient Overvoltage in Precision AC-DC Measurement System

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ABSTRACT

Reduction in size and improvement of sensitive margins in modern semiconductor devices makes them increasingly susceptible to stress and subsequent damage caused by the overvoltage.

A fast responding and higher energy absorbing overvoltage protection is desired. A hybrid solution is proposed. Moderate energy absorbing device is connected in parallel with a fast responding device to complement each other. Non-linear current-voltage characteristics of these devices enables them to least interfere with the performance of the precision AC measurement system while reducing the effects of transient overvoltage on the system.

In this paper, the causes of transient overvoltage in AC-DC measurement system are analysed and a hybrid semiconductor devices voltage limiting solution is proposed.

Keywords – Transient overvoltage, electrostatic discharge, hybrid connection, semiconductor devices, precision AC measurement.

1. INTRODUCTION

Recent developments in modern semiconductor technology, leads to an increase in susceptibility of the aforementioned devices to transient overvoltage. Consequently, in many electronic device applications, fast responding and higher energy absorbing transient overvoltage protection is highly desirable [1] – [3]. Transient overvoltage is a sudden and very fast increase in circuit voltage due to lightning or switching of the device. The calibration history of the precision AC voltage measurement standards is affected by transient overvoltage, which is introduced into the system through human interfacing (manual or remote control) or stray electromagnetic coupling paths.

Semiconductor devices are characterised by a region where electron transfer between the donor (n-type) and the acceptor (p-type) materials, called the p-n junction. Depending on the strength of the electric field applied to the device, the junction performs functions such as rectification, switching, amplification, and other functions. Parameters such as junction capacitance and impedance vary nonlinearly with applied voltage whereas admittance (ac conductance) varies with varying current [4]. The current-voltage characteristics of p-n junction devices give them greater suitability for transient overvoltage protection.

In this paper, the causes of transient overvoltage in AC-DC measurement system are explored and a solution is to achieve the transient overvoltage suppression proposed. Since overvoltage protection has captured attention since the mid-1900s, designs and implementations are already existing. Therefore, in this research the existing research is utilised to identify a better solution for the precision AC measurement system through mathematical modeling, simulations and experimental implementation.

2. PROBLEM STATEMENT

In the process of operation of the measurement instrumentation, transient overvoltage might be caused by either or both of the two factors – human errors or system errors. The former includes electrostatic discharge (ESD) coupling from the user and when the user mistakenly inputs AC voltage value higher than the system rated value, whereas the latter includes reactive kickbacks during switching and active circuit control action [5].

The system is protected by an Uninterruptible Power Supply system for the mains power backup and reduction of lightning-caused ESD induction, and the power supply parameters are monitored. These measures address only the external factors; the in-circuit overvoltage prevention still requires a customised solution that would least interfere with the measurement system performance.

3. SUPPRESSION OF TRANSIENT OVERVOLTAGE

A hybrid transient overvoltage solution is presented, shown in Fig. 1. It utilises two stages of conduction complementing each other. Each stage is comprised of at least one voltage limiting semiconductor device. The first stage makes use of the nonlinear current-voltage characteristics of the Metal Oxide Varistor (MOV), whereas the second stage uses an array of diodes comprised of back-to-back Zener diodes between the two nodes of the array [6] – [10].

3.1 Stage 1

The protection device used is characterised by multiple p-n junctions between ZnO grains distributed throughout the device for uniform heat dissipation. The junction blocks conduction of current at low voltages and conducts at high voltages [11] – [12]. Thus, a high impedance path is created during non-transient operation and low impedance path during transient operation. Thus, this switching mechanism should be suitable for transient overvoltage protection.

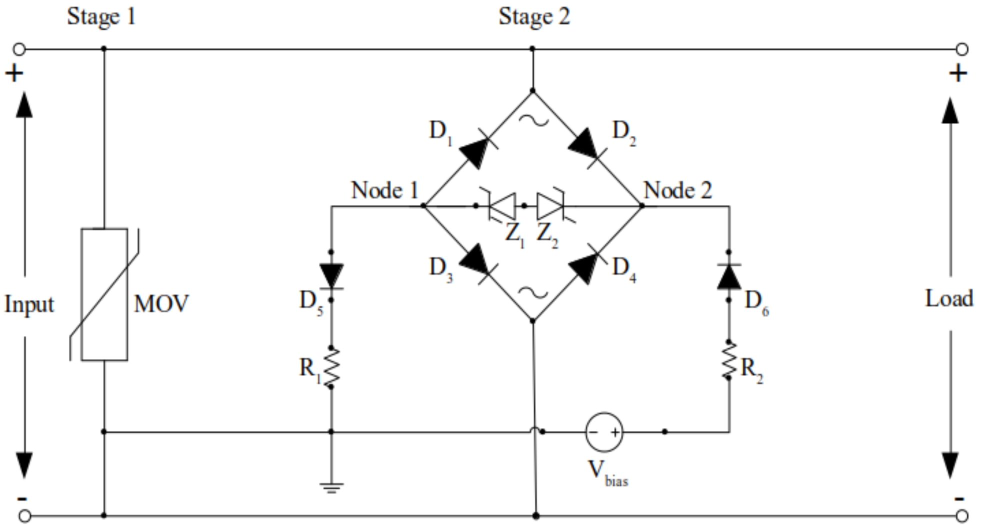

Figure 1: Two stage transient overvoltage protection.

The IV characteristics of the MOV are given by the power law:

$$I = kV^{\alpha}$$

The nonlinearity exponent, α, can be obtained by analysing two points V_1, I_1 and V_2, I_2 from the voltage-current characteristics curve, hence:

$$\alpha = \frac{\log\left(\frac{I_2}{I_1}\right)}{\log\left(\frac{V_2}{V_1}\right)} \tag{2}$$

The associated energy is determined by:

$$E = \int_{t_1}^{t_2} V(t) \cdot i(t) \ \cdot dt \tag{3}$$

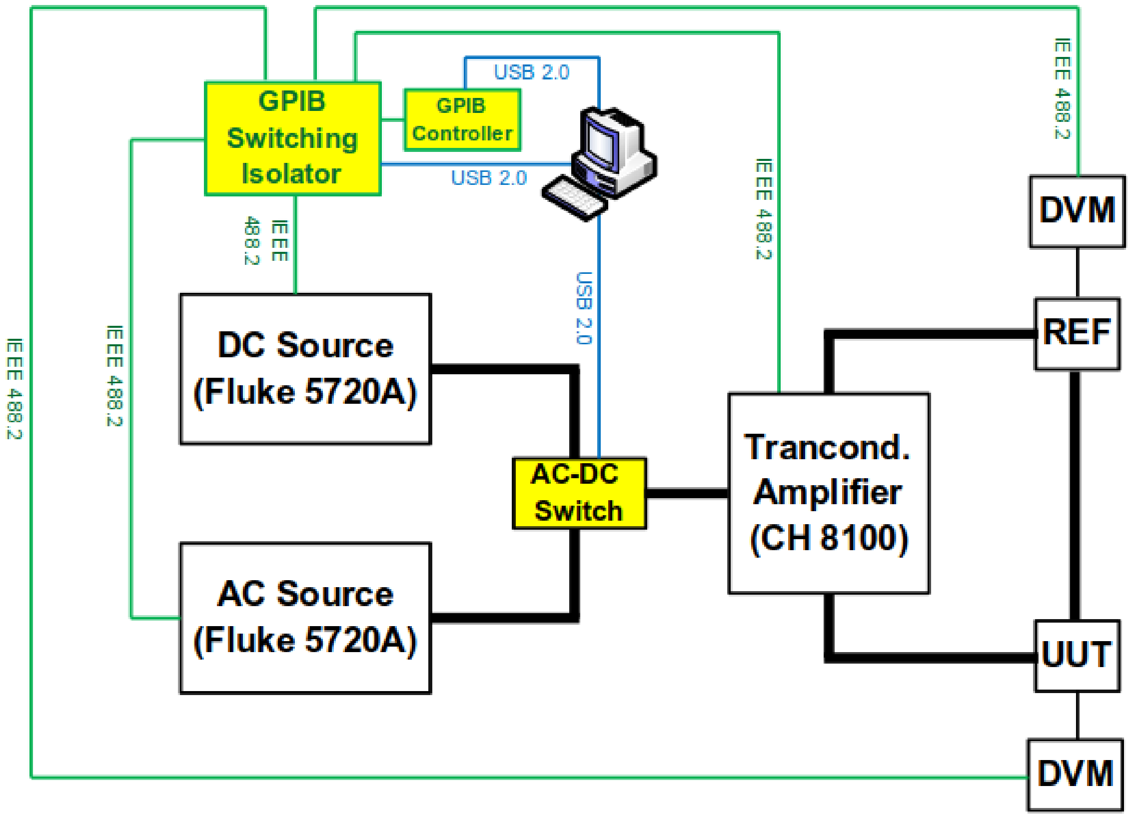

Figure 2: AC-DC measurement system.

The MOV is capable of absorbing transient energy of about 50 joules without damage, however it is associated with a drawback of slow response time, typically just under a microsecond [6], [7].

3.2 Stage 2

A bidirectional transient overvoltage protection device for symmetric IV characteristics is chosen. The device is connected between the two nodes of the diode array. The bias voltage is applied across the device through a pairs of resistors (R_1 and R_2) and diodes (D_5 and D_6) to block the conduction from the negative terminal of the bias voltage during transient operation. Diodes D_2 and D_4 also block propagation of current from the bias voltage source into the system, however, separation of AC signal and the V_{bias} at Node 2 is required. The bias voltage is applied to keep the capacitance of the device from varying with the input voltage, and is chosen in such a way that it is higher than the normal input voltage but lower than the protection device breakdown voltage [9], [10], [13].

Current through and voltage across the diode can be modelled using the Shockley equation:

$$I_D = I_O\left(e^{\frac{V_D}{nV_T}} - 1\right) \tag{4}$$

where V_D is obtained by rearranging (4):

$$V_D = nV_T \log\left(\frac{I_D}{I_O} - 1\right) \tag{5}$$

3.3 Protection circuit module operating principle

The principle of the hybrid circuit shown in Fig. 1 is to absorb the transient energy produced by the AC voltage source and limit the transient voltage to a safer level. Thus, transient current is shunt to the ground while the voltage is clamped.

During steady-state both Stage 1 and Stage 2 appear like open circuit due to their high impedances. As soon as transient state occurs, the impedances of both stages change to be lower, thus creating a path for current to flow, thus appearing like short circuits.

The fast turn-on time, typically picosecond to lower nanoseconds, characteristic provided by lower breakdown voltage of the protection device in Stage 2 allows it to conduct first and clamps the transient voltage to a desired level, however the energy therein may exceed the typical 1.5 joule energy handling capability of the device [7]. That is where the protection device in Stage 1 come into play. As soon as the breakdown voltage of the MOV is reached, within higher nanoseconds, the back-to-back Zener diodes in Stage 2 should be guaranteed not to fail since the MOV now absorbs sufficient energy [6], typically 100 joules and up.

4. PRECISION AC-DC MEASUREMENT SYSTEM

The measurement system consists of five instruments with remote control through the IEEE 488.2 interface bus. A PC equipped with an Automated Measurement System software is utilised to achieve this remote control. A simplified sketch of the measurement system is shown in Fig. 2 [14].

The outputs of the AC voltage source and the AC amplifier share the same output. This output and the output of the DC voltage source are connected to an automatic AC-DC latching switch for toggling between AC and DC voltages during measurement. However, the AC voltage source output is more likely to exhibit an overvoltage event due to the load regulation process. The load represent a balance of the reference (REF) thermal voltage conversion standard and a thermal conversion standard under test (UUT) which are connected in parallel through the splitter adapter, whereby the conductive shoulders are characterised equal electrical strength. [14].

5. SIGNIFICANCE OF RESEARCH PROJECT

Upon successful implementation of the transient overvoltage protection module, the calibration state of the protected measurement standard would be guaranteed at all times. A seamless provision of calibration accuracy and traceability in the AC voltage and current by NMISA as an NMI would be ensured.

ACKNOWLEDGMENT

Special thanks go to the NMISA Electromagnetic Metrology division for the provided resources and support. The author would like to thank Dr Golovins for his input and continuous supervision and mentorship. The supervision provided by Mr. Venter and Prof. Nicolae is also an important contribution to this project and cannot go unnoticed.

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