Why Do GFCIs Keep Tripping?

I thought this outlet worked before?

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***Abstract*—As well known, ground fault circuit interrupters (GFCIs) are used to protect people from electric shock. Recently, a manufacturer installed variable speesd drives (VSDs) in all their products. After receiving feedback from their customers, they realized that their products would only work when powered through some GFCI outlets but not work when powered through others. To investigate this problem, the authors purchased different types of commercially available GFCIs and tested each using the standard Electrical Fast Transient (EFT) test. The purpose of the EFT test was to simulate the emissions of a variable speed drive. Three out of eight GFCIs tested were found to trip at different voltage levels indicating that the EFT test could be useful to differentiate the performance of different types of GFCIs in terms of their ability to handle impulses from VSD products.**

***Keywords*— Electric Shock, GFCI, Ground Fault Circuit Interrupter, Variable Speed Drive, VSD**

I. Introduction

A company who manufactures construction equipment recently added variable speed drives (VSDs) to the motors of all their products. Later, they heard from their customers that due to ground fault circuit interrupter (GFCI) tripping, their products would not always work when powered through a GFCI protected outlet. Other companies who use switch mode power supply (SMPS) have also recently experienced GFCI tripping issues. GFCIs are required to be used at construction sites to protect workers from electric shock. The tripping thus caused the products to be unusable. The products' inconsistent performance for certain customers seemed to be due to differences in the GFCIs' immunity to feedback from the newly added VSDs. The interference is presumed to be conducted rather than radiated and the Electrical Fast Transient (EFT) test was selected to simulate the conducted emissions characteristic of VSDs. Several commercially available GFCIs were purchased and tested to determine if the EFT test is a valid test which could be used to distinguish between the quality of different GFCIs in handling fast transient feedback from VSDs.

This paper serves as an introductory study to the problem of GFCI and VSD compatibility with a focus on the GFCI side of the problem. There has not been much published research in this area. Currently, a search on GFCI compatibility in IEEE Xplore only returns two papers: a paper investigating compatibility with household adjustable speed drives [1] and a paper investigating compatibility with smart meters [2]. More information in this area would be helpful in applying GFCI into a system and in determining compatibility between connected units.

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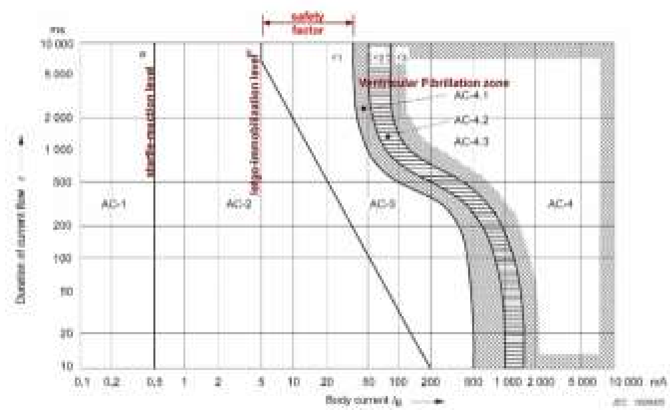


Fig. 1. IEC 60479-1 Effect of AC Current and Time on Electric Shock

II. Background

A. Safety in Electrical Systems

Electric shock is the physiological reaction or injury caused by electric current passing through the body. Fig. 1 shows the effects of AC current in terms of its magnitude and duration of time on the human body [3]. The values provided in Fig. 1 for each effect vary from person to person with the average values being highest for men, then women, then children [4]. The average startle-reaction level, 0.5 mA, is the threshold value of current which can cause an involuntary reaction. The let go-immobilization level, 5 mA, is the maximum amount of current that can flow through a person who is experiencing electrical shock where he or she can still release and disconnect from the charged object. Currents above 5 mA cause involuntary muscle contractions resulting in perspiration which lowers the body's resistance and increases current through the body [5]. Preventing currents from exceeding the let-go threshold is important because ventricular fibrillation can occur at currents as little as 30 mA and cause death without medical intervention.

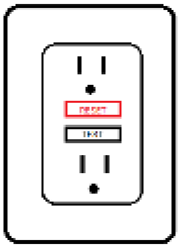


Fig. 2. Typical Duplex GFCI

B. Ground Fault Circuit Interrupters

A GFCI is a device that is used to prevent death caused by electric shock [6]. When it detects that current is flowing through an unintended path, it trips, shutting off power to the load. GFCIs trip at 5 mA because this current level has been accepted as the let go threshold for nearly everyone [3]. The National Electrical Code specifies where GFCIs are required to be used. Generally, they are required for temporary wirings such as at construction sites and in places where water can interfere with electronics. Examples include: kitchens, bathrooms, laundry rooms, pools, and garages [7].

A typical GFCI unit is shown in Fig. 2. GFCIs will cut off power to the load when it detects an imbalance in the current leaving and returning from it. A GFCI detects the current difference using a transformer placed between line and neutral as depicted in Fig. 3. When the sense circuit detects a 5 mA differential current, the GFCI trips and opens the circuit preventing current to continue flowing.

III. Testing Procedure

Eight different GFCIs were tested using the EFT test. One was an old GFCI from the 1990s and seven were new units which were picked up from the local hardware store. Most GFCIs were redesigned by 2000, so the one from the 1990s was expected to respond worse than the newer ones. The new GFCIs used represent a wide variety of GFCIs that are available to a consumer. The brands tested included Defiant, Eaton, Lagrange, Leviton, and ShockBuster. Of the GFCIs tested, half were duplex wall outlets and the other half were in-line devices.

The standard EFT test was chosen to simulate the fast transient feedback from the VSDs. Since the customers' VSDs were located far away from the GFCIs powering them, the problem was most likely due to conducted, not radiated interference. Referring to interference caused by VSDs, Kraz writes, "Generation of drive pulses causes sharp changes in current consumption from the mains, which, in turn, causes high-frequency conducted emission flowing back into these mains" [8, p. 11]. The EFT signal which consists of a series of pulses with fast rise times and high peaks mimic the high frequency emissions from a VSD.

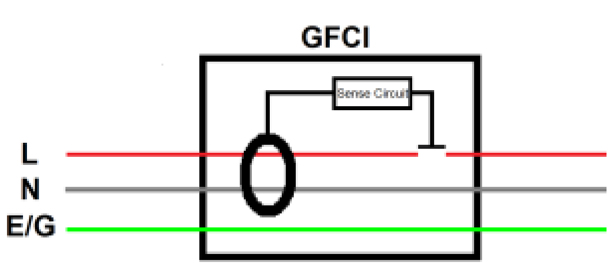
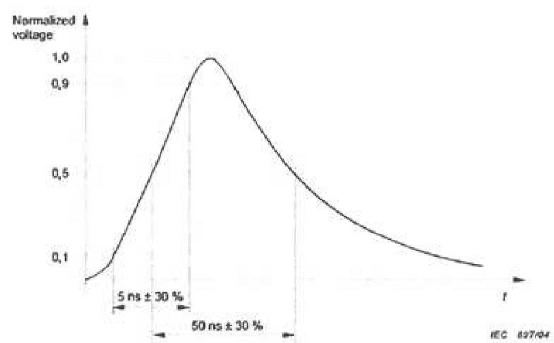


Fig. 3. Diagram of a GFCI

The standard EFT test [9] (IEC 61000-4-4) is a standard EMC immunity test used to simulate the switching of inductive loads [10]. It consists of a series of bursts each made up of multiple high voltage pulses. Each pulse has about a 5 ns rise time and 50 ns pulse duration as shown in Fig. 4. Each burst is 15 ms in duration and consists of a series of pulses at 5 kHz, one every 200 µs. During the test, there is a burst every 300 ms as depicted in Fig. 5 [11]. The EFT test signal can be applied to any combination of line, neutral, and ground, and the signal can have either a positive or negative polarity.

A diagram of the test setup is shown in Fig. 6. As shown, the GFCI was connected to AC mains on its line side and to a load on its load side as is done during common usage of a GFCI. In order to simulate the feedback from a VSD, the signal from the EFT generator was directly coupled into the load side of the GFCI. Fig. 7 shows a picture of a GFCI being tested. A



b. IEC 61000-4-4 ed.2.0 "Copyright © 2004 IEC Geneva, Switzerland. www.iec.ch"

Fig. 4. IEC 61000-4-4 EFT Pulse

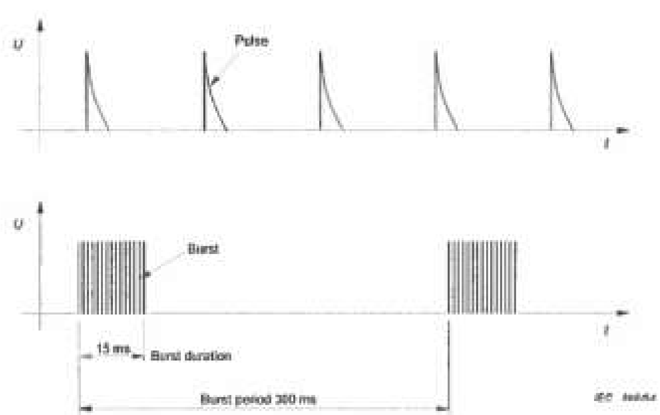


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Fig. 5. IEC 61000-4-4 EFT Burst

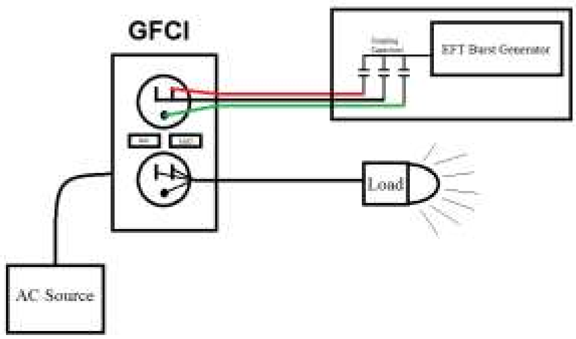

Fig. 6. Diagram of Test Setup

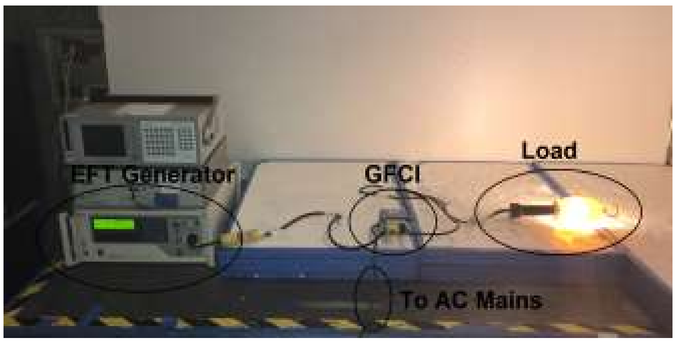

Fig. 7. A GFCI Being Tested

lightbulb was chosen as the load since it is a linear load and a good indicator of whether or not the GFCI is in its tripped state.

The GFCIs were tested by varying the amplitude of the EFT signal. The first set of tests were performed on all eight GFCIs. Each GFCI was tested in an automated sequence with the signal applied to line, then neutral, then ground, first with a positive polarity and then with a negative polarity. For each GFCI, the EFT test was first conducted at 2 kV. If it failed at that voltage, it was tested again at 1 kV, and if it failed again, it was tested at 500 V. The maximum voltage tested used for the test was 2 kV because this was the highest voltage that the EFT generator could produce. Whether or not the GFCI tripped was recorded after every test. After all GFCIs were tested, each device that failed was tested further to determine in which configurations and polarities it failed. This included applying the EFT signal to each wire (line, neutral, ground) separately and then applying the EFT signal to combinations of two wires simultaneously (line & neutral, line & ground, neutral & ground).

IV. Results

The results of the first set of tests conducted are shown in Fig. 8. As indicated, five out of the eight GFCIs passed at the maximum voltage of 2 kV. The other three failed at 2 kV and 1 kV but passed at 500 V. The EFT test was able to trick these three GFCIs' internal circuitry into thinking that a ground fault was present. For this reason, the EFT test provided differentiation between the different GFCIs in terms of their susceptibility to fast transient feedback. Further testing was conducted on the GFCIs that failed the first test. The results of these tests are summarized in Table I.

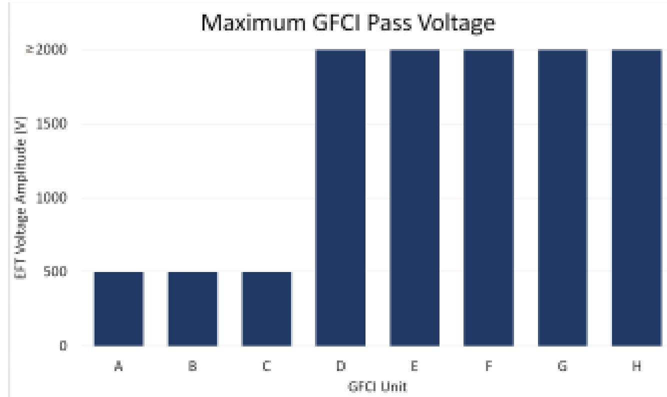

Fig. 8. Results of GFCI Tests

TABLE I. Failed GFCIs Failure Modes

Applied Signal	EFT Voltage	Device A	Device B	Device C
L	+1 kV	Pass	**Fail**	Pass
	–1 kV	Pass	**Fail**	**Fail**
	+2 kV	**Fail**	Fail	**Fail**
	–2 kV	Pass	Pass	**Fail**
N	+1 kV	Pass	**Fail**	Pass
	–1 kV	Pass	**Fail**	Pass
	+2 kV	Pass	Pass	Pass
	–2 kV	**Fail**	**Fail**	Pass
G	+1 kV	**Fail**	Pass	Pass
	–1 kV	Pass	Pass	Pass
	+2 kV	**Fail**	**Fail**	Pass
	–2 kV	**Fail**	**Fail**	Pass
L & N	+1 kV	Pass	Pass	Pass
	–1 kV	Pass	Pass	Pass
	+2 kV	**Fail**	Pass	Pass
	–2 kV	Pass	Pass	Pass
L & G	+1 kV	**Fail**	Pass	**Fail**
	–1 kV	Pass	Pass	**Fail**
	+2 kV	**Fail**	Pass	**Fail**
	–2 kV	Pass	Pass	**Fail**
N & G	+1 kV	Pass	**Fail**	Pass
	–1 kV	Pass	Pass	Pass
	+2 kV	**Fail**	**Fail**	**Fail**
	–2 kV	Pass	**Fail**	Pass

V. Conclusion

The results of the tests presented in this paper indicate that the performance of various GFCIs differ under fast transient feedback. These differences could be the cause of the issues that the construction company's customers were experiencing. Similarly, these differences could be the cause of the problems experienced by companies using SMPSs. Since both SMPSs and VSDs have switching circuitry and produce fast transient emissions, GFCIs which performed poorly when used with VSDs are also likely to perform poorly when used with SMPSs. More standardization of GFCIs is needed to address and prevent these types of problems. For this reason, further research needs to be done to guarantee the interoperability between GFCIs and electronic loads.

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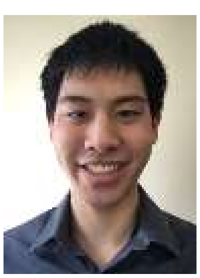

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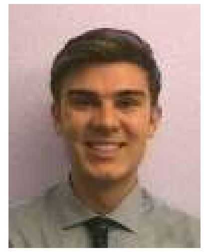

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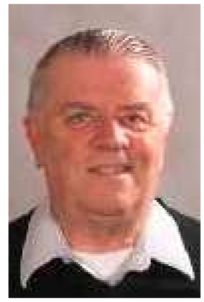

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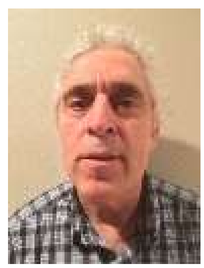

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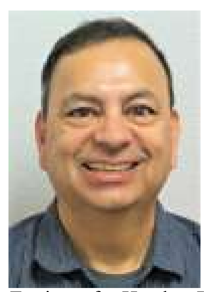

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