

# Stray Voltage: Two Different Perspectives

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*Abstract: Stray voltage has become a major concern, in recent years, to humans as well as dairy cows. The problem is that dairy farms have considerably different requirements than the general customer population. Meeting the farm criteria may become much too expensive (and unnecessary) for all classes of customer service. At this point in time, the utility industry is trying to install one standard for all their customer classes. The purpose this paper is to present the dairy farmer and the utility sides of the topic. This is done via authorship by a utility consultant and a dairy farmer. Ultimately, the purpose of the paper is to allow for both the utility and the dairy farmer to reach agreement over this long standing problem.*

multi-grounded. This means that the 3 phase system carries a neutral wire which is grounded periodically on the system. While this system has many advantages over other designs, one of the more significant advantages is that it can supply single phase loads using only 1 phase wire (and the neutral conductor and earth as the return path). One of the characteristics of this design is that the neutral wire, which is part of the return path, carries current and as such creates a small voltage drop. As seen in figure #1, this current can be the result of the 3 phase unbalance or simply the return current on the single phase tap. This neutral-to earth voltage, sometimes referred to as “stray voltage” (usually less than 5 volts) can be transmitted to the neutral of the secondary voltage system, since the neutrals of the distribution transformer primary and secondary are connected together to meet NESC standards.

## I. Introduction

Most of the utility distribution systems in the United States are 3 phase, 4-wire and

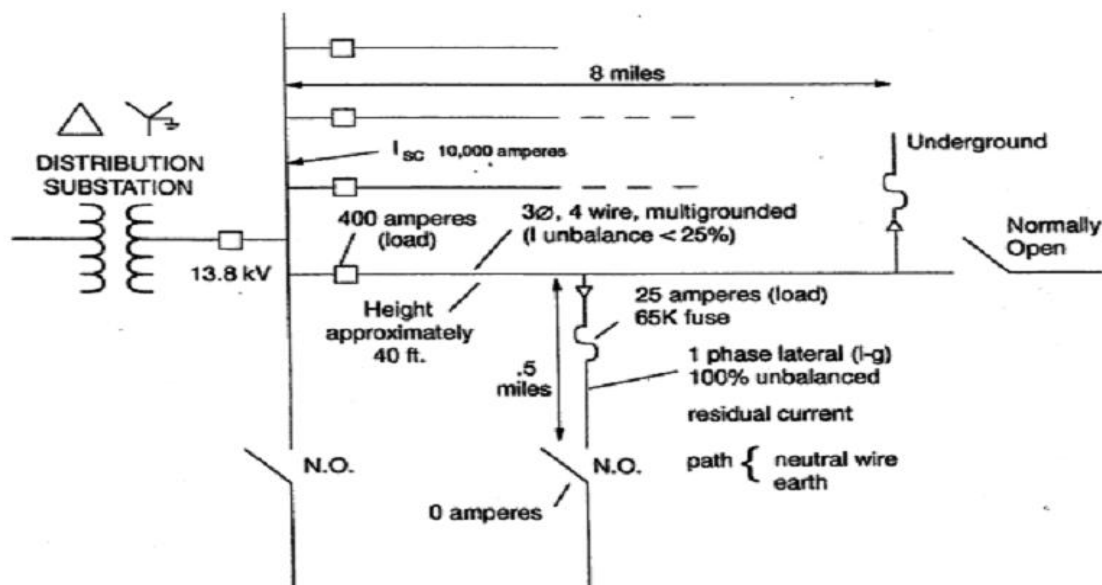


Figure #1 – Typical 4-Wire Distribution System

## II. Stray Voltage Impact on Human Beings

There are a number of references used in the industry that discuss the resistance of the human body [1,2]. It is common to use 1000 ohms from one hand to the other, hand to foot, etc. (see IEEE Std. 80, which gives a range of 500 to 5000 ohms). The authors' own tests show human resistance values for hand-to-hand as follows:

- Dry skin – 172K ohms
- Wet skin – 10K ohms
- Wet (salt water) – 5K ohms

The above tests were for full hand contact with solid metal objects and maximum pressure to minimize contact resistance. From this it might be concluded that use of 1000 ohms for human resistance could be considered fairly conservative for most situations.

Human sensitivity to current varies considerably from one human being to another. Some typical *minimum threshold* values are as follows:

- Perception – 0.1 mA
- Startle – 2.2 mA
- Let-Go – 4.5 mA
- Breathing Difficulty – 15 mA
- Fibrillation – 35 mA

If we assume that the resistance of a human being is greater than 5000 ohms and we are concerned with let-go current levels, we could argue that stray voltages less than 22.5 volts are not a significant problem. If we take a more conservative approach and use 1000 ohms for the resistance of the human body (a value the author has never been able to attain), then 4.5 volts would be the limit. It would seem that a practical limit of stray voltage in the consumer environment on the order of 5 volts or even higher can be justified.

Figure #2 shows a relatively common problem where the swimming pool experiences a stray voltage between the vinyl lining and the bonded ladder. In most cases the deck, ladder, and other metal objects do not present a problem. The issue here is that the vinyl liner of the pool is at a slightly different potential than the rest of the bonded structure and creates uncomfortable sensations to the swimmers. The levels of current that cause this discomfort are very low (e.g. 0.1 mA) and the only effective solution (besides neutral isolators) is to install a metal grate under the pool during initial construction or install a neutral isolator.

Practically speaking, the argument could be made that workman wearing shoes and possibly gloves, could withstand much higher stray voltage values without lethal consequences. For example, OSHA Standard 1910.333 “Electrical Safety Related Work Practices: Selection and Use of Work Practices, uses a limit of 50 volts for working on energized equipment.



**Figure #2 – Stray Voltage Measurement at Pool**

## III. Stray Voltage Impact on Dairy Farms

From the standpoint of stray voltage, dairy cows differ from humans in three major areas:

1. **Exposure**– dairy cows, because of their environment are exposed to stray voltage throughout the day during the drinking, milking and feeding process.
2. **Sensitivity** – it is argued, by some, that cows are more sensitive to stray voltage levels than are human beings.
3. **Resistivity** – most experts agree that cows have less resistance (in ohms) than do humans so that the same level of stray voltage produces more current in the cow.

There have been numerous studies [2 to 14] on the impact of stray voltage on dairy cow production, health and avoidance reactions (see figure #3). The majority of evidence from these formal studies suggests the following minimum limits:

- Minimum cow resistance is about 250 ohms [4, 8, 12]
- Cows do not react to less than 2 mA [11,12]

- Stray voltage levels of 1 volt or less do not appear to affect cows. [6,7]

On the other hand, dairy farmers, some studies, and others associated with testing will passionately argue that dairy cows are more sensitive than the standard published data indicates and suggest the following limits:

- Minimum cow resistance about 225 ohms
- Cows react to currents on the order of 0.7 mA [4]
- Stray voltage levels should be limited to about 0.5 volts (or even less) [4,7,10]

It should be noted that the limits shown above do not satisfy Ohm's Law and are not meant to. For example, by using the minimum resistance and minimum currents some suggest a **stray voltage limit of 0.16 volts**, which is extremely low. The Public Service Commission of Wisconsin, known in the industry for their stringent requirements in this area, considers a 1 volt limit very conservative. This, quite frankly, is the dilemma which separates the dairy farmer and the utility from agreeing on one acceptable limit.

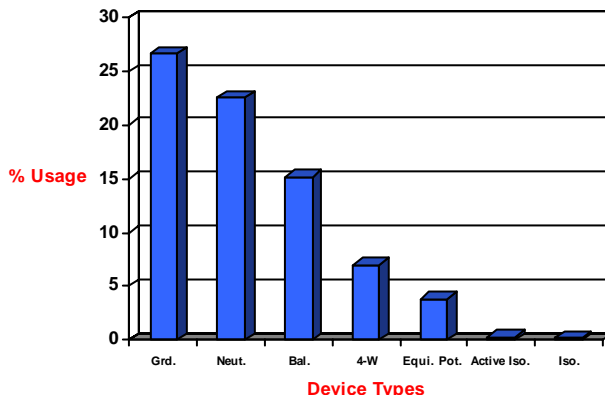


**Figure #3 – Happy Cows Feeding**

One very valid argument from the farm industry is that stress caused by stray voltage to cows may, similar to human beings, result from the fear of getting these shocks and any shock, no matter how low, reconfirms this overall fear and could eventually result in health problems and lost production. Low shock levels may not show obvious behavioral patterns but the cow may be stressed over the fear that there is “more to come”. Others indicate that until very low “stray voltage” levels are obtained, cows appear nervous, especially during periods of rain.

#### IV. Solutions

There are a number of things that utilities can do in an effort to reduce stray voltage. Figure #4, shown below, lists some of these based on the percentage of their usage.



**Figure #4 – Utility Mitigation Practices for Stray Voltage**

The authors' experience is that the most used mitigation technique, i.e. grounding, is not very effective in most situations. On the other hand, the least used technique, i.e. the neutral isolator, has been very effective. Some of the methods used for dairy farmers are described below:

- **4-Wire, Multi-grounded Neutral System** – On a single phase supply all the current must return through the earth and neutral, creating maximum N-E voltages. Using a 4-wire, multi-grounded supply minimizes the “stray voltage” since only the unbalanced current returns through the neutral/earth path. If the balance is perfect, no current returns via the neutral and the earth and no stray voltage is created.
- **Delta Primary** - The delta distribution system has only 3 phase wires and no neutral. As such it isolates the customer neutral system from the utility system, which can improve the stray voltage environment at the farm. It should be noted, however, that the delta primary system does have drawbacks regarding the ability of the utility protection to detect line to ground faults. Also, since the system grounding is restricted to the farmstead, faults or unbalanced loads at the farmstead are likely to have a greater impact than they would have had if the farm had been connected to a 4-wire, multi-grounded primary.
- **5-Wire Distribution Primary** [15] – This system has the positive characteristics of the

4-wire multi-grounded system and the 4-wire uni-grounded system. It is designed to minimize the impact of stray voltage since the utility new uni-grounded neutral conductor (the new 5<sup>th</sup> wire) carries all the load current and the original multi-grounded neutral (now called the ground wire) does not carry any load current and consequently does not transmit stray voltage into the secondary neutral. The downside to this system is cost, since it requires the following:

- Existing 4-wire system
- 2 bushing single phase transformers
- A fifth wire which is isolated and grounded only at the substation
- **Neutral Isolator** - The neutral isolator is a device which isolates the utility system neutral from the customers neutral under normal conditions and reconnects it during abnormal events, such as lightning and internal faults, in accordance with the NESC. For these devices to work properly, the utility system neutral ground and the customer (dairy farmer ground) must have sufficient separation. Also, other utilities (e.g. telephone and cable TV) must also be isolated. Experience of virtually everyone using these devices has been excellent (see appendix). Properly installed, they seem to provide very good isolation of the utility neutral. They do not solve stray voltage problems caused by issues on the dairy farmer's secondary system. The neutral isolator apparently provides the level of isolation that satisfies even the most demanding dairy farmers.



**Figure # 5 – Neutral Isolator Installation**

## V. Conclusions

It is evident from the values shown in this paper that the dairy farmer requires a much lower “stray voltage” level than do typical consumers. This is due to the fact that cows are in an environment where additional stress from stray voltage during feeding, drinking and milking can contribute to health problems which can result in death. Humans, on the other hand, simply feel a brief discomfort. Based on this, it would seem to be inappropriate for the industry to develop one set of standards for the entire industry. The following stray voltage limits, for both dairy farms and residences, are suggested by the authors:

- **Residences** – 5 volts (or more)
- **Dairy Cows** – 0.5 volts (or less)

It is important to note that the one utility mitigation technique that may be able to attain such a low neutral voltage on a dairy farm is the use of the neutral isolator. It might even be advantageous to consider the neutral isolator as a standard piece of equipment for service to the dairy farm. Feedback from dairy farmers indicates that they would be agreeable to absorb the costs for this device if indeed it will provide a solution. It should also be pointed out, to the dairy farmers, that if the dairy industry accepts 0.5 volts as a necessary maximum stray voltage, they may have difficulty attaining such a low level due to the characteristics of their own facility.

## Appendix – The anatomy of an actual stray voltage problem on a dairy farm

It started as it often does, with the farm operating in a normal manner. The cows are productive and all is going well. Then, suddenly it seems, everything deteriorates.

That's the way it happened on the Reed farm. Until March 17, 2007 everything was fine. Then, Gloria noticed a case of mastitis during the evening milking. Somatic cell counts had been low – less than 100,000, but now, they began to climb – to 340,000, then to 1 million by the 29<sup>th</sup>. The vet was called, and several possibilities were reviewed. None of the usual suspects seemed to fit the situation.

The farm was participating in the Herd Profit Improvement program, so a system check was run on the milking equipment, and practices were reviewed. No problems could be identified.

Finally, on a chance suggestion, the local power utility, Sioux Valley Energy (SVE), was called and a request was made for stray

voltage testing. That happened on May 2<sup>nd</sup>, nearly six weeks after the initial problems appeared.

SVE is a customer owned cooperative utility, and prides itself on its pro-active approach to customers' problems, so the stray voltage specialists appeared on the Reed farm that same day.

Primary neutral current from the utility was found on the farm's secondary system, so a Dairyland Isolator was installed. That reduced voltages that had been detected in the barn. And, two days later, Ken Reed reported that production was up 200 lbs/day for their 52 cows. But later that day, Gloria called back to report that the cows were acting up again. The stray voltage specialist was back on the farm the next day, and changed a circuit in the barn to balance loads on the electrical distribution. The cows started drinking better.

Things were up and down for the next ten days, but then more problems appeared. The SVE crew was again on the scene, bonding the stanchions to the milk and water lines.

Twenty days after their first visit, the stray voltage team placed their test trailer on the farm and let it record readings from several key points for two full days. The tests showed that the isolator was working and the voltage readings in the barn were low.

Then, on June 1<sup>st</sup>, the Reeds had a feed man stop by with a megohm meter which measures the insulation on electrical wiring and equipment. The lighting systems and transfer pump checked out ok. Further tests a week later found damaged wiring on a sump pump.

During the next two months SVE moved the secondary ground on the isolator 15' away from the primary ground, the stray voltage trailer was brought back for additional testing, and the farm was operated from a generator while system load testing was conducted. SVE discovered high primary neutral resistance, but verified that the isolator was working correctly to counter the problem. Cow behavior was variable, sometimes good, but then poor for a time. Ken Reed noticed a correlation between cow difficulties and the wet ground following a storm.

It was now August 3<sup>rd</sup>, fully three months since the Reeds had called the utility. Chuck Untiedt, a dairy farmer, living 80 miles away, was consulted because he had been dealing with electrical problems on his farm over a period of six years, but was now achieving reliably positive results.

August 16<sup>th</sup> - On this date meeting took place between SVE people, the Reed's electrician, and Chuck Untiedt. Chuck reviewed the test methods that had worked for him, and described the wiring configuration that led to acceptable herd performance in his case. After some discussion a plan of action was formulated.

SVE agreed to install a new 37.5 kVA transformer at the road and run parallel 4/0 quad overhead to a new meter pole near the existing one. They also installed a new 400 amp disconnect and new CT metering. The Dairyland isolator was reinstalled near the new transformer. SVE assisted Rod Goth, the Reeds' electrician, as he installed a new 4-wire service for the barn. This work was completed on August 17<sup>th</sup>. By August 31<sup>st</sup>, the on-farm rewiring had been completed by Goth.

#### **Measurable results achieved**

In summary, when all the work was completed, voltage sags under load were greatly reduced, voltages at cow contact points in the barn all but disappeared, the grounding system was cleaned up to include only those points required by code, and ground current on farm was measured at about 4 mA total. It took corrections and changes by the utility, a rewire of the on-farm distribution, and, most importantly, the cooperation of all parties involved, to finally achieve these results.

The results can be summed up in the words of Gloria Reed, "It rained and the cows are happy." She praises SVE, Rod Goth, and Chuck Untiedt for their respective contributions to what appears to be a winning result.

But, systems can weather and deteriorate, so periodic testing is required to detect subtle changes before disaster strikes. A simple 'light bulb test' can verify that wiring is correct after servicing or replacing electrical equipment, and tests of the current flowing in the ground rods can indicate that problems may be developing which can lead to rising cow contact voltages. With vigilance, future serious problems can, for the most part, be avoided through continued cooperation between the dairy farmer and the utility.

#### ***Stray voltage correction can be a win for all concerned***

"It rained and the cows are happy." These are the words of one of our customers who run a dairy farm. Believe me, as the Engineering and Operations Manager for a customer-owned utility serving dairy farmers, these words are like music to my ears.

Our members receive electric service at the lowest possible cost and have a voice in how the Cooperative is operated. We try to use the philosophy that when we are dealing with a stray voltage call, we find and solve the problem, no matter its location, or its source.

Too often the emphasis is placed on finding out who is to 'blame' for the stray voltage. Unfortunately, we do live in a litigious society and some of these lawsuits have been extremely costly for both parties. Because of the constant threat of litigation, the emphasis is typically spent finding and documenting that one party or the other is not to 'blame' for the stray voltage. This thought process does not help either the customer or the utility company.

The number of stray voltage experts, each with their own theories on how to get rid of stray voltage, can be extremely frustrating to the utility company. Each of the experts has their own solution to the problem, and they typically do not agree with one another. So one day the utility company will be working with an expert that states the only way to solve this stray voltage is to...you can fill in the blank here. The next day you then have a meeting with another expert on a different dairy farm and you are then told the only way to get rid of the stray voltage is to...you can also fill in the blank here. I can virtually guarantee the recommendations from the two experts talked about above are completely different solutions. Some of these solutions seem to have very little basis in electrical theory.

The utility engineers I know would do anything necessary to get rid of a stray voltage problem. One issue with this is that we are directed to do whatever the expert of the day wants. We are quite likely threatened with litigation if we don't.

I feel that every utility engineer would love to know what is causing all the stray voltage, and if there were one solution to fix it all it would be great. But we all know that this will never happen. The best we can do is to quickly solve the problems at that location that we can identify and control, and then assist the customer in dealing with the problems that may be originating on the farm.

Working together, we can and do get results. And that feels good.

. – Ted Smith, Sioux Valley Energy

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