TESCO Hot Socket Gap Research

and the use of this data in the development of tools for the early detection and handling of dangerous field conditions

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PART 1: Introduction

The deployment of new AMI meters has resulted in an increase in the occurrence of fires reported at the meter box. Initial concerns are whether these fires were caused by meters or meter sockets or something else. Our laboratory investigation could find no indication of fires being caused by the meter. Empirical investigation revealed a variety of sources in the meter box including loose or broken connections, bad or missing insulation or other electrical hazards. The most common cause and the symptom most commonly supported by the evidence was heat generated at the meter socket jaw to meter blade interface. The cause of this heat source is a worn meter socket jaw. A compelling need for early detection devices and inspection processes to identify dangerous field conditions prior to catastrophic failure was quickly identified.

Of the potential causes for temperature rise, energy dissipated as heat due to contact resistance seemed likely; however our research showed that the temperature rise generated by contact resistance is not sufficient to cause the significant meter deformation observed in the field. Instead, electric arcing across small gaps between meter stabs and compromised socket jaws was found to be the source of the elevated temperatures and eventual destruction of meters which failed catastrophically. Compromised jaws were further defined through lab experiments to be jaws whose required insertion force (of the meter stab) is significantly less than that of a standard socket jaw. A threshold of 3 to 5 pounds of force per jaw was found to be the threshold between safe and unsafe conditions.

Conditions required to create these situations are not unusual in typical residential meter installations once a meter has been inserted into a box that has a compromised socket jaw. Elevated temperatures can be created under typical, residential power consumption levels. As arc temperatures can approach 11,000 degrees Fahrenheit (about 6,100 degrees Celsius), they allow for a relatively fast heat transfer from the arcing location (meter stab) to internal components of the meter. We were able to repeatedly simulate these conditions and results in our lab, on a variety of meters. We then observed and tested a variety of socket jaws, and determined that insertion force is a measurable parameter that differentiates good jaws from jaws that create hot socket conditions. Some compromised meter socket jaws were readily identified by visual inspection while others were not. A go/no-go tool was designed based on the lab data to determine if a particular meter socket jaw was compromised or not.

This paper aims to:

1) Support the theory that most meters damaged by heat were likely exposed to arcing at the socket jaws.

2) Demonstrate conditions that facilitate arcing in meter sockets

3) Suggest characteristics of socket jaws that can be used as indicators of conditions that facilitate arcing and the destruction of meters.

4) Explain the tool we developed that indicates a potentially dangerous socket jaw.

5) Discuss what can be done to leave the installation safer than when you found and identified the dangerous socket jaw.

PART 2: Observations from the Field

Some of our research was funded by large investor-owned utilities and some was funded by meter manufacturers. This paper is based solely on data from the research performed in conjunction with the meter manufacturers. No Utility data is used as part of this report.

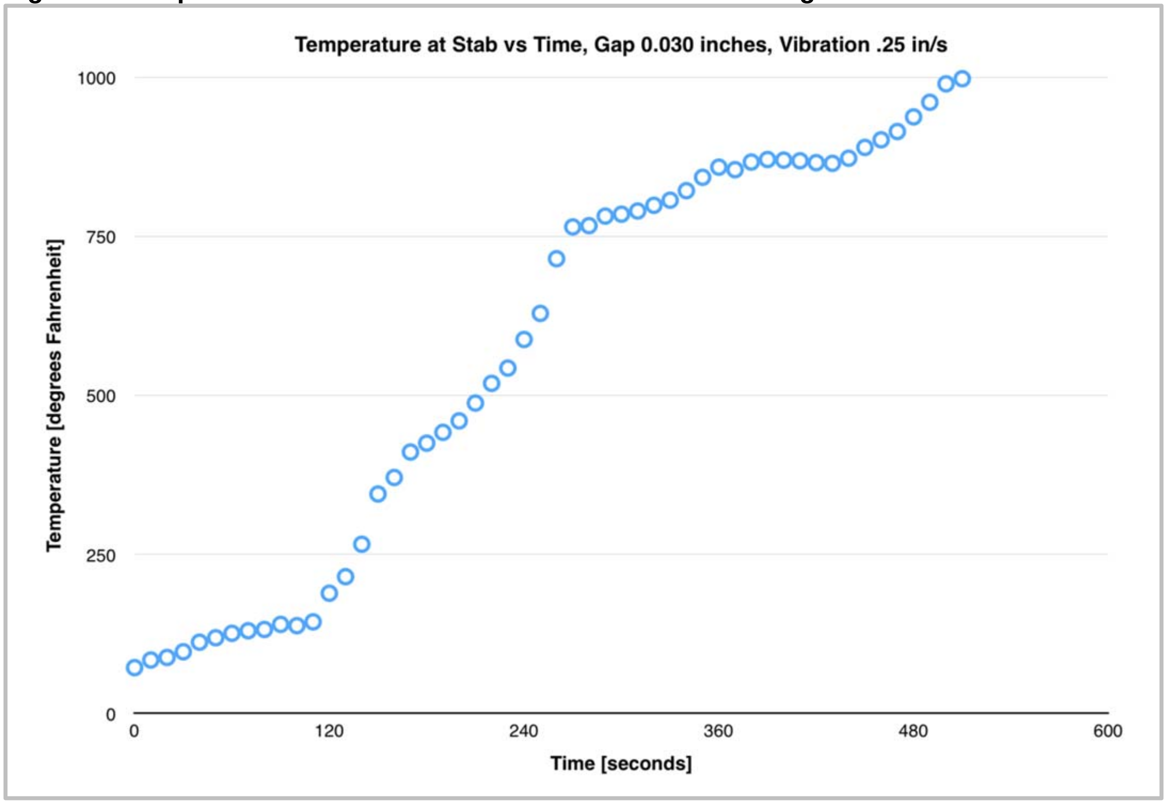
Through our own meter shop we have access to thousands and tens of thousands of returned AMR and pre-AMR meters that have been scrapped. Heat damaged meters were sorted and cataloged for similarities and to help identify patters. Initially we did not have access to many meter sockets as utilities typically don't have ownership and control of the sockets. In most cases sockets belong to the customer. We have been able to secure a supply of used meter boxes from the field so this problem was transitory in nature only.

A common characteristic of the heat damaged meters was a roughening of the surface of the meter stab (or stabs) that were exposed to the most heat, shown in Figure 1. The roughening was pitting and carbon deposits, the result of an electrical arc contacting the surface.

Figure 1. Pitting and Discoloration of a Hot Socket Meter Stab Returned from the Field

Laboratory experiments simulating anything other than micro-arcing (e.g. contact resistance, small blades, water in the meter, contamination in the meter) failed to provide the elevated temperatures required for catastrophic failure of the meter. We set up experiments that aimed to correlate an increase in measured resistance at the contact to an increase in surface temperature under load. In the most extreme case with a high resistance tungsten pad representing a poorly conducting surface, the temperature rise over a full day was less than 100 degrees Fahrenheit (less than 40 degrees Celsius). In contrast, when we were able to control the arcing at the jaw-stab connection, we observed temperature rises of over 1,500 degrees Fahrenheit (over 815 degrees Celsius) in less than ten minutes, shown in Figure 2. These experiments were conducted under a 25 amp load; this is on the high side of what a typical house would be drawing. The damage on the meters produced by controlled arcing was indistinguishable from the damage on most burnt meters returned from the field.

Figure 2. Temperature Rise at Meter Stab with Controlled Arcing



Anecdotal evidence from the field showed that the same pitting and roughening of the corresponding meter jaw socket could also be seen. Our study of collected sockets is covered in Part 4.

PART 3: Conditions for Arcing

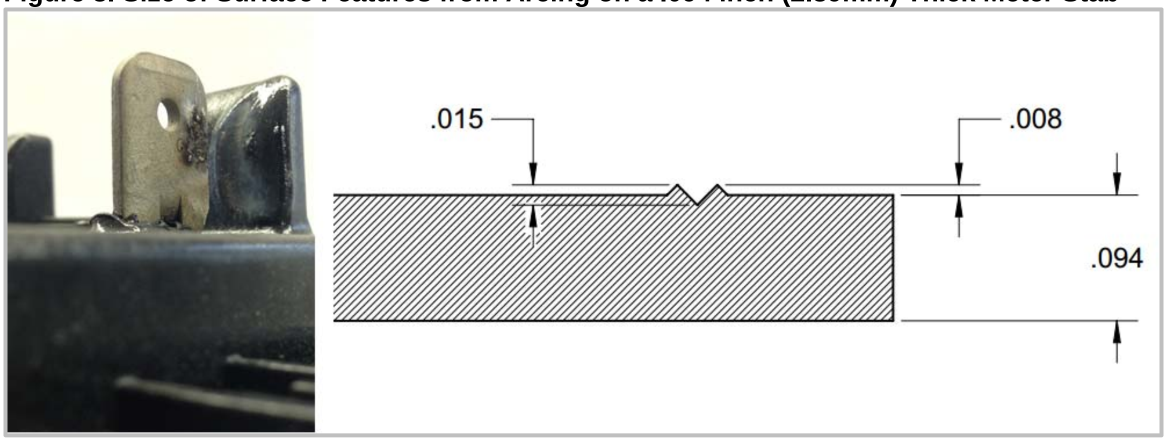
Paschen's Law suggests arcing will occur at certain gap sizes between two plates at different voltage potentials. Based on research conducted by German physicist Friedrich Paschen, the breakdown voltage necessary to create an electric arc between two electrodes is a function of air pressure and gap distance.

Theoretical calculations suggest that if arcing was indeed causing hot sockets, we would expect about an .015 inch gap present between a compromised socket jaw and meter stab (see calculations in Appendix 1). This size gap can be present in exceptionally loose jaws, or ones with obstructing debris. We found that gap size and a potential differential between the electrodes (meter socket jaw and meter blade) were necessary but not sufficient to induce arcing. Two additional elements were required; nominal current and a catalyst. The nominal current was found to be more than 10 mA (the amount of energy required to simply power the meter from the line side of the service) and 0.25 amps (the lowest current tested other than just the electronics on the meter).

We were able to demonstrate repeatable arcing and resulting temperature rises when we applied moderate levels of vibration to a jaw and stab connection with this size gap, under otherwise normal power conditions. This is when we began to produce damaged meters in our lab that appeared very much like the meters removed from hot sockets, specifically the appearance of the pitting on the surface of the stabs.

Vibration was used as a catalyst to the arcing and to sustain the arcing. In a steady state (constant power, no vibration), an arc will quickly deform the plated-copper on both the meter and stab, creating conductive and non-conducive features. The difference in height between the peaks and valleys of these features can be in the same size range as the gap that allowed the arcing, illustrated in Figure 3. These features would either help or hurt sustaining the arc beyond our control, as they could open or close the gap in a way. When we opened the gap slightly, and introduced vibration (opening and closing the gap at a fixed frequency), we were able to consistently sustain the arcing to durations that would cause significant meter damage. This led us to hypothesize if and how this could occur outside the lab. We quickly found our minimum vibration threshold capable of producing arcing can be obtained quite easily and often if meters are installed near highways, near washers or dryers, or even near a frequently traversed walking area in frame construction homes.

Figure 3. Size of Surface Features from Arcing on a .094 inch (2.39mm) Thick Meter Stab

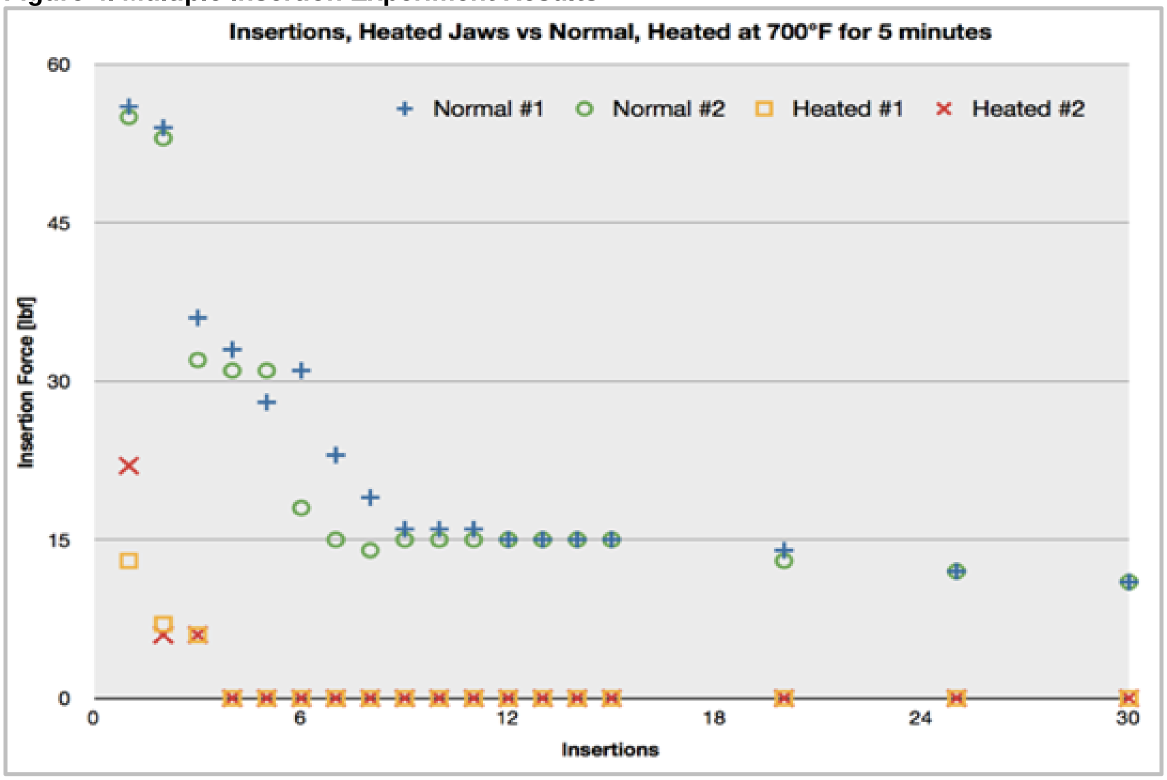


PART 4: Characteristics of Socket Jaws

A this point we were satisfied that we had found a way to create and observe a mode of failure that agreed with field observations, and the hypothesis of others working to understand this problem. Although we identified other sources of heat and fire in meter enclosures, the vibration and socket meter jaw gap created incendiary meters that matched the meters found in our meter shop which has been exposed to high heat. Our research on arcing was handed off to utilities and meter manufacturers who have the ability to continue the study on a much larger scale, and come up with alarm protocols for early detection of hot sockets as well as to design meters which can withstand a hot socket better than earlier generations of AMI meters. Our concern shifted to finding a way to flag potentially problematic jaws in the field during AMI installations or at any other time where the utility has an opportunity to inspect the meter enclosure.

We noted that visual observations of the mating surfaces and potential gaps could be subjective. We focused on finding features which could be measured and then research these features to see if we could identify a danger threshold that could be inspected for. Our understanding of mechanical fatigue and creep led to a test where the insertion force into a jaw was measured and recorded on multiple insertions into the same jaw. This data showed exponential decay of the insertion force with each meter removal and insertion. Initially high insertion force above 40lbs quickly dropped and stabilized around 15lbs after the first five to ten insertions. When the jaws were heated to the maximum allowable temperature (as per ANSI C12.1; C12.10 and C12.7) under heavy load conditions before the test (400 degrees Fahrenheit, about 200 Celsius), the decay on average stabilized at 15lbs in slightly fewer insertions then in cold tests. This was still nothing indicative of a problem as the conditions were still normal for what the jaws were designed to withstand. Finally when preheated to 700 degrees Fahrenheit (about 370 Celsius), we repeatedly observed a rapid decay to zero pounds insertion force, within the first two or three insertions. 700 degrees Fahrenheit was quickly reached at the jaw in our arcing tests, and was the temperature where noticeable damage that deemed a meter a “hot socket” meter occurred (e.g. plastic melting on the meter around the stab, pitting on the meter blade and the socket jaws). The difference in holding force between normal and heated jaws is illustrated in Figure 4. We drew a threshold line under 15lbs at 10lbs, and developed a tool that simulated a stab being pushed into a socket jaw with 10lbs force. We distributed the tool for testing in the field.

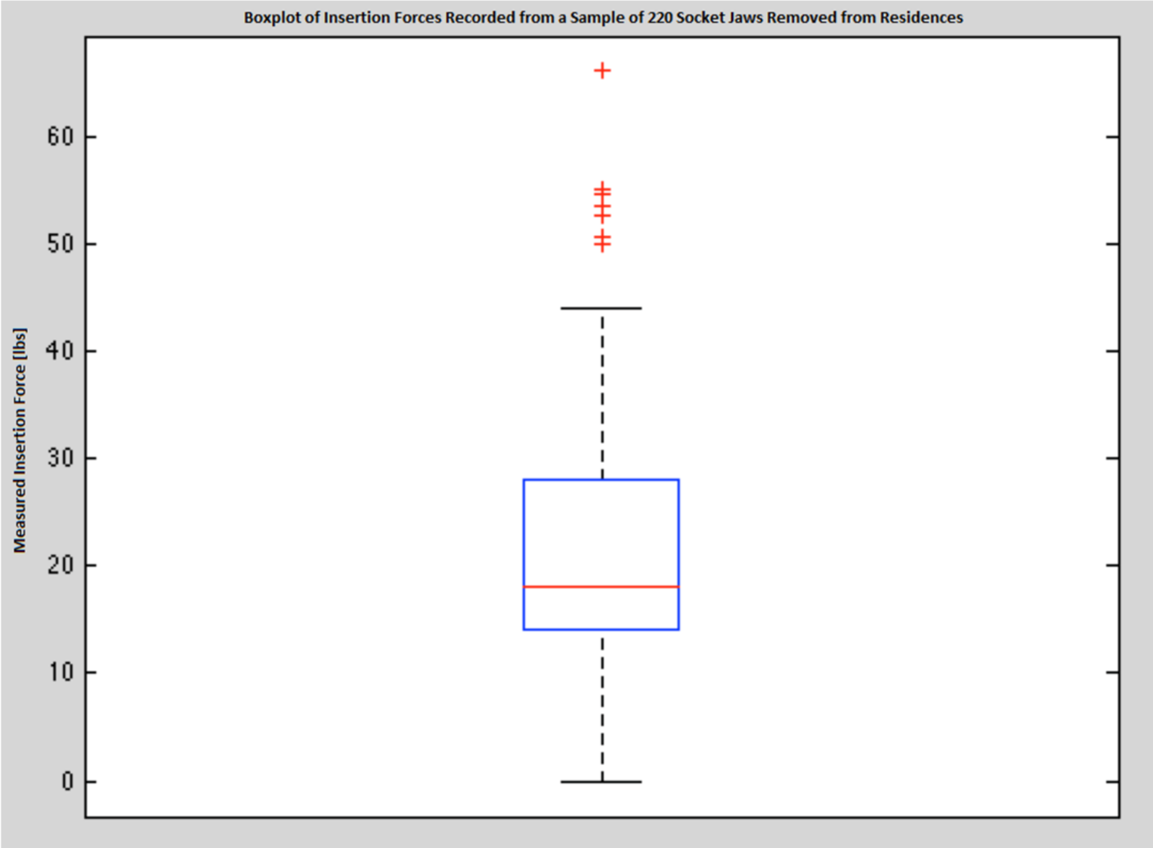
Figure 4. Multiple Insertion Experiment Results



A well-defined minimum holding force for meter socket jaws hasn’t yet been specified by ANSI or UL. ANSI C12.7 defines the outer dimensions of the jaw, but doesn’t specify gap size or holding force. UL 414 focuses on maximum insertion forces to keep the operator safe and prevent damage to the socket and meter in sections 5 and 19, but also doesn’t define a specific minimum holding force. UL 414 section 14 comes closer to defining a holding force by requiring a meter in a socket with no supplementary insertion force cannot move over 1/16th of an inch out of the socket by its own weight. As modern plastic meters have become much lighter than their mechanical counterparts, this would mean a very light holding force would be acceptable; what may be sufficient to hold one meter may fail to hold a heavier meter in the same socket.

As we had been conducting our experiments and tests, we had meanwhile collected a sample of sockets pulled from homes by local contractors. Of close to 50 sockets (200 plus jaws), we found two jaws that had evident signs of abnormal temperature elevation; pitting, a gap, and discoloration. Both jaws had a measured insertion force of zero lbs. The insertion data we collected from all the collected jaws in shown in Figure 5.

Figure 5. Insertion Forces from Collected Socket Jaws



PART 5: Hot Socket Gap Indicator (HSGI)

The hot socket gap indicator (HSGI) was developed to search out meter sockets with holding forces close to the five pound threshold. The HSGI was also designed to not slip into a meter socket if the socket had at least a holding force of ten to twelve pounds of force, giving the user a safety margin of roughly five pounds. Also every insertion of any meter stab into the meter socket jaw will degrade the meter jaw by some amount. This is also part of the reason for the safety margin as we know that the next meter insertion will weaken the meter jaw by some unknown amount, leaving the jaw and the meter closer to the danger zone.

A second tool was also introduced with the same dimensions as the meter stab (0.094 in nominal) and tin plating to reflect the same plated stab being introduced to the meter socket jaw. This tool was introduced to handle two situations found during the field testing of the original tool. The first is the use of meter man's grease during AMI installations. This grease has been introduced during some AMI deployments to allow the meter techs a faster and easier meter insertion. This grease temporarily decreases the holding force of the meter socket jaw to less than the force measured by the narrower blade on the original tool. The second tool flags sockets with six to eight pounds of holding force. The second situation found in the field are sockets that are manufactured with two parallel sides that are not intended to touch, but are parallel to each other. This design is to allow 100% blade to socket contact when a meter is inserted in the meter jaw. The narrower blade thickness of the first design failed this meter socket as a result of this gap, even though the holding force was in excess of the danger zone. The wider blade thickness eliminated this issue and correctly passed good versions of this meter socket type and failed fatigued socket jaws.

The original tool has been the preferred tool for utilities without this style meter socket jaw and who do not use grease or lubricant on their meter socket jaws. The issue found with the socket lubricant is that after several years this lubricant dries out and the meter is "cemented" into the socket jaw. When that meter is removed for testing or replacement the meter jaw will tend to come with the meter and although the situation for a hot socket did not exist with the "cemented in" meter, the socket after meter removal is now a "hot socket" with one or more jaws that no longer have the required minimal holding force. The greater safety margin of the original tool has also made this one the preferred option of many utilities. Both are valid tools based on the same design criteria and data, the first provides a larger safety margin and the second handles more field situations.

The HSGI has been designed to be simple and easy to use. The stab is attached to a red block that acts against a 10lbsf spring. In the initial state the indicator always shows red, when the stab is pressed against a good jaw the red is pushed back and hidden with the operator exercising roughly ten to twelve pounds of force on the tool. When the tool is pressed against a bad jaw the red stays visible. The spring is rated for over one million compression cycles by the spring manufacturer. After assembly each HSGI is inspected for spring force within tolerance (plus or minus one pound) and cosmetic defects. Since a HSGI shouldn't see one million compressions in five years and that is the longest a tool should be in the field without inspection, we have a five-year calibration date on each unit so the unit can be sent back to us and inspected, refurbished, calibrated or replaced. The design has been drop tested in a range of usable temperatures (32F to 120F, C), and has been tested for electrical insulation up to 3,000V. The HSGI should still be used with Personal Protective Equipment (PPE). The tool is useful for testing jaws where grease buildup hides a gap or signs of elevated temperature, the lubrication effect of the grease has not been found to throw off the tool. The beveled edges on the thicker standard model allow the tool to work consistently on the full range of jaw designs we've acquired, eliminating misreading due to angle of insertion or removal (for tools designed to measure the insertion force by being inserted into the meter socket).

PART 6: Conclusion

TESCO's Hot Socket Gap Indicator is a simple and reliable diagnostic assistant for flagging potential hot sockets. The jaws that it indicates as bad should be further observed for signs of unusually weak holding force, discoloration, debris, and pitting from arcing. If these signs are present, the jaw or socket should be replaced to prevent overheating of the meter and the possibility of fire. AMI deployments have made hot sockets a front page issue, as removing a meter from an old socket and forcing a new one in can actually create a problem. However, the deployments are also an opportunity to observe and flag sockets that are potentially dangerous.

We at TESCO designed the tool after a successful effort to replicate a common mode of failure observed in the field; overheating due to arcing. Our goal was to develop a tool that can help reduce the number of meter fires. The HSGI is in the first line of defense, along with operators who have an understanding of what to look for to identify hot sockets. We feel obligated to share what we learn, and help the industry develop knowledge and diagnostic methods to prevent catastrophic situations.

Appendix 1. Theoretical Calculations

Based on research conducted by German physicist Friedrich Paschen, the breakdown voltage necessary to create an electric arc between two electrodes is the following function of air pressure and gap distance between two electrodes:

$$V_{arc} = \frac{apd}{\ln(pd) + b}$$

In the equation, p is the air pressure between the electrodes, d is the distance between the electrodes, and a are b are constants with the values 43.6 V/(Pa(m)) and 12.8 respectively. For our purposes, the two electrodes creating the arc were a meter stab and socket jaw. With a 240 Volt potential difference across the electrodes, representing the standard maximum voltage provided to residential power customers, and standard air pressure (101325 Pa), d is found to be approximately 0.015 inches.

It is also of note that by finding the resistance of the air between the electrodes – $R_{air} = \frac{\rho d}{A}$ where ρ is air resistivity, A is the cross-sectional area being examined and d is the distance being considered – and substituting that into Ohm's law – $I_{arc} = \frac{V_{arc}}{R_{air}}$ – one can subsequently determine the current produced in an arc. At 20 degrees C, air resistivity ranges between 1.3 x 10^16 to 3.3 x 10^16 ohm(m). Arc temperature has a direct relationship with arc current, as current increases, temperature increases. The arc temperatures typically seen in the conditions present in power meters are about 11,000 degrees Fahrenheit.