Electrical Fires and Explosions

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14.10.2 Damage to insulators

Since porcelain or ceramics are brittle materials, they can be readily damaged by mechanical impact, e.g., falling objects. But insulators may also be damaged by excessive arcing. Guile[140] concluded that fracture becomes more likely when arcing is prolonged, e.g., longer than 0.5 s, or so. But the fault current value is also important and higher fault currents are more likely to lead to damage. Apart from this general guidance, not much detailed information has been published on the topic, although a theoretical treatment has been proposed[142]. Tslaf[143] showed some results for progressive melting of track along a fused quartz insulator. For durations below about 0.2 s, no melting was found, but longer time periods the depth of melting was found to be proportional to $\sqrt{t}$. The insulator will become compromised, since the electrical resistivity of the molten material is several orders of magnitude lower than the solid insulator.

14.11 Meters and meter sockets

Incidents involving a suspected meter fire have to be investigated carefully. Fires originating at a meter will generally leave distinct patterns (**Figure 73**). The meter location generally also has copious other wiring and the meter may be the victim, not the cause of the fire. In the incident illustrated in Figure 71, if the fire had originated at the meter or meter socket, a massive arc fault would likely occur at that location, de-energizing branch circuit wiring and eliminating the potential for downstream arcing.

Fires at meter sockets are commonly due to improper functioning of the stab connection, often due to it being misaligned and making minimal contact (Figure 72). Poor contact force can be checked by means of a *hot socket gap indicator* tool. This tool was developed by the TESCO company and is a very simple mechanical device that indicates inadequate spring force when inserted into the stab connection. Meter socket fires appear to have become more problematic since the introduction of smart meters, see below.

(a) Burn patterns near meter

(b) Actual fire origin at branch circuit wiring inside the wall (note beading)

Figure 71 Burn patterns suggesting meter fire; meter was actually victim of fire
(Photos: Eric Jackson)

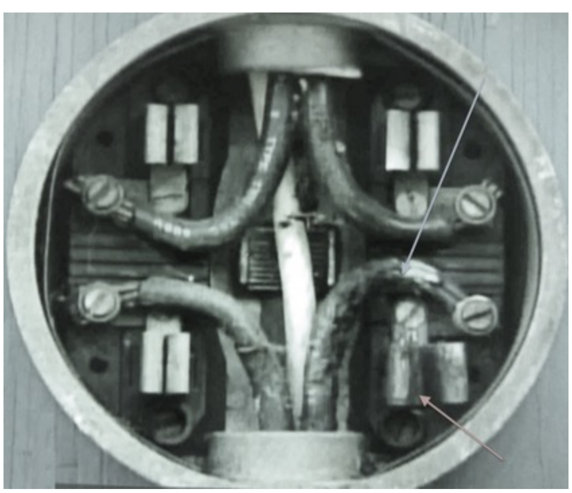


Figure 72 Overheating of wire (blue arrow) connected to meter base load-side connection due to poor connection at stab (red arrow)
Photo: Curtis Bennett

(a) Localized, but limited burn damage to wall

(b) Burn patterns on back of housing

(c) Major damage was inside the structure

Figure 73 Damages due to meter fire

(Photos: Eric Jackson)

Figure 74 Smart meter installation, showing two ordinary smart meters (center, right), and a collector meter (left). Note that the collector meter differs in having an extra-deep base.
(Photo: Jim Brown)

14.11.1 Smart meters

14.11.1.1 Technical details

Smart meters are an innovative type of electric meter that uses RF/microwave signaling to communicate with the electrical utility (Figure 74). The basic function is enabling data on the consumption of electricity to be conveyed to the utility without need for manual meter reading. The meter reports readings frequently (at least hourly), enabling time-of-day pricing to be implemented. But various schemes can also be implemented whereby signals going in the other direction can be used for control purposes, e.g., for controlled load shedding. Smart meters are considered a component of Advanced Metering Infrastructure (AMI), but the latter is a broader concept and can include gas metering, water metering, etc. Nonetheless, industry often refers to smart meters as '*AMI meters*.'

Smart meter technologies and implementations vary in different countries, but they generally involve high intensity, short-duration RF signals being emitted, and this radiation is a cause of diverse health concerns[144-148]. The other major category of concerns (apart from privacy intrusion) has been meter fires. The meters contain multiple RF/microwave transceivers which can communicate with the power utility by PLC (power line carrier, i.e., imposing an RF signal on the powerline), or by a wireless ad hoc network. Meters often incorporate a signal routing technique where signals can be dynamically allocated between RF and PLC pathways[149]. Physical implementations can vary by utility. In many cases, smart meters use an external construction intended to resemble traditional analog meters which are in use in that particular country or locale. In North America, however, traditional-style smart meters are likely to have a polycarbonate housing, instead of glass. Smart meters are made by a small number of companies, including Itron, Landis+Gyr, Aclara, Sensus, and Honeywell (Elster).

The RF energy is sometimes represented as benign due to the fact that the duty cycle is low and, thus, averaged over a period of minutes or hours, the effective radiated power is low. It is true that the duty cycle is not close to 100%, but the severity of chemical reactions depends on peak values. An additional factor is that the transmitters are configured as mesh networks, where any node can serve to retransmit data from other parts of the network. In such implementations, the duty cycle can increase enormously, compared to the transmitting duration of a single, unmeshed unit. In addition, the antenna gain may be greater than 1.0.

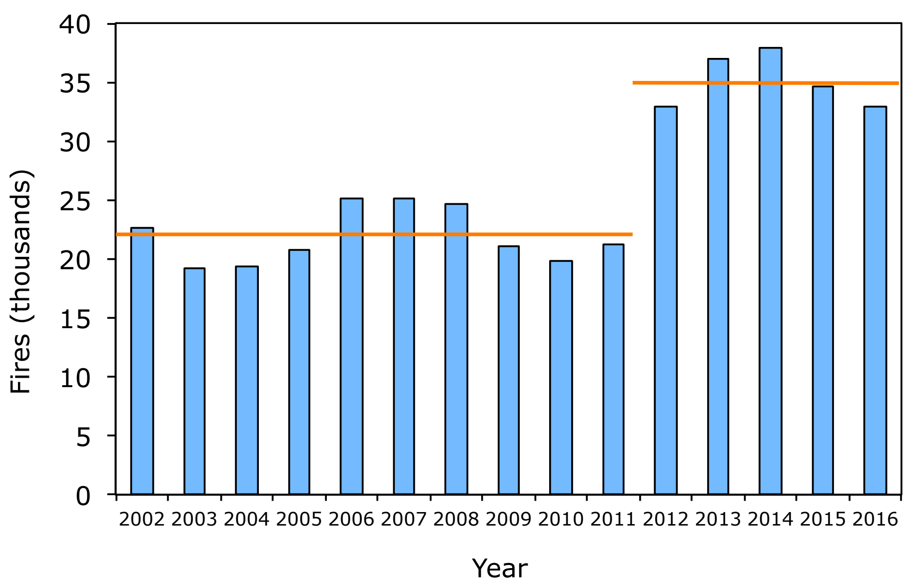


Figure 75 Electrical fires in the US for 2002 – 2016. Note the surge in electrical fires during 2012 – 2016. The change in electrical practices in the US during this period was the introduction of smart meters, which took place in many areas primarily during 2012 – 2015.

This means that power is preferentially radiated in a certain direction. This decreases power in other directions but increases it in a specific direction over what would be radiated by an omnidirectional antenna.

California's PG&E utility reported that their smart meters emit bursts in the 902 – 928 MHz band of 1000 mW at the transmitter, which is equivalent to 2500 mW effective radiated power due to antenna gain. They also reported that the average number of bursts transmitted per day is 9,981, while the 99.9th percentile number is 190,396. With their meters, there are only 6 bursts per day sending data from the metered premises, with the remaining data bursts being mesh network traffic. The average cycle is 45 s, with the 99.9th percentile being 875 s. The length of a single burst averages 46 ms. They also reported that the meters have additional RF modules operating in the 2.4 GHz band for communicating with 'smart' appliances. The two bands are sometimes referred to as 'LAN' for the 900 MHz band, versus ZigBee for the 2.4 GHz. In some models, a third band, at 1.9 GHz, is also used, either in place of the 900 MHz band, or in addition to it. One of the few studies to directly examine the unintended effects of the RF emissions from smart meters demonstrated that they can cause false triggering of GFCI devices[150]. The same research group[151] also noted that consumer electronics are sometimes destroyed due to surges created by 'hot-plugging' of smart meters by installers.

The RF emissions discussed above are purposive signals. But in addition to these purposive electromagnetic emissions, there are unintended emissions due to the power supply design. Smart meters invariably use switched-mode power supplies (SMPS) to obtain the low voltages needed for the internal electronics[152]. These provide unintended EM emissions, since the basic element in an SMPS is an oscillator, generally in the range of 25 – 200 kHz, and commonly at 50 kHz. Such emission are well-known[153-156] as one of the major sources of EMI, or 'dirty electricity.' In the presence of any nonlinear circuit element, these SMPS emissions can cross-modulate with purposive RF signals from a smart meter, yet this issue does not appear to have been adequately resolved or even systematically investigated.

Smart meters also open up new avenues for cyber attacks on the electrical power grid. This is a real concern, and the US Congressional Research Service[157] is not optimistic about the role of smart meters with regard to such attacks.

14.11.1.2 Statistics

In the US, the surge in electrical fire occurrence during 2012 – 2016[158] mirrors the surge in rollout of smart meters during 2012 – 2015[159] (Figure 75). Electrical fires during 2002 – 2011 averaged around 22,000, while after 2012 they average around 35,000, for an increase of over 50%. There has been no other change in wiring practice that would have a negative effect on fire safety. On the contrary, the NEC progressively enhanced requirements for AFCI usage, which would have a positive safety effect.

14.11.1.3 Safety concerns

Concerns have been raised in the media about the safety of smart meters, since numerous units have caught fire or exploded[160]. Fires appear to be caused by one of two root causes:

(1) inadequate design of the device; or
(2) poor installation practices.

Examined from the point of view of the fire origin location, fires attributable to smart meters originate at one of these locations:

1) at the meter base or at the meter/base stab connections;
2) elsewhere within the smart meter; or
3) in wiring remote from the meter.

Utilities generally only recognize the first two types of fires. However, all three categories will be considered below.

One smart meter manufacturer informs installers[149]: "*Do not install the meter where failure of the device could cause death, injury or release sufficient energy to start a fire*." This would be sound and important advice; however, the maker gives no instructions to the installer to determine where such risks will exist.

Some smart meters contain internally a battery, used to power the internal clock during a power outage. The battery is soldered-in and is expected to last the life of the meter (which is unspecified).

The problems experienced with smart meters have been extensively studied by Nina Beety[161], who compiled a list of over two dozen different fault types or failure mechanisms. A large number of additional web sites have documented various case incidents, but these have generally compiled incidents, without the benefit of engineering analysis. Thus, the focus here will be on reports provided by engineers.

The problems created by smart meters being installed in the Province of Saskatchewan, Canada were documented at length in a government-funded study[162]. Smart meter installation in that Province began in October 2013. But during a two month period in 2014, six catastrophic meter failures received widespread attention, 'catastrophic meter failures' being defined as "*meters which had burned, melted, blackened, caught fire, arced, sparked, or exploded/blown from premises*." Two other incidents resulted in fires of lesser damage, while 10 additional meters failed by overheating but without causing an external fire. As a result, the government required removal of the installed meters and authorized the study, which determined that the utility involved had not recognized the possibility of catastrophic failures. The study also documented that a similar problem had occurred at the Philadelphia Electric Company (PECO) in 2012, when Sensus brand smart meters (the same brand installed in Saskatchewan) were installed and then had to be removed due to fires. However, the study revealed that PECO was unwilling to provide SaskPower with any substantive information concerning the nature of the failures experienced in Philadelphia.

The government also commissioned a study by an electrical engineer[163]. The engineer examined some failed meters and found that failures typically involved arcing or arc tracking on the circuit boards. He concluded that the meter was not designed to adequately keep moisture and dust out of the meter, that no gasket was provided to seal the meter against the meter socket, and that the proximate cause of the failures was moisture entering the meter. He also reported that Sensus Generation 4 meters had significant design improvements, compared to the Generation 3.3 meters installed at SaskPower, but that meters from another maker (Landis+Gyr) had a yet more robust design. Unlike in some other locales, it appeared that none of the SaskPower failures were due to overheating at the stab connection interface. The report also identified that the meters have temperature monitoring capabilities, but these were often non-functional, either due to monitoring problems, or due to overload of communications circuits. It was also determined that none of the fires was caused by an unexpectedly large overvoltage.

14.11.1.4 Meter-socket stab connections

Thus, far, the largest fraction of fire incidents appear to have originated at the meter-socket* stab connections, sometimes called 'jaws.' For example, a study[164] by the Canadian utility BC Hydro described the results for a 6-month period in their service area. There were 29 incidents attributed to meter base or meter stabs, and one incident involving an MOV overheating inside a meter.

The jaws in a good meter socket should resemble those shown in Figure 76. If there is a failure or a defect at the interface, the condition is termed a 'hot socket'; this connotes thermal overheating, not a leakage of electrical current. One meter manufacturing firm[165] identified the following potential failure modes of meter socket jaws:

- excessively large gap size
- the opening is no longer in the intended plane of opening (i.e., jaws are skewed)
- corrosion due to overheating
- incompetent installers spreading open the jaws with a screwdriver to facilitate installation.

In judicial action before the NLRB, documents[166] were filed indicating that some fires originating at the stab connections were due to a design defect in that some models of smart meters were designed with stab connectors made of thinner metal than the analog meters that they were replacing. As a result, there was the potential for an intrinsically loose connection.

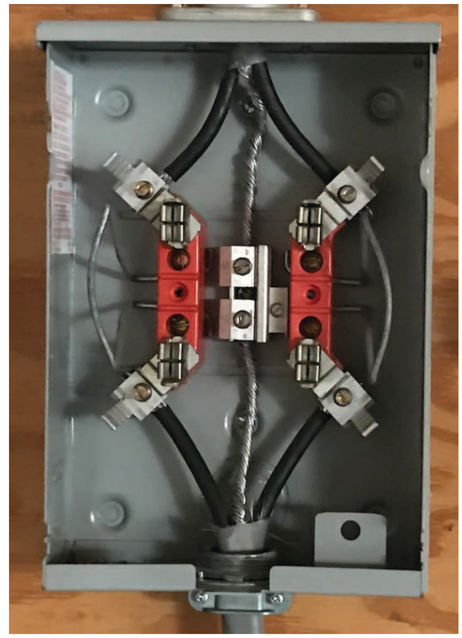


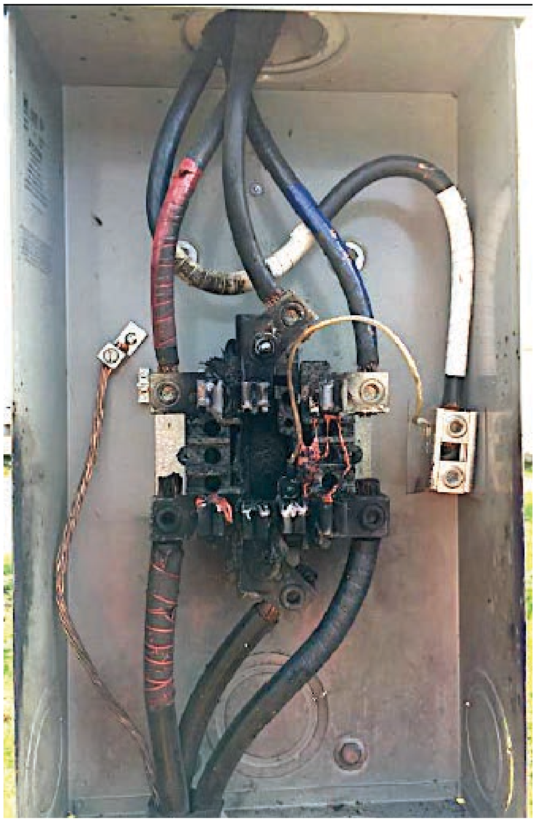
Figure 76 New, undamaged meter socket showing good stab connections. Note that the jaws are straight and do not have excessive gaps
(Photo: Vyto Babrauskas)

Lawton[167] studied the 'hot socket' problem and concluded that:

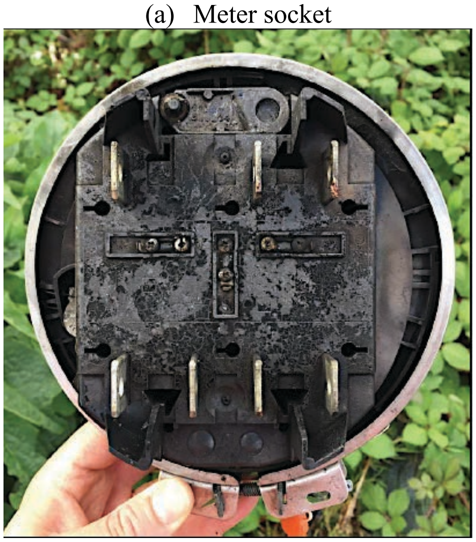
- electromechanical meters withstand hot sockets better than smart meters
- current level is surprisingly unimportant in the failure of connections
- even small amounts of vibration can facilitate failure of a bad connection
- hot socket problems are typically seen only for single-phase meters and are almost nonexistent for 3-phase meters
- sprung-wide jaws cannot be successfully repaired by closing them down with pliers.

Fires due to poor installation practice typically create a heating stab connection between the meter and the socket. This has sometimes been due to inadequate inspection—failing to repair or replace meter bases that are corroded, warped, or otherwise deteriorated. But not all fires are attributable to poor installation practice—some models have evidently been designed improperly. Not only have some incidents occurred due to undersized male prongs provided in the meter, but overheating incidents have also occurred due to an improperly-sized outer flange of certain meters[161]. The smart meters are supposed to fit mechanically into the same meter sockets as used by traditional electromechanical meters. If designers make errors in sizing the mating parts (electrical or mechanical), then clearly failures may ensue.

* For the purposes of this book, the terms *meter socket* and *meter base* are considered to be synonyms; they comprise a receptacle into which a meter is to be inserted.



(a) Meter socket



(b) Rear view of blown-off meter

Figure 77 Meter base and meter from an incident where "*the revenue meter had blown out of the meter base and landed approximately 4.5 metres away*" due to a power anomaly on the distribution feeder
(Photos: BC Hydro)

14.11.1.5 Other areas of the meter

A design concern with smart meters is that they typically omit surge protection features. Conventional electromechanical meters use a robust way of limiting surge voltages, a spark gap, which is generally not present on smart meters. As EPRI explained[168], "*Electromechanical meters had no digital circuitry. They utilized spark-gap to control the location of arc-over and to dissipate the energy of typical voltage events. As a result, they were generally immune to standard surge events. This nature is evidenced in the section of ANSI C12.1 that specifies voltage surge testing, but allows that 'This test may be omitted for electromechanical meters and registers.'*" Smart meters typically contain varistor protection against surge voltages, but this involves substituting a proven, highly reliable technology with one of lower reliability[152].

Another design problem of smart meters has been the use of plastics. Traditional electromechanical meters had a glass enclosure, which is non-combustible and, to a certain extent, can even act as a flame barrier. By contrast, smart meters are manufactured with a plastic enclosure[197], typically polycarbonate, which is a combustible material.

Apart from lacking a crucial safety feature present in electromechanical meters, smart meters have a new feature that may not be properly designed. Smart meters are typically equipped with a relay to allow the utility to turn power off or on by remote signal. Traditional electromechanical meters could not ignite or explode due to remote power turn-on operations since they lacked such switching capability. But the design of the relays in some smart meters has evidently not been adequate. A former utility meter reader[161] reported that: *"they do catch on fire when they are remotely turned back on when a customer who is delinquent in their bill finally pays their bill. These meters catch fire*." Meanwhile, an electrical contractor[169] pointed out: "*that a* [safely designed] *200 amp disconnect enclosure would be sized roughly 20"x20"x6", several times larger than a smart meter*." Yet, the physical size of smart meters, in most cases, directly duplicates the electromechanical meters that they replace. An electrical engineer[152] who analyzed some commercial smart meters agrees: "*The biggest weakness is in the power disconnect, it suffers from a small surface area for the disconnect contact and would be prone to excessive heating and likely result in contact pitting and carbon deposits that are not readily visible by the customer and there is not a sensory circuit that could detect it and report it to the consumer or the utility. This design would be prone to creating unpredicted fires*." A similar situation was also found in Canada[170]: "*The* [internal 200 A disconnect] *switch is not CSA certified, yet it is being used as a 'Service Disconnect Switch,' for which it is not designed*."

Since they contain extensive electronics, smart meters generally contain a temperature sensor to detect overtemperature conditions. Bao and Li[171] noted that a properly-designed smart meter should have a temperature sensor in a vulnerable place and to monitor the temperature correctly. Poor, early designs sometimes monitored only the temperature of the CPU, which is not likely to be the location of overheating. Another temperature sensor problem was documented by the Illinois Commerce Commission[172]: "*The majority of ComEd's AMI meters (GE) are equipped with temperature sensors and can report their internal temperature on command. ... However, a problem with the scans soon made itself known. The ability of ComEd's smart meters to accurately measure and report their internal temperature is not clear. Apparently, radio frequencies can enter the meter and cause the temperature sensor to report significantly inaccurate measurements*." The same study pointed out another unanticipated problem. With traditional electromechanical meters, the meter and base receive a visual inspection every time that a meter reader takes readings. With the automated data gathering scheme of smart meters, no such visits are made. Therefore, some problems which might have been caught early on will escape detection.

Smart meter explosions are typically caused due to power surges. In one incident documented in Stockton, California, a number of smart meters exploded when a truck demolished a utility pole, causing HV distribution wiring to fall down onto 240 VAC secondary wiring[160]. Beety[161] has documented a number of other incidents of smart-meter explosions due to intermix faults (a higher voltage line coming into contact with one carrying a lower voltage). A typical incident description has been "*the meter was blown right off and the wires were sticking out*." It appears that such explosions have repeatedly been experienced with smart meters due to two primary reasons: (1) failure to provide spark-gap surge voltage protection, of the kind traditionally included in electromechanical meters; and (2) failure to design electronics to resist a 6 kV surge voltage (see Chapter 10). In one incident in Canada[173], a phase dropped out and this eventually led to a ferroresonance condition (see Chapter 10). This created a voltage surge and blew the smart meter off its meter socket (Figure 77).

It bears emphasis that, while surges can be damaging to any electrical installation, smart meters are remarkably more vulnerable than the electromechanical meters that they replace. In a 2011 incident in East Palo Alto, CA, some 80 smart meters caught on fire, yet the utility reported[174] "*that surges have not burned out the city's analog meters*."

An additional concern is that smart meters contain a lithium-ion battery in order to maintain data during power outages. By contrast, no batteries have been used in traditional electromechanical meters. The fire and explosion problems of Li-ion batteries are discussed separately in this chapter.

Apart from large buildings, electric meters are generally installed outdoors, typically directly onto an exterior wall. While this means that initial flaming from the device will not be in the occupied space, this is not necessarily an advantage. Many buildings are equipped with smoke detectors, automatic fire sprinklers, or both. These are designed to respond rapidly to a fire sensed in the interior of a structure. Conversely, a fire originating at the outside façade may grow to a large magnitude before it is sensed by fire protection devices in the interior of the structure.

14.11.1.6 Wiring remote from the meter

One unusual problem sometimes experienced with smart meters are fires which start in the general vicinity of a smart meter, but not directly nearby (commonly some 3 – 5 m distant). In situations where the location is inside a wall cavity and inspection does not reveal any likelihood of mechanical damage, the interpretation suggests that the cause is due to the smart meter, even though the exact mechanism has not yet been identified. Figure 78 shows a fire originating in mid-run of a branch circuit NM cable, away from any potential sources of mechanical damage, about 4 – 6 months after installation of a smart meter. Another similar case is illustrated in Figure 79.

Perhaps the most revealing fire is illustrated in Figure 80 and Figure 81. Figure 80 shows the locale in the ceiling where fire broke out. A smart meter had been installed at the house around 4 months prior. The fire investigator decided to examine some unburned circuits in the area and found another location on an NM cable where severe insulation failure had occurred, but fire had not yet broken out (Figure 81). Due to extensive record-keeping, the homeowners were able to provide some very detailed, useful information on the case About 2 months after the installation, the homeowners brought their dog to the veterinarian since he was repeatedly scratching his ears. The vet found no malady with the dog. One month later after the behavior failed to normalize, the owners again brought their dog in for medical attention and again received no diagnosis. But around the same time, the owners noticed that their cats started to concertedly avoid the room in which the fire later broke out. After the fire occurred and the fire damages were remediated, none of the animals continued to show aberrant behavior. The most likely explanation is that failure of the insulation on the NM cable caused arc tracking to be initiated, leading eventually to arcing across air (see *Arcing across a carbonized* path in Chapter 7). Dogs and cats are able to respond to ultrasonic frequencies which are beyond the audible range for humans. The emission of ultrasonic sound waves from arcing is discussed in Chapter 5 under *Acoustic noise*. It may be concluded in this case that the behavior of the animals indicates that arcing was already occurring about 2 months after smart meter installation, but that it took another two months for fire to break out.

Figure 80 Fire originating mid-run on a branch circuit, about 3.9 m away from a smart meter which was located on the exterior face of the wall along the left side of photo. Note two joists with extremely heavy saddle burns, while no damage was seen to adjacent joists. No staples, nails, or other mechanical causes of damage were found.
(Photo: Jim Brown)

Figure 81 A damaged section from a cable in the same fire as shown in the previous figure. Note that there is no fire damage here, but a severe, localized insulation failure. The two dimples (in the middle of the yellow circle) are not mechanical damage. There was no mechanical damage, but evidently the cratering of the insulation occurred due to localized damage from RF waves. This location was about 2 m away from the smart meter.
(Photo: Jim Brown)

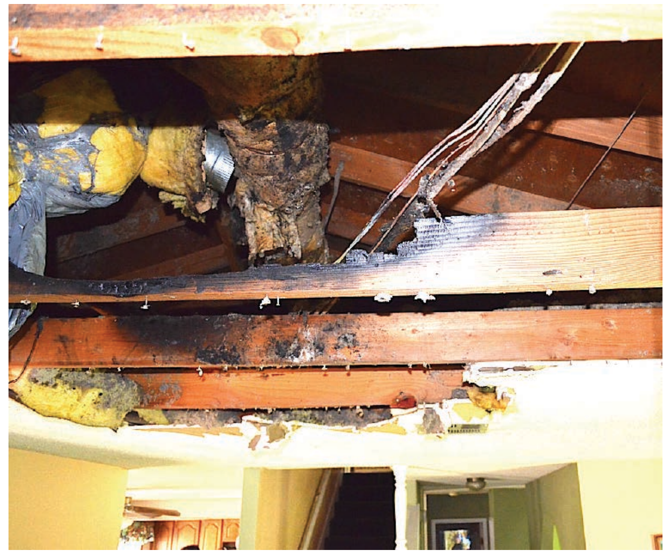


Figure 78 Fire originating mid-run on a branch circuit, about 3 – 4.5 m away from a smart meter which was installed some 4 – 6 months earlier. Examination of the fire origin area did not reveal any fasteners that could have damaged the cable, nor any other potential sources of mechanical damage.
(Photo: Jim Brown)

Figure 79 Fire originating in a wall cavity causing heavy damage to two studs. The smart meter was located about 4.6 m away. No arc marks were found on the NM cable. No staples, nails, or other mechanical causes of damage were found. The photo also shows some bare wires which were part of the wall stucco construction method.
(Photo: Jim Brown)

Why are these fires occurring? Surprisingly, microwave ignitions have been studied only to a very limited extent (see *Microwave ovens* in Chapter 15); also see *Degradation: Electromagnetic fields* in Chapter 7. Despite incomplete knowledge, it is well-known that microwaves have a highly directional aspect to their propagation. Furthermore, intensities can be increased locally due to additive effects of reflections[175,176,177]. The fact that ignition are taking place at some sizable distances beyond the meters suggests that local reflection or waveguide effects may be dominating. There are also differences between microwave ovens and smart meters, and these can may play a role in the hazard. Microwave ovens, of course, emit much more power than a smart meter. But (1) smart meters produce high choppy, pulsed emissions while microwave ovens operate as CW (continuous wave) devices; and (2) designers optimize oven designs to minimize hot spots, but such efforts cannot be undertaken when microwaves from smart meters radiate into an uncontrolled locale. There are some specific electrical design faults with some commercial smart meters that may make them especially prone to excessive EMF production. An electrical engineer who examined some of these meters concluded that[152] "*lack of a common mode and differential filtering of the [switching-mode power supply] oscillations being injected from the meter onto the house wiring circuit, thus making the whole house into an antenna with dangerous RFI/EMI*."

Time-averaging of emissions (or delivered energy) is inappropriate if thermal degradation of plastic insulation materials is to be correctly evaluated. While both time and temperature play a role in determining the degradation of a material, time enters the relationship in a linear way, while temperature enters as an exponential factor. Thus, a time-average does not properly assess the damage. Details are discussed in Chapter 7 under *Aging*. But, to clearly illustrate the effect, using the data of Morsy and Shwehdi for the lifetime of PVC insulation given in Chapter 7, if the temperature is increased by 10%, from 300 K to 330 K, the lifetime of the material drops by 95.5%. Thus, the effect is clearly extremely nonlinear.

One area worth investigating is that increased losses can exist in dielectrics due to reflections within thin layers. Duan[178] found sharp microwave power absorption peaks at ¼ λ and ¾ λ, where λ = wavelength of radiation. The largest absorption peak for PVC was found to correspond to around 3.2 mm layer thickness for a wavelength corresponding to 2.4 GHz. In addition, the field of microwave-metal interaction pyrolysis has been researched only to a very limited extent. But the observation of Gasner et al.[179] is noteworthy: "*The presence of the two parallel copper wires led to a concentration of microwave energy within the coal mass and the wires in effect acted as antennae for microwaves*." These authors were studying coal as the target material, but Hussain et al.[180] found a similar effect for a copper conductor with polystyrene, who further noted that the copper exhibited catalytic properties with regards to pyrolysis of the plastic. Another observation of potential relevance is that microwave absorption by char may be much greater than of a virgin material prior to pyrolysis[181,182]. This would suggest that once pyrolysis of an organic insulation material starts, a self-accelerating factor may come into play. Another factor is that heating received is proportional to the loss tangent, tan δ, of the material (see Chapter 7). But tan δ for many materials, including PVC[183], rises with temperature. This can also contribute to a positive-feedback result.

Hot spots can arise in microwave heating due to the way that the microwaves are generated and propagated, e.g., cavity resonances, reflections, etc. But what has been less explored is that an organic material (e.g., an electrical insulation) can generate a local hot spot by means of a chemical instability, which arises due to nonlinearities in its electrical properties. The phenomenon has been researched enough to establish its mathematical bases[184-188], but not enough to provide practical guidance. This can be attributed to the fact that most of research to date has been done by mathematicians, instead of engineers.

The industry position has been that smart meters have been studied in detail and that none of their emissions violate FCC (Federal Communications Commission) standards or requirements[189,190]. That may well be true, but of course this does not explain the fires that occur.

14.11.1.7 Standards

Standards pertinent to utility meters, including smart meters, are published by IEEE as IEEE Std 1377[191], IEEE Std 1701[192], IEEE Std 1702[193], IEEE Std 1703[194]. In Europe, the equivalent standards for data protocols are in the IEC 62056[195] series. Since these standards only include data protocols, but not safety requirements, in 2014 UL issued UL 2735[196], which does include safety provisions. There are no requirements, however, mandating that manufacturers comply with safety standards for meters, and voluntary compliance level appears to have been low. In the US, neither the NEC nor other regulatory bodies generally provide for any requirements mandating certification of electric meters with regards to their safety performance. Furthermore, testimony before a state public utilities commission[197] described that "*UL has a new certification standard that is said to have been developed to insure the safety of 'smart' meters, UL Standard 2735. But, even this certification is not sufficient. The very meters that have received this certification, Sensus and Landis+Gyr, have caused fires*."

14.12 Outlets

14.12.1 General

Outlets and *receptacles* are synonymous terms referring to fixed, female connection points where electrical power may be received. In the UK, these devices are termed *power points*, *sockets* or *wall sockets*. Normal US household outlets are very simple devices. Figure 82 shows the interior view of a common, 15 A 120 VAC outlet. There are only two plastic components, the cover and the body. In addition, there are three main metallic components, apart from screws: the ground strap, and the two female receivers (Figure 82). During the 1950s – 70s, the plastic parts were typically made from a thermoset plastic, e.g., phenol formaldehyde, melamine formaldehyde, or urea formaldehyde. Currently, the majority of household outlets are made from thermoplastic plastics, typically PVC or polypropylene, although larger-current outlets, such as those for use with clothes dryers or electric ranges often remain made from thermoset plastics. This material choice has an implication for failure modes of

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