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FE Use of Arc Mapping/Arc Fault Circuit Analysis in a Residential Kitchen Fire Investigation

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Abstract

A fire occurred in a single-story, single-family residence. At the time of the fire, two individuals (a husband and wife) occupied the residence. During the early morning hours, the wife was awakened by the smell of smoke, and discovered a fire in the kitchen. Initially, the area of origin for the fire was the kitchen. Utilizing arc mapping, the area of origin was further defined. This enabled fire investigators to use available fire effects to ultimately determine the point of origin and cause of the fire. The intent of this paper is to detail those efforts, enabling others to benefit from this case study.

Keywords

Electrical survey, arc, arc site, arc mapping, area of origin, point of origin, fire effects, fire patterns, electrical safety, arc fault circuit analysis, forensic engineering

Introduction

A fire occurred in a single-story, single-family residence during the early morning hours (**Figure 1**). Prior to the discovery of the fire, the two occupants (husband and wife) were asleep. The wife was sleeping in the master bedroom, and her husband was sleeping on a sofa in the family room. At approximately 1 a.m., the wife was awakened by knocking at the front door. A friend of the husband came to the residence to drop off one jacket and pick up a different one that was mistakenly taken home by the husband. The wife went back to bed approximately 15 minutes later. She reported that at the time she went back to bed, the television/lights were still on. Therefore, she assumed the husband had fallen back asleep on the sofa.

Figure 1
Exterior photograph of the residential structure.

At approximately 3:30 a.m., the wife was awakened by the smell of smoke. She exited the master bedroom to investigate the source of the odor. Walking down the hallway toward the family room and kitchen area, she noticed it was now dark inside — and eventually realized there was a fire.

She returned to the master bedroom and exited the residence via one of the master bedroom's windows. She traveled around the exterior of the residence to the garage vehicle door, entered the code for the vehicle door, and the garage door opened. She entered the garage, and

Safety

"Electricity can be very dangerous occupational hazard." [sic] *Working within fire scenes may expose investigators to electrical hazards. Documents such as the National Fire Protection Association's NFPA 70E,* Standard for Electrical Safety in the Workplace[1]*, address safety-related work practices that can help reduce the risk of electrically related workplace injuries. — **National Fire Protection Association***

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then proceeded to open the service door that led from the garage into the kitchen. After entering a few feet into the kitchen, she was met with heat from the fire, and could not proceed any farther. She recalled seeing fire to her right and overhead. She exited the kitchen into the garage, and then proceeded to the back of the residence. With the aid of a neighbor, she attempted to gain access to the residence by breaking the door wall glass, but those efforts were not successful. The husband expired in the fire.

Arc Mapping Primer

Arc mapping, also referred to as arc fault circuit analysis, is a generally accepted method within the forensic engineering community whereby a trained, experienced, and skilled practitioner uses the electrical system to reconstruct the fire scene to assist in the determination of its origin and progression. Several papers have been published on the topic of arc mapping[2,3,4].

Arc mapping is often thought of only in the terms of origin determination. However, it is not simply a one-dimensional approach. More accurately, it is a multi-dimensional method that can also be used for such tasks as scenario development and scenario testing. Additionally, it seems that when investigators speak of arc mapping, the presence of an arc site (see **Figure 2** as an example) is the emphasis. Skilled practitioners will understand that the lack of electrically caused damage can be just as important as finding electrically caused damage.

Arc mapping is not simply a pattern recognition tool. The practitioner cannot plot arc-site locations on a fire scene diagram and — by those locations — discern the area of origin of a fire or determine heat flow through a compartment. The practitioner must have a grasp of the installation that is provided through the performance of an electrical survey, which provides the foundation for being able to discern the data that can be gathered from the post-fire condition of the electrical system.

Figure 2
Arc site found at the fire scene.

Presumptions

When performing arc mapping, certain foundational presumptions are made, including:

1. The electrical system was energized at the time of the fire.

2. The electrical system available fault current will be such that an arcing event will leave physical damage.

3. Circuit lengths and installation methods are such that fault current will not be attenuated to the point that physical damage will not be made.

The fire will affect conductor insulation in the same manner as other combustible materials. In addition to the above, it is expected that the practitioner who possesses the skill necessary to perform arc mapping will recognize when circumstances exist that require additional considerations.

Fault Current

The amplitude of current a transformer can supply to a fault is directly related to the utility system's available fault current, transformer impedance, transformer secondary voltage, transformer kVA rating, circuit impedance, and fault impedance. Guidance related to the calculation of fault currents is provided in references such as the *Standard Handbook for Electrical Engineers*[5].

Electrical Insulation

The intent of electrical insulation, when placed between conductors at different potentials, is to permit only a "small or negligible current to flow through it."[5] Electrical insulation can be considered a combination of resistors and capacitors. The basic circuit representation of electrical insulation is shown in **Figure 3**. When exposed to heat from fire of sufficient time and magnitude, the insulation can go through a decomposition process that results in the insulation no longer functioning as intended.

Initial Scene Examination by the Lead Fire Investigator

The lead fire investigator retained by the property insurance company conducted an initial scene examination. During this examination, the lead fire investigator documented the fire scene and collected information

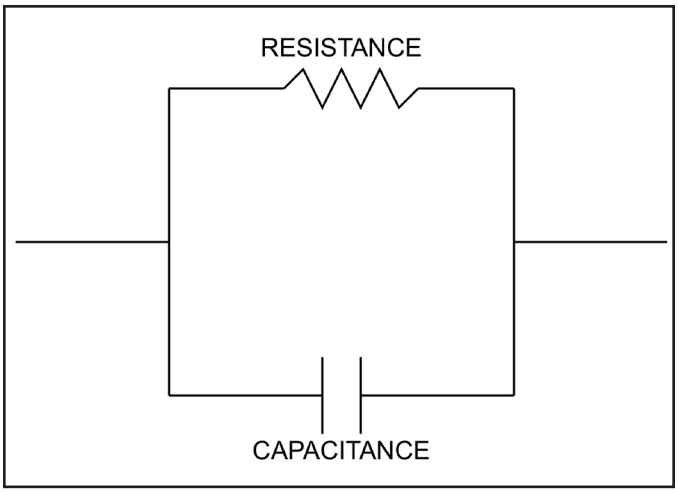

Figure 3
Basic circuit representation of electrical insulation.

related to the discovery and response to the fire. The area of origin determined by the lead fire investigator at this point was, for all intents and purposes, the entirety of the kitchen area. Several potential ignition sources were present in the kitchen, including a gas stove, small remote-controlled toy, appliances, and structural electrical and attached devices.

Forensic Electrical Engineering Scene Examination

A joint-scene examination was scheduled and conducted in conjunction with the attending experts for the identified interested parties that were notified of the fire loss.

Forensic engineers should follow a systematic approach[6]. The author's post-briefing scene documentation efforts began with an initial walk-around. This consisted of photographic documentation and note-taking in conjunction with an exterior electrical survey.

For the purposes of the examination, the residence was considered to face east. The residence was supplied with electricity via an overhead service drop to a weather-head that was located on the northwest corner of the residence. The copper service entrance conductors (enclosed in metallic raceway) were then routed on the exterior of the residence, and traveled east where they eventually terminated within the service meter enclosure. The service conductors then exited the service meter enclosure, entered the residence, and terminated at the main service disconnect located within the main circuit-breaker-style load center mounted to the interior north wall of the garage.

During the electrical survey, it was noted that an arc site was present on the service entrance conductors in the area of the west side of the kitchen window (**Figure 4**). This was the sole site in this area, meaning it was the only site on this section of the circuit. This provided the following information:

- The utility service consisted of enough available fault current to result in an arcing event that would leave physical damage to circuit conductors.
- At the time the wife utilized the garage vehicle door keypad to open the door, the fire had not yet breached the kitchen window and caused the service to fault.
- The west side of the kitchen window was the location where the fire first breached the kitchen window and service entrance.

The electrical examination then turned to the area of the load center, which was attached to the garage's south wall (near the service door that led into the kitchen from the garage). As stated, earlier the wife passed this area and entered the kitchen through this same door. Therefore, it can be concluded that the fire damage to the equipment happened after this occurred.

Electrical survey efforts proceeded to examination of the electrical system within the kitchen. In this area, the electrical system consisted of such items as light fixtures, receptacles, light switches, non-metallic sheathed cables, and connected appliances. Most of the branch-circuit

Figure 4
Arc site found on service conductors.

wiring was concealed behind wall and ceiling finishes that provided initial protection from heat from the fire. However, it was noted that in addition to the connected appliances located on the kitchen counters, one ceiling surface-mounted light fixture, one surface-mounted fluorescent light fixture located above the kitchen sink, and powered range hood were all permanently wired. The branch-circuit wiring within these devices would not be physically protected by wall and ceiling finishes and would present circuit areas of opportunity for a developing fire to affect the branch-circuit wiring.

The electrical survey in the form of circuit tracing efforts revealed that the branch-circuit cable supplying the junction box that the ceiling light fixture was attached to consisted of a three-conductor with ground cable. From the ceiling light junction box (**Figure 5**), one section of two-conductor with ground non-metallic sheathed cable was routed to the surface-mounted fluorescent light fixture positioned over the kitchen sink. Further examination revealed that the branch circuit was constantly energized — and that the same section of branch circuit also supplied the range hood that was mounted above the stove.

Another section of two-conductor with ground non-metallic sheathed cable was routed from the ceiling light junction box to the west wall — where it was eventually terminated to the duplex receptacle that supplied the gas stove. Based on this information, it was logically inferred that the developing fire attacking one of these would result in an arc site that could be used to further define the area of origin and help to determine the path of fire travel.

Further Defining the Area of Origin Using the Electrical System

Examination efforts then turned to attempting to further define the area of origin of the fire. Due to the damage to the combustible surfaces (such as hanging cabinets), fire pattern analysis was initially of little benefit. Therefore, arc mapping was heavily relied upon to collapse the origin to a more defined area.

The question of whether the origin could be at or near the coffee maker was posed. If this was the case, then the principles of fire dynamics would dictate that the first location of the fluorescent light fixture/range hood circuit affected by fire would be either at the fluorescent light fixture located above the sink or the ceiling-mounted light fixture. Examination of the wiring related to the light fixtures revealed no arc sites within the fixture wiring or the portion of the branch-circuit conductors that would be an opportune target for heat from the fire.

Figure 5
Ceiling light junction box in relation to over-sink light fixture.

The location of the arc site on the service entrance conductors and lack of arc site(s) related to the over-sink fluorescent light fixture, ceiling-mounted light fixture, and associated wiring for both led to the determination that this, in fact, would be a strong indicator that the fire originated toward the west side of the kitchen. Attention then turned to the range hood (**Figure 6**). Since the range hood consisted of a metal enclosure, heat from the fire would easily be conducted through the metallic walls to the wiring. Examination of the wiring within the range hood revealed an arc site (**Figure 7**). Based on the understanding of the electrical system from performing an electrical survey, the arc site in the range hood, the arc site on the service entrance conductors, and lack of an arc site within

Figure 6
Range hood.

Figure 7
Arc site found on range hood wiring.

the fluorescent fixture wiring indicated that the fire had originated at the west side of the kitchen.

Point of Origin and Cause of the Fire

After the area of origin was narrowed down to the west side of the kitchen using the electrical system, fire investigators were able to utilize fire effects. Examination of the range hood revealed fire effects in the form of oxidation patterns on the surface that would have faced downward toward the cooktop. The range hood was more oxidized on the right side than the left side.

This discovery led to the examination of the cooktop and four gas burners. Examination of the cooktop revealed differential damage to the four gas burners. While all four burners exhibited melting from heat, the right front burner was more melted from heat than the other three.

Remains of melted aluminum mesh were found on top of the right front burner grate (**Figure 8**). It was first thought that the remains consisted of the remains of aluminum filters from the range hood. By reconstructing the range hood position — and then using documentation techniques to determine if the filter material would drop onto the front burners or not — investigators determined this would not be the case (**Figure 9**).

The wife was interviewed again regarding the use of aluminum mesh screens for cooking. She indicated that the husband liked to cook jalapeno peppers stuffed with cream cheese and wrapped with bacon on the grill, using a small aluminum mesh screen. She did not recall seeing the husband ever use the stove for that purpose. The kitchen area was searched, and additional aluminum mesh screens of the type that the husband would use were found (**Figure 10**). When compared with the remains found on the right

Figure 8
Reconstructing the range hood.

Figure 9
Mesh found on right-front burner.

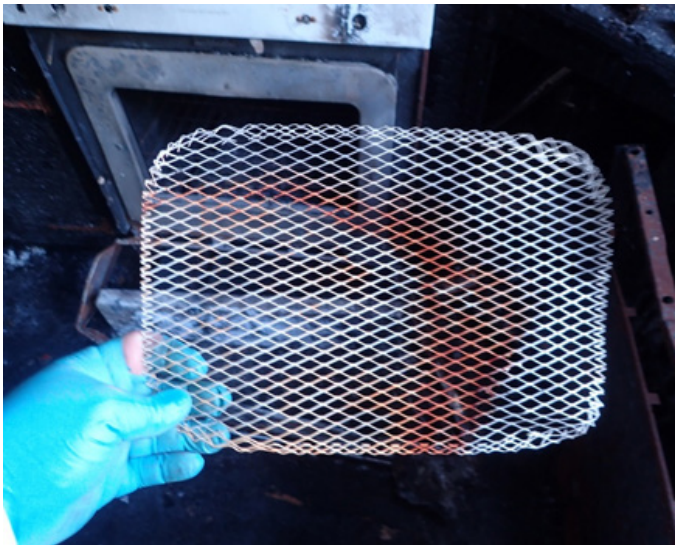

Figure 10
Exemplar mesh screen.

front burner grate, they matched.

Examination of the cooktop gas control valves revealed that all control valve stems (except one) were in the OFF position. The stem associated with the right-most gas valve control, which controlled the right front burner, was not in the OFF position. During the initial interview, the wife stated that when she had gone back to bed the husband was not cooking anything. As a result, examination efforts were then focused on determining if the valve was truly not OFF (due to it falling and physically being out of position).

The cooktop was raised so the gas valve positions could be compared. It was determined that the right-front gas valve was slightly dislodged from its installed position (**Figure 11**). Further comparing it with the remaining three gas valves revealed that when the gas valve was rotated back to its installed position, the gas valve stem would still have been in a position other than OFF. It was estimated that the burner was at a medium-high setting (**Figure 12**).

Based on the available data, it was determined that at some point the husband started cooking and fell asleep with the stove on with foodstuffs on the right front burner grate.

Summary

Based on the examination of the electrical system, it was determined that the fire was contained within the structure at the time the wife entered the garage. The fire first affected the electrical system within the structure prior to breaching the kitchen window and affecting the service entrance conductors. The location of electrical damage to the service entrance conductors indicated the fire first breached the window at the west side. The location of the arc site on the service conductors (combined with the results of the arc mapping in the kitchen) showed the fire originated at the west end of the kitchen. This enabled origin and cause investigators to use the available fire effects related to the range hood and stove to determine the point of origin and cause for the fire.

Figure 11
As-found position of the right-front burner control valve.

Figure 12
Estimated setting of the right-front burner control stem.

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