Incident Summary #II-1126869-2021 (#20405) (FINAL)

SUPPORTING INFORMATION	Incident Date		January 1, 2021
	Location		Chilliwack, BC
	Regulated industry sector		Electrical - Low voltage electrical system (30V to 750V)
	Impact – Injury	Qty injuries	0
		Injury description	N/A
		Injury rating	None
	Impact – Damage	Damage description	Damage consisted of blown potential transformers (PT's) used for instrument transformer metering in 600-volt services (See figure 2), a destroyed 100-amp main switch and 100-amp 600-volt utility meter (see figure 7 and 8), a destroyed 200-amp 600-volt utility meter (see figure 4), damage to several 347-volt high bay lights, ahand dryer, an overhead door operator, a main fire alarm panel, and a surge suppressor.
		Damage rating	Major
	Incident rating		Major
	Incident overview		A utility pole steel guy wire swung up after being cut free from a motor vehicle accident and shorted out high voltage overhead power lines. This created a massive voltage surge because of a phenomenon called ferroresonance. The massive voltage surge caused significant electrical damage to an event centre / fair ground facility, a golf course irrigation shed, and an operations / maintenance office building.
INVESTIGATION CONCLUSIONS	Site, system and components		The event centre / fair ground facility (See figure 1) consists of a main building that is used for events such as home and garden shows, circus's, motor cross racing, and other events similar in nature. On the exterior of the property is the fair grounds area including a grandstand, riding rings, barns, and other outbuildings used for events. Around the exterior of the buildings and the parking lot, there are 7 lockable enclosures about 8 feet long by 6 feet wide, referred to as kiosks. Each kiosk contains electrical equipment that provides power for exterior lighting, RV hook ups, food truck hook ups, the grandstands, and the riding rings. The electrical service to the facility is made up of: -Two utility pad mount transformers (PMT 1 and PMT 2), located to the east of the main building that are fed by underground high voltage cables that come from a utility pole located on the main road. -PMT 1 is a 500 KVA 14.4/25 kilovolt (KV) – 347/600-volt pad mount transformer. PMT 1 supplies the main building with an 800-amp 347/600-volt electrical service, and kiosk #1 with a 400 amp 347/600 volt electrical service. Kiosk #4 and kiosk #5 have 347/600-volt sub distribution equipment that is fed from kiosk #1. -PMT 2 is a 300 KVA 14.4/25 KV – 347/600-volt pad mount transformer. PMT 2 supplies kiosk # 2 with a 400-amp 347/600-volt electrical service, and kiosk #7 with a 200-amp 347/600-volt electrical service. Kiosk #3 and kiosk #6 have 347/600-volt sub distribution equipment that is fed from kiosk #2.

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	The operations / maintenance building (See figure 5) is located just under a kilometer east of the events centre / fairgrounds facility. The building is made up of offices, a workshop, and a works yard for storage of materials and vehicles. The electrical service to the building is made up of: -A 500 KVA 14.4/25 KV – 347/600-volt utility PMT, located on the north side of the building, fed by underground high voltage cables that come from a utility pole located on the main road. The PMT supplies the building with an 800-amp 347/600 volt service. The golf course (See figure 5 & 6) is located at the property adjacent to the municipal maintenance office building. The electrical service to the irrigation shed on the golf course is made up of: -Three 14.4/25 KV - 347/600-volt pole mount utility transformers, located adjacent to the irrigation shed. The transformers are fed from underground high voltage cables from a utility pole located on the main road. The three pole mount transformers supply overhead power to the 100-amp 347/600-volt service in the irrigation shed.
Failure scenario(s)	When the steel guy wire swung up from being hit by the car, it crossed the A and B phase conductors of the overhead utility high voltage lines. This caused a dead short across two phases that blew the A phase fuse. What happened next was an extreme voltage surge, or over voltage, due to ferroresonance. All the electrical services involved were being fed from an overhead 3 phase high voltage system with a portion of the system being underground. With the A phase disconnected, the services were only being fed from two phases, B phase and C phase. The B and C phase energized the disconnected A phase through induction with all three phases wound around the same core. The A phase circuit of the transformer then became a purely resistive and resonant circuit due to the capacitance of the underground cable coming into series with and cancelling out the inductance of core in the transformer. With little or no electrical load on the secondary side of the transformers, a voltage of up to 5 times the normal value most likely occurred on the de-energized leg of the 3-phase secondary system. This is what is referred to as ferroresonance. This over voltage caused major damage to the electrical systems in each of the facilities involved.
Facts and evidence	It was stated by the power utility that they are 95 percent sure that the cause of the voltage surge was a phenomenon called ferroresonance. Ferroresonance is a phenomenon that can cause extreme electrical equipment damage in some cases. -Ferroresonance can occur when the capacitance of an electrical circuit comes in series (resonance) with the inductance of an iron (ferro) core transformer. In an electrical circuit the inductance leads by 90 degrees, and the capacitance lags by 90-degrees. When the inductance and capacitance come into series with each other the circuit becomes resonant, or purely resistive with very little or no electrical loads present this resistance essentially becomes a short circuit and can cause much higher voltages than normal. -Long underground runs of high voltage cables can increase the severity of ferroresonance. -Lightly loaded electrical services can increase the severity of ferroresonance.

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-Ferroresonance can occur during loss of phase(s) of a three-phase transformer if the transformer is lightly loaded.
-During ferroresonance, the iron core of a transformer becomes saturated, and the result is an overvoltage situation that can cause up to five times the regular secondary system voltage.

Facts collected from power utility:

- A phase and B phase of the utility high voltage overhead lines were shorted out when the steel guy wire made contact with them.
- The A phase fuse dropped out, creating a loss of phase in the utility high voltage 3 phase system.
-The A phase lightening arrestors, which are rated for 18 KV, were blown. This is indicative of a spike in voltage.
-The events centre / fair grounds facility PMT's are fed from utility underground high voltage cables. Further determined that the underground run is approximately 750 feet long to PMT 1, and then approximately 350 feet to PMT 2.
-The operations / maintenance office building PMT is fed from utility underground high voltage cables. Further determined that the underground run is approximately 30 feet long.
-The golf course irrigation shed pole mount transformer bank is fed from utility underground high voltage cables. Further determined that the underground run is approximately 350 feet long.
-Pad mount 3 phase transformers are configured wye primary and wye secondary.
-Overhead 3 phase transformer bank is configured wye primary and wye secondary.
-The underground runs of high voltage cable acted as a capacitor.
-The iron cores of the transformers are inductors.

Facts collected from interview with electrician that oversees operations / maintenance building as well as event centre / fair grounds facility:

-The fair grounds facility had no electrical loads on the utility PMT 2 at the time of the event.
-The events centre / fair grounds facility had a small electrical load on PMT 1 at the time of the event.
-The operations / maintenance office building was unoccupied, and had very little electrical load on the utility PMT.

Facts collected from interview with owner of golf course:

-The golf course irrigation shed electrical service is not used in the wintertime, and therefore had zero electrical load on the three pole mount transformers, at the time of this incident.

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	Definitions **Counter electromotive force (EMF)** A transformer in its normal state acts as an inductor and resists or chokes the flow of current through its primary windings. This is referred to as counter electromotive force (EMF) and is by design to avoid the primary windings acting as a short circuit between the connected source voltage lines. **Inductor (inductance)** An electrical circuit element that opposes changes in current. Inductance is typically provided by a coil of wire. An example of an inductor is transformer windings. In a purely inductive circuit, the voltage leads the current by 90 degrees. **Transformer inductance** The utility pad mount transformers and pole mount transformer bank each have a common iron core that is shared by the primary and secondary transformer windings The iron cores of the transformers and the electrical conductors (windings) that wrap around them together comprise inductors. **Capacitor (capacitance)** An electrical circuit element that resists changes in voltage. Typically provided by two metallic plates separated by an insulator. An example of a capacitor is underground high voltage cables with a concentric neutral construction. In a purely capacitive circuit, the current leads the voltage by 90 degrees. **Concentric neutral cable capacitance** Underground high voltage cables are constructed with a concentric neutral meaning that there is an outer ring of conductor that is separated from the center conductor by a thick layer of insulation. The concentric neutral cables create capacitance due to the two conductors being separated by an insulator. (See figure 11) **Resonance** Occurs when the inductance of a circuit is equal to the capacitance and the circuit acts like a short circuit. **Ferroresonance** When there is enough capacitance in the de-energized transformer phase circuit(s) it can cancel out the inductance and the purely resistive/ resonant circuit acts like a short circuit. This phenomenon is referred to as Ferroresonance.
Causes and contributing factors	The incident was very likely caused by ferroresonance. Contributing factors to the occurrence of ferroresonance include: -Underground runs of capacitive high voltage cables, with greater damage where these runs are long distances. -Very little or no electrical loads on the pad mount, and pole mount transformers that feed the electrical services to all of the buildings / kiosks that sustained electrical damage.

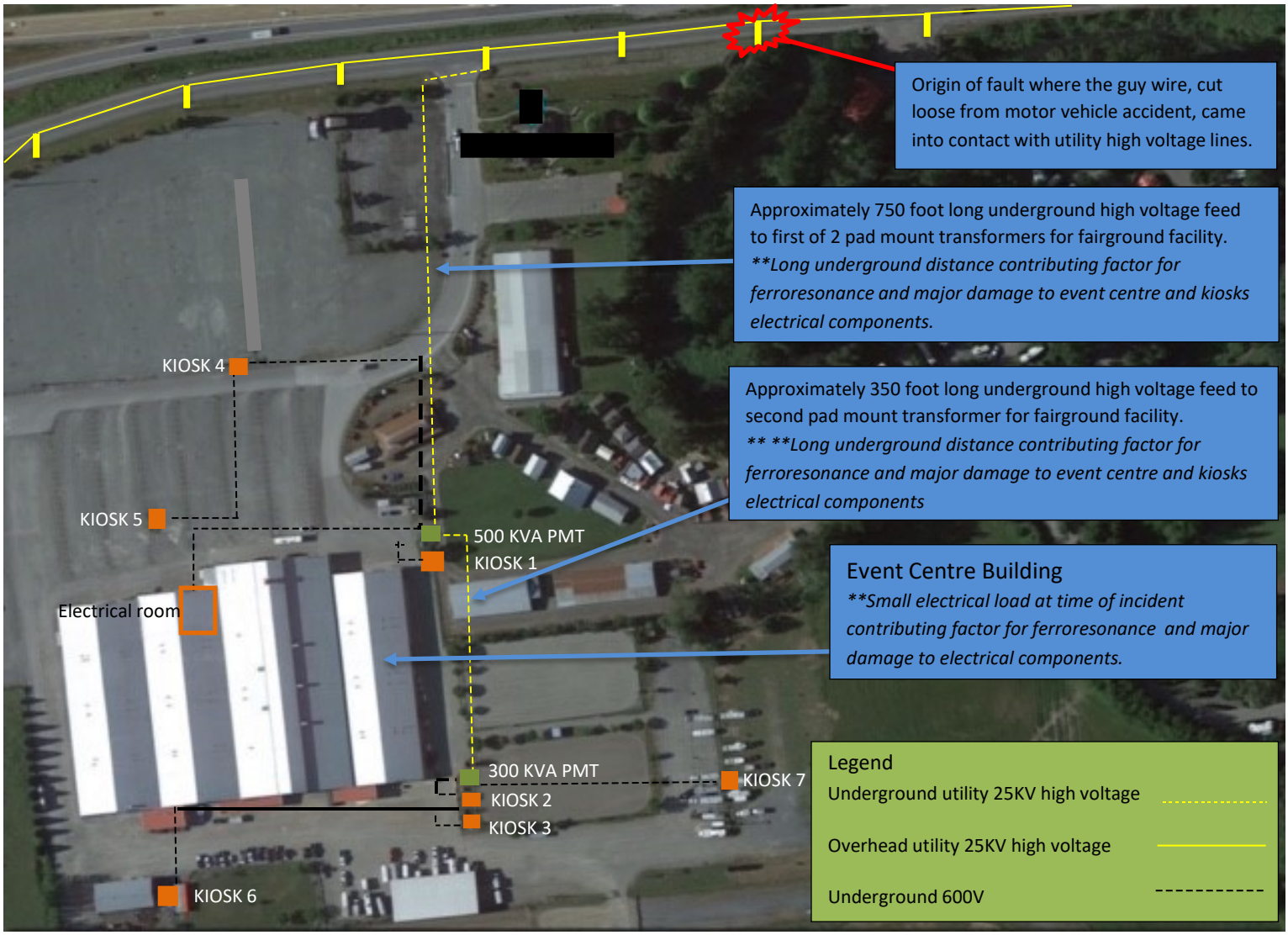
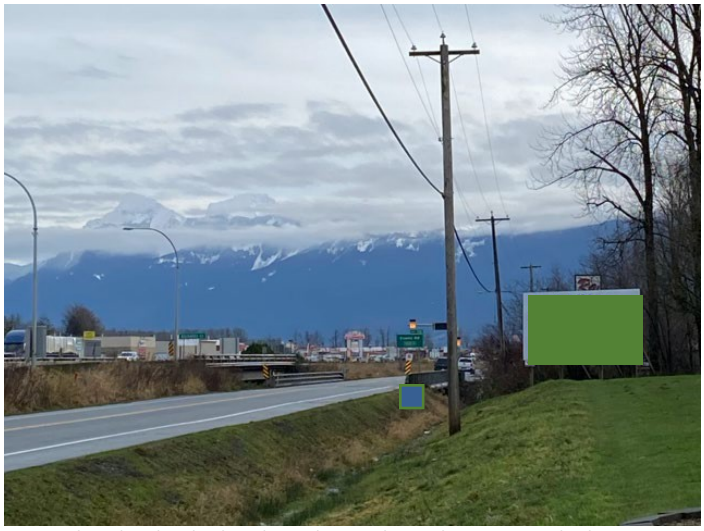
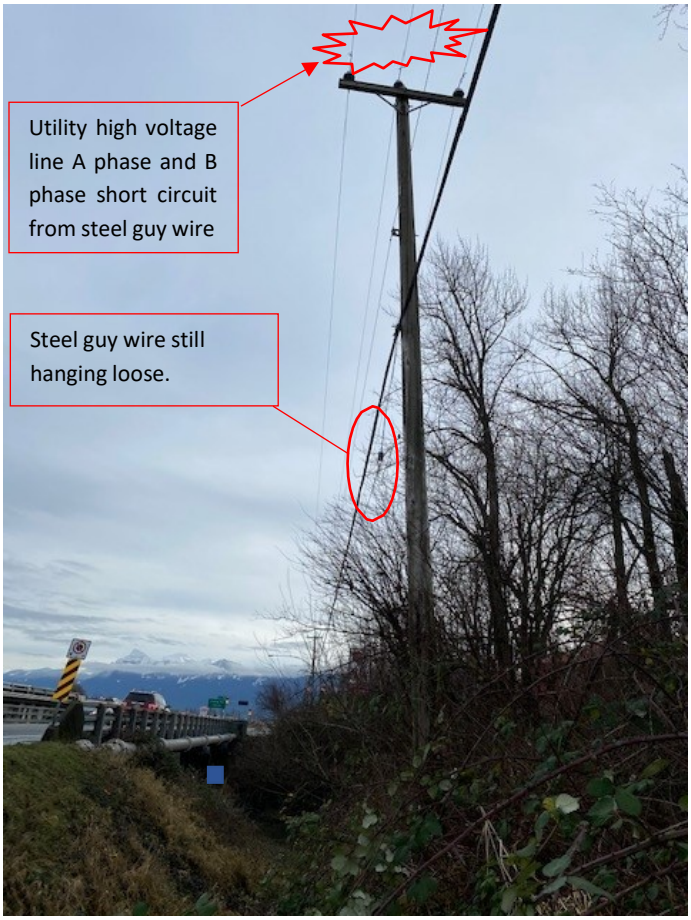


Figure 1 – Overhead view of Event centre building and fair ground facility showing contributing factors to ferroresonance



Overhead utility high voltage lines where the motor vehicle accident occurred.



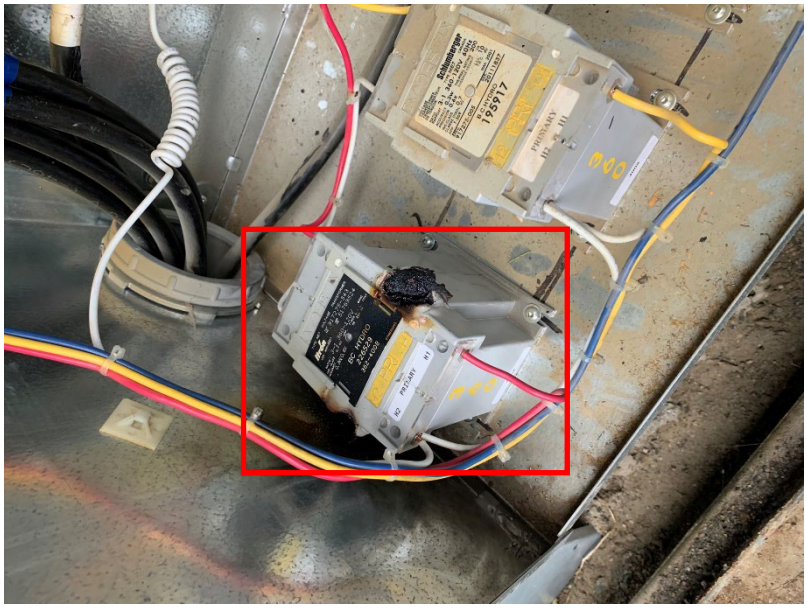
Close up of utility pole guy wire where it shorted out A phase and B phase of the overhead lines.

Motor vehicle left road and entered this ditch cutting the steel guy wire loose.

Figure 2 – Motor vehicle accident scene

300 KVA Pad mount transformer (PMT 2) and kiosks 2 and 3 at fair ground facility

Inside of one of the kiosks at fair ground facility



A phase damaged PT inside utility instrument metering cabinet

Figure 3 – Events centre / fairground facility electrical equipment

Figure 4 – Damage to 200 amp 600 volt meter enclosure inside Kiosk 7 at fair ground facility

Figure 5 – Overhead view of operations / maintenance building and golf course showing contributing factors to ferroresonance.

Utility high voltage lines to golf course irrigation shed service

High voltage lines go underground for approximately 350 feet across the operations center parking lot and come overhead to the irrigation shed.

Utility 3 phase transformer bank mounted to pole for golf course irrigation shed service

Figure 6 – Golf course irrigation shed 3 phase transformer bank fed from underground section of cable.

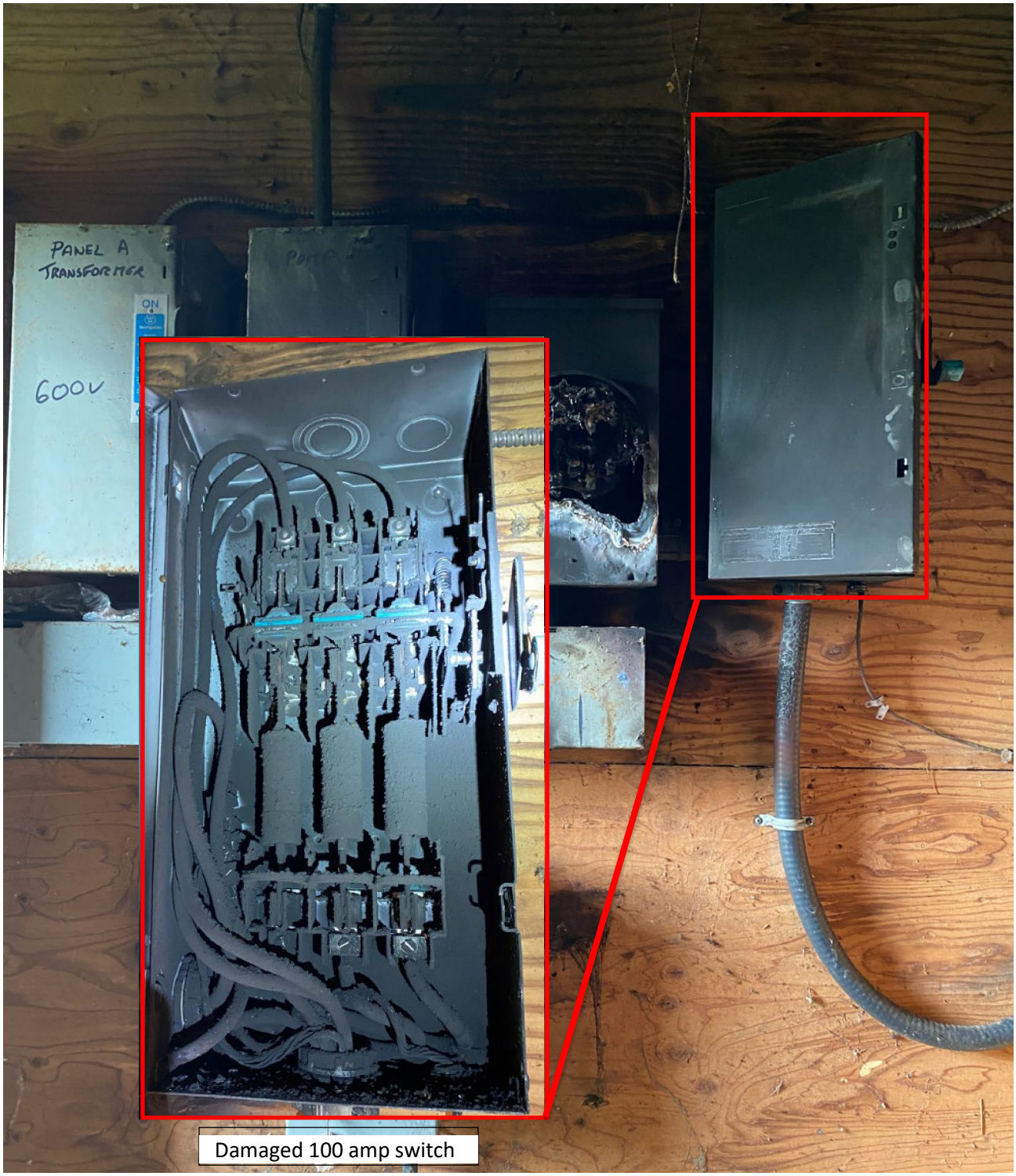


Figure 7 – Damage to golf course irrigation shed electrical equipment

Figure 8 – Damage to golf course irrigation shed electrical equipment

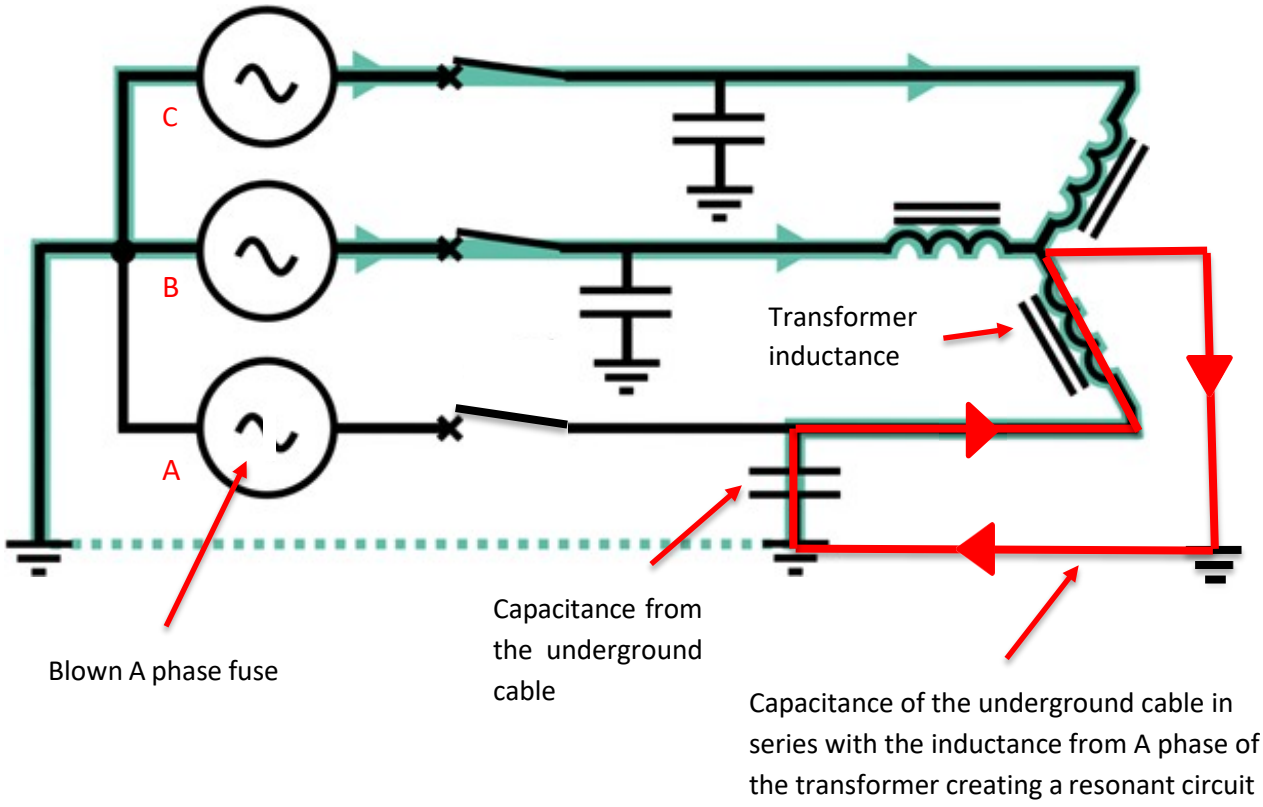


Figure 9 - 3 phase wye grounded transformer showing the ferroresonant circuit that was created in this incident. The A phase winding in the transformer became energized due to all three phases being wound around the same core and current being induced to the A phase from the. The capacitance of the underground cable and the inductance of the transformer cancelled each other out on the A phase. This left only a resistive circuit and the ferroresonace condition which can create voltages up to 5 times the normal value on the A phase secondary circuits of fed transformers.

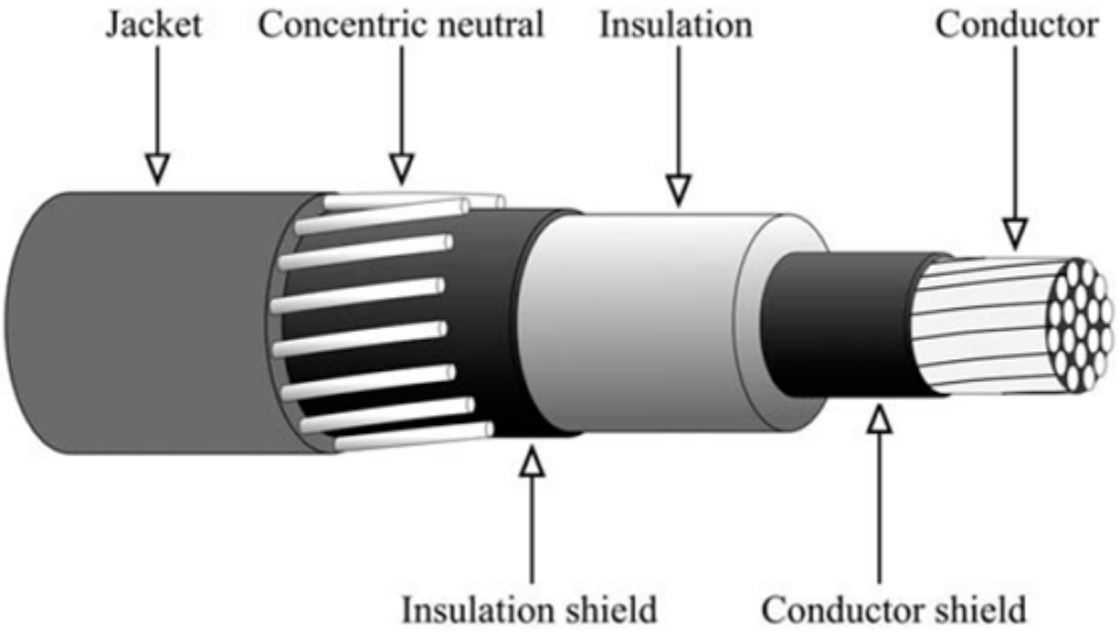


Figure 10 – The construction of a high voltage underground cable. Capacitance is built up between the outer concentric neutral and the inner conductor under normal operation.