Electrical Transformer Fire and Explosion Protection

By Jackson Bishop; Alonzo Rodriguez, P.E.;

Electrical transmission and distribution (T&D) systems are at the heart of every developing economy. Demand for electricity rapidly increases as a nation or country becomes more developed and industrialized.

Economies that are emerging or expanding such as China and India, as well as those in the Middle East and Latin America, are currently experiencing a period of rapid growth and expansion of their electrical T&D systems. According to Lloyd's of London the number of new transformers built around the world each year is less than 100 while manufacturers are weighed down by orders from these emerging economies, where new electrical grids are being built to cope with the demand for power.

Aging U.S. Transformers:

Growing concerns continue to surround the aging T&D systems in the United States. The electrical power system in the United States experienced its booming growth period beginning in the early to mid twentieth century, reaching a peak in 1973-1974, when enough new transformers, capable of handling 185 GVA (giga volt amperes) of electricity, went into service.

The transformers installed in the boom of the 1960's and 1970's are now over forty years old and are operating past their service life expectancy. Add to this the continually increasing operating stress that results from system growth driven load increases, and the potential for transformer failure becomes unavoidable.

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Why Transformers Fail:

Transformer failures occur for a variety of reasons including insulation deterioration, lightening, line surges, overloading, material failure, and oil contamination to name a few. According to an insurance sponsored study titled “Analysis of Transformer Failures” completed by HSB Inspection & Insurance Co., the number one cause for failure was the deterioration of aging insulation which accounted for 25% of transformer failures included in the study. NEMA, the National Electrical Manufacturers Association has recognized that the principle underlying cause of transformer failures involves breakdown of the insulation.

When Transformers Fail:

When a transformer does fail, the results are often catastrophic. If the failure was not caused by an existing fire, the potential for a new fire resulting from the failure is extremely high. A power substation by its nature contains all of the right ingredients to generate the perfect fire storm. A typical substation transformer bank is comprised of three or more transformer tanks, each containing up to 45,000 gallons of extremely flammable mineral oil. The ignition of the hot oil can come from any number of sources during a failure including internal component failure, solid particles of insulation and conductor produced by arcing fault, or short circuit forces or electrical arcing inside the tank which then generates heat and pressure sufficient to rupture the tank.

The Consequences of Fire:

Once a rupture has occurred, oxygen rushes into the tank and the oil explodes resulting in a blast of intense radiation scattering flaming oil, steel shrapnel, gaseous decomposition products, solid insulation, and molten conductor material out onto everything in the surrounding area. The effect of the explosion and radiation is instantaneous and has been documented to ignite neighboring transformers more than 60 feet from the initial fire. The temperature of an oil fire is in the range of 960°C to 1200°C. The duration of a power transformer fire ranges from 4 to 28 hours, which in most cases is the time it takes the fire to burn itself out. As larger substations are often located in outlying areas, response times from the local fire department can be lengthy. In addition, fire trucks are rarely equipped to suppress these supersized oil fires.

Assets Worth Protecting:

The cost to replace a large failed transformer can range from $2 to $4 Million per phase depending on transformer type. However major additional cost can result from damage or loss of nearby transformers, equipment, and property as well as the resulting service or business interruptions. Uncontained fires caused by transformer failure can quickly result in the partial or total loss of the entire electrical substation. Specific transformer failures are difficult to anticipate and prevent, however additional damage is preventable with the proper fire containment plan in place.

Fire Containment Planning:

Often, the best defense is a good offense. Anticipating and planning for transformer failure is the first step to minimize damage to other nearby transformers, equipment, structures and property.

Key Containment Strategies:

Transformer Fire Wall

A transformer firewall serves as a fire containment barrier between one oil-filled transformer and other neighboring transformers, building structures, and site equipment.

Effective transformer firewalls must be made from materials that can withstand the intense high temperature and long duration of transformer oil fires. They must also be designed such that both thermal and mechanical requirements are met before, during, and after the fire.

Projectile Blast Barrier

A projectile blast barrier having sufficient impact resistance to survive shrapnel impingement is also essential to protecting nearby assets. Fire caused by transformer failure may initiate an explosion, blasting projectiles such as steel fragments and porcelain up to 250’ or more into the surrounding areas. Such projectiles have been found embedded into transformers, equipment and office walls in nearby buildings. As there is yet no standards for firewall impact loading, experts in the fields of ballistics and explosives have recommended applying UL Standard 752. This is equivalent to a firewall panel stopping a 44 Magnum projectile with no through-penetration or spalling.

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Material Matters:

Traditionally, fire walls are built from reinforced concrete and/or concrete blocks. Concrete made with common Portland cement is limited to temperatures up to about 650°C. When Portland cement-type concrete is exposed to temperatures above 700°C, the cement becomes dehydrated and loses its structural integrity, retaining only about 35% of its room temperature strength. While some firewalls incorporate steel panels or columns, steel has practically no strength left at 650°C and the failure process will accelerate as the temperatures increase. Typical concrete fire walls and firewalls made with steel components would fail under the actual conditions of a transformer oil fire because these materials do not perform as needed under those high temperatures. For a transformer fire containment wall to be successful in real world conditions it must be made of a material that enables it to withstand the extreme temperatures of an oil fire having a working temperature of between 960°C and 1200°C for a minimum of four-hours, followed immediately by a high-pressure water jet blast. One such material is refractory concrete.

Refractory Concrete Ballistics Test

Refractory Concrete:

Refractory Concrete refers to concrete made with refractory materials. Refractories are heat resistant materials that have the ability to withstand sudden temperature changes, prolonged high temperatures as well as load and abrasive forces. High alumina cements and fireclay refractory materials such as crushed fire brick are commonly used as aggregate in refractory concretes. Depending on the mix, refractory concretes can embody and exhibit exceptional reversible thermal expansion properties. When materials are heated they expand, and as they cool they contract. The reversible thermal expansion properties of a material determine the strength and stability it has as it cools through the various phase transformations.

Refractory concrete is versatile in application and can either be cast in place or precast into relatively lightweight thermal panels and columns to create a stable, high performance fire containment wall that retains considerable strength at temperatures of up to 1300C (2372 F). Refractories emit no volatile organic compounds or hazardous material when exposed to prolonged high temperatures, and have been used for centuries to handle molten metal in foundries and smelters. Refractory concretes are designed to meet the thermal and mechanical requirements over the service life of an electrical substation.

Primary Transformer Fire Ignites Secondary Transformer

Installed Modular Refractory Concrete Firewall

Ideal Fire Protection:

Factors to be taken into account when considering transformer fire containment include the rapid, prolonged and extreme temperature phase transformations, the age of the T&D system, the sensitivity of the surrounding environment, and the explosive projectile blast potentials. Given these factors, the ideal transformer fire containment solution is a firewall and blast barrier that is manufactured using refractory concrete and will not only perform at the prolonged high temperatures typically found in an oil fire, but will simultaneously perform as a projectile blast barrier. While refractory concrete firewalls can be poured in place, precast refractory concrete offers several advantages and benefits over cast in place concrete. Cast in place concrete firewalls involve very extended cure times, labor intensive forming, and unreliable weather conditions that affect concrete mix quality. Precast refractory concrete firewalls are pre-manufactured in a controlled environment resulting in consistent mix quality, can be delivered and installed in one day, and are "in service" immediately with no cure time.

Understanding the potential for failure as well as the dangers and conditions present in an electrical transformer fire provides the tools for identifying the most effective fire containment solutions available to keep transformer fires in their place.

[3] Lloyd's of London 08-24-2010 *Transformers-A Risk to Keeping the Power On*
[4] William H. Bartley *Analysis of Transformer Failures* Presented at Stockholm, 2003

Refractory Concrete Firewall Test

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After completing this CES Module participants will have a better understanding of:

- Transformer Failures
- Transformer Fire Causes
- Effects of Transformer Fires
- Oil Fire Extremes
- Limits of Portland Cement
- Projectile Blast Barriers
- Refractory Concrete
- Transformer Fire Protection

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Continuing Education Series

Electrical Transformer Fire and Explosion Protection

Quiz Section

1. NEMA has recognized that the principle underlying cause of transformer failures involves breakdown of?

a) Coil Winding
b) Cooling Oil
c) Tank Lining
d) Insulation

2. Above 700°C, Portland Cement Concrete retains what approximate percentage of its strength?

a) 35%
b) 50%
c) 65%
d) 100%

3. Concrete made with common Portland cement is limited to temperatures up to **?**

a) 350°C
b) 650°C
c) 1000°C
d) 1200°C

4. Mineral Oil fires can have a four hour working temperature of between **?**

a) 1000°F -1200°F
b) 350°C -650°C
c) 650°C -700°C
d) 960°C -1200°C

5. The growth and expansion of the U.S. Electrical Power System reached a peak in **?**

a) 1923-1924
b) 1953-1954
c) 1973-1974
d) 1993-1994

6. Refractory concrete retains considerable strength at temperatures of up to **?**

a) 650C
b) 700C
c) 1000C
d) 1300C

7. According to Lloyd's of London the number of new transformers built world wide each year is less than?

a) 10
b) 100
c) 500
d) 1000

8. Transformer failure may initiate an explosion, blasting projectiles such as steel and porcelain up to **?**

a) 50'
b) 100'
c) 150'
d) 250'

9. eThe UL Standard equivalent to a fire wall stopping a 44 Magnum projectile with no through-penetration**:**

a) UL 365
b) UL 552
c) UL 752
d) UL 852

10. Refractories are heat resistant materials that have the ability to withstand:

a) Sudden temperature changes
b) Prolonged high temperatures
c) Load and abrasive forces
d) All of the above

CUT ALONG DOTTED LINE

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Answer Section

Instructions: For each question above select the correct answer and circle the corresponding letter below.

1)	a	b	c	d
2)	a	b	c	d
3)	a	b	c	d
4)	a	b	c	d
5)	a	b	c	d
6)	a	b	c	d
7)	a	b	c	d
8)	a	b	c	d
9)	a	b	c	d
10)	a	b	c	d

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