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The Boundary of Restoration

Replacement Considerations for Dry-Type Transformers and Open-Frame Motors in a Post-Loss Environment

Executive Summary

In the aftermath of a fire, the deployment of specialized decontamination professionals is one of the most effective strategies for preserving complex machinery. By utilizing precision methodologies, they can frequently arrest corrosion and restore multimillion-dollar systems to their pre-loss condition. However, successful restoration requires a surgical approach and a firm recognition of the physical limitations of specific components. Dry-type electrical transformers, each consisting of a laminated magnetic core, wrapped coil windings, and exposed terminal connections, are among the most contamination-vulnerable components in these complex systems. Open-frame motors with exposed internal windings present similar restoration boundaries, particularly when contamination reaches winding and insulation interfaces that are not economically recoverable in the post-loss environment.



Dry-type electrical transformers, each consisting of a laminated magnetic core, wrapped coil windings, and exposed terminal connections with labeled primary, secondary, and auxiliary taps.

The Anatomy of Vulnerability

To understand why field cleaning fails on these specific components, we must begin with their construction. Dry-type control transformers of this class are open-ventilated assemblies with laminated magnetic cores, densely wound coils, and exposed primary, secondary, and auxiliary terminations. They are not sealed or hermetically isolated from the environment. As a result, their winding insulation systems, including paper barriers and varnish-coated conductors, remain directly susceptible to soot intrusion, contaminant embedment, and dielectric compromise. Crucially, the microscopic layers of copper conductor are separated only by specialized high-temperature insulating paper and thin varnish films. This insulation system provides the dielectric strength required to withstand voltage stress safely.

When equipment is exposed to smoke, soot deposited on these windings cannot be assumed harmless. NEMA GD 2-2021, published as a NEMA white paper rather than a consensus standard, states that smoke and soot

from burning materials can be particularly damaging because the residue may be corrosive and conductive [9]. Depending on the materials consumed and the conditions of combustion, the deposited residue may contain corrosive byproducts capable of damaging metal surfaces and impairing insulation performance [1]. Even apart from its chemistry, contamination lodged within densely wound, inaccessible assemblies may remain difficult to evaluate and remove reliably. This in turn raises legitimate concerns regarding the component's future reliability. This point should be understood as part of a broader engineering analysis, not as a substitute for independent testing, OEM guidance, or site-specific judgment.

The Physics of Conductive Particulate on Solid Dielectrics

The threat posed by combustion by-products is a fundamental alteration of the component's electrical field. While often studied in ultra-high voltage environments, the underlying materials science principles remain universal. Peer-reviewed research demonstrates that the adsorption of conductive micron-nano dust onto solid insulator surfaces causes intense, localized electric field distortion [2]. This distortion is catastrophic for densely packed windings. Engineering analyses of medium-voltage rotating machines confirm that when conductive contaminants accumulate on varnished windings, they create an active leakage path [3]. This leads to electrical tracking, a progressive degradation of the insulation surface that ultimately results in a short circuit. Over time, this continuous partial discharge erodes the insulation layer. The literature confirms that winding insulation degradation (specifically inter-turn short circuits) is a highly common mechanism for transformer failure [4]. When exposed to fire byproducts, this baseline aging process is vastly compounded by accelerated thermal degradation and surface contamination, both of which actively create conducting paths across the winding surfaces [3].



Open-frame electric motor with a vented housing, exposed internal windings, and multiple external lead conductors.

The Fallacy of Air Pressure and Aqueous Intervention

When a technician attempts to clean a dry-type transformer or open-frame motor using compressed air, the procedure is not equivalent to controlled decontamination. Rather than extracting embedded contamination, compressed air may remove only loose surface debris while driving fine soot and combustion residue deeper into the winding structure, insulation system, and other inaccessible internal spaces. Recognizing the risk of damaging or inadequately cleaning winding assemblies, engineering standards limit the manner in which compressed air may be used. The IEEE Recommended Practice for Installation, Application, Operation, and Maintenance of Dry-Type Distribution and Power Transformers (IEEE Std C57.94-2015) is directly applicable and provides that compressed air used for cleaning should be applied at relatively low pressure, not over 25 psi [5]. This 25 psi threshold is not merely theoretical; it is universally echoed by major equipment manufacturers. For instance, Hammond Power Solutions explicitly instructs in their maintenance documentation that a vacuum should be used first, followed only by compressed air limited to 25 psi [6]. This is further corroborated by federal maintenance manuals, which similarly restrict air pressure to 20 to 25 psi specifically to avoid embedding small particles into the insulation matrix [7]. Standard shop air typically operates at pressures far above the 20 to 25 psi limits described in maintenance guidance, increasing the likelihood that fine contaminants will be driven deeper into winding and insulation interfaces.

Furthermore, liquid-based cleaning of these specific components presents its own hazards. Original equipment manufacturers warn against the use of liquid cleaners on dry-type transformers because such agents can adversely affect winding insulation materials [6]. That concern is specific to the construction at issue here. Unlike rigid, non-porous insulators used in other classes of electrical equipment, dry-type transformers and open-frame motors rely on layered winding insulation systems, including paper and varnish, within densely packed conductor assemblies. In our engineering judgment, when those materials are exposed to aqueous or solvent-based cleaning, they may absorb liquid or dissolved contaminants into internal spaces. These spaces cannot be reliably inspected or dried in the field, creating a risk of residual contamination and long-term dielectric degradation.

The Industry Consensus and the Servicing Distinction

For this equipment category, NEMA GD 2-2021, Evaluating Fire- and Heat-Damaged Electrical Equipment, provides unfavorable guidance toward restoration. Although GD 2-2021 is a white paper rather than a NEMA standard, its Table 1 places all dry-type transformers, regardless of kVA rating, and all dry-type control circuit transformers in the "replace equipment" column after fire- and heat-related exposure [8, 9]. The point must be emphasized: this is NEMA's published white paper guidance for that category of equipment, not a codified consensus standard and not a substitute for independent engineering analysis. Following this guidance for highly vulnerable sub-components does not diminish the value of decontamination for the broader machine. It is vital to distinguish between a component for which reconditioning is prohibited and one that merely requires normal servicing. Assemblies with accessible, non-porous surfaces are prime candidates for normal servicing. However, when a component relies on porous paper insulation and tightly spooled, inaccessible windings, superficial cleaning is scientifically insufficient, and restoration may cease to be technically verifiable or economically justified.

Expanding the Boundary: Distribution Components and Wiring Devices

While dry-type transformers and open-frame motors illustrate the limitations of decontamination in large machinery, the broader electrical distribution system contains its own array of equally vulnerable devices. In evaluating a post-loss environment, the objective is to return the facility to a condition consistent with safe and reliable operation. That analysis requires acknowledging that certain ubiquitous components are not cost-effective to restore after exposure to smoke, soot, or thermal stress.

Molded-case circuit breakers (MCCBs) are a primary example. These devices rely on precisely calibrated internal mechanisms, thermal-magnetic trip units, and factory-applied lubrication to perform as intended. Because MCCBs are comparatively low-cost components, the labor required to disassemble, clean, evaluate, test, document, and reinstall them after exposure to smoke, soot, or thermal stress often exceeds the cost of replacement. For that reason, they are generally not cost-effective to restore.

The same practical limitation applies to standard low-voltage fuses. Although simple in appearance, fuses are inexpensive, sealed components whose value does not justify the effort required for exhaustive decontamination and post-cleaning verification. In most post-loss settings, replacement is the more economical and technically appropriate outcome.

A similar cost analysis applies to ground-fault circuit interrupters (GFCIs), arc-fault circuit interrupters (AFCIs), surge protective devices (SPDs), and other common wiring devices. These components are widely used throughout modern electrical systems, yet their relatively low unit cost makes comprehensive restoration difficult to justify economically after smoke, soot, or thermal exposure. The same is true of standard receptacles, switches, and similar devices. The issue is not that restoration is inconceivable in theory, but that the time, labor, and documentation required to perform it properly are often disproportionate to the value of the component itself. In these cases, replacement is typically the more practical and cost-effective course.

Recognizing these boundaries does not diminish the value of specialized restoration. Rather, it helps define it. By identifying which components can be reasonably restored and which are more economically replaced, the overall recovery effort remains technically sound, financially rational, and aligned with the goal of returning the facility to service efficiently.

The Economics of Certainty

In a post-loss environment, the objective is to return the facility to service in a safe and efficient manner. Attempting to reverse-engineer, de-spool, chemically clean, re-wind, and recertify a dry-type transformer or a small open-frame motor is often far more expensive than replacement. A similar cost imbalance exists for many smaller distribution and wiring devices, where the labor necessary to decontaminate, evaluate, test, and document the component can exceed its replacement value. By directing restoration resources toward the larger machine structure, while replacing selected low-cost components that do not lend themselves to economical restoration, the overall approach preserves the larger asset and supports a practical return to reliable operation.

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