Root Cause Analysis of Collector Ring Fires In Power generators

Flashover definition

In this paper we draw attention to a specific type of flashover, collector ring fires. The textbook definition of a 'flashover' is defined as any undesired current path from a point of differing potential to ground or between polarities. Explosive flashovers occur when sufficient combustible gas develops from arcing or from gases given off from the heating of combustible materials or from insulation failure.

Components and Their Functions within the Excitation System

The collector ring brush and brush rigging part of the system of a generator has the primary function of transmitting DC power through the main field of the rotor of the generator. This system energizes or 'excites' the field winding on the generator's rotor. Following, we will look at the function of each component.

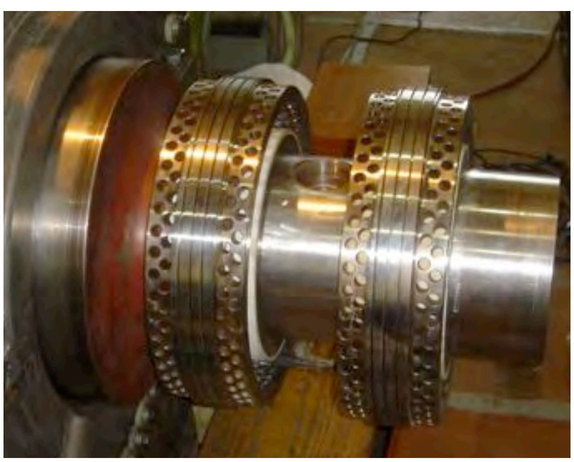


Figure 1: Collector Rings

The collector rings in a generator (also referred to as slip rings) are used to 'collect' the energy from the stationary part of the circuit and transfer it through the rotating part of the circuit into the rotor and then back out completing the circuit. Collector rings in power generators are most commonly made from heat-treated steel forgings that are shrunk fit over an insulated sleeve(s) onto the generator's main rotor shaft. They may also incorporate a steel insulated hub that is shrunk onto the shaft before the rings (Figure 1).

Graphite brushes are then used in the circuit to transfer electrical energy from the stationary part of the circuit to the rotating part (Figure 2). Graphite brushes are used not only because of their conductive properties, but because graphite is also an excellent lubricant.

Figure 2: Graphite Collector Ring Brush

As a result of using graphite brushes, graphite along with moisture and oxides are deposited onto the surface of the collector ring creating a thin film that is technically called patina. This film allows the transfer of the electrical energy through it to the collector rings. Through this film DC Current is carried to the ring. The thin film that forms is critical to ensure a good connection because of the low friction between the brush and the film.

The brush rigging in the excitation system is comprised of various components (Figure 3). Its primary function is to keep the brush in constant contact with the collector rings. The brush holder is the primary component within the brush rigging that accomplishes this important function. If you have sufficient pressure of the brush against the ring with no restrictions of brush movement, the system will work.

Each generator OEM design utilizes a unique brush rigging system, but the function and fundamental principle of operation is always the same.

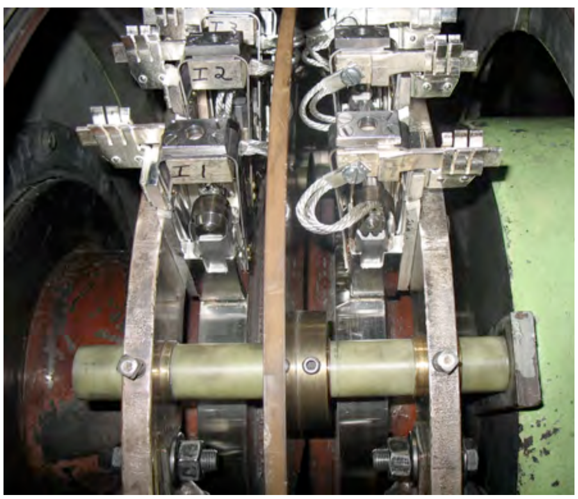


Figure 3: Example of Brush Rigging

Collector Ring Fires

The generator collector ring fire that occurs is a specific type of catastrophic failure of components that does not usually involve an explosion (Figure 4). These failures in most instances result in an unscheduled outage with an extended down time to restore the generator back to full operation. In this paper we will discuss the sequence the damage to each area must occur in revealing the root cause.

Figure 4: Effects of a Collector Ring Fire

The root cause of a collector ring fire usually is not properly understood and rarely diagnosed correctly. In fact, many instances where collector ring fires have occurred, the investigation into the root causes often leads to erroneous conclusions as the timing sequence is not understood or considered. This leaves an increased risk that another fire may occur as proper corrective actions have not taken place to prevent it.

After a collector ring fire, it can be difficult to visually determine what occurred first due to the extent of damage typically sustained if the time sequence is not understood.

Progression of a Collector Ring Fire

Every collector ring fire that has occurred in the industry started as a result of several brushes losing proper electrical connection with the ring. This begins with minor arcing that increases over a period of time that ultimately can result in a collector ring fire.

During this fire the air can be funneled to a specific point as the brush rigging and ring compartment deflects it. If that funneled air hits an area that is arcing the added oxygen acts like a blowtorch melting the metal or burning the insulation in that area. The burnt metal in this area will leave a molten or 'flowing' surface to it. (Figure 5)

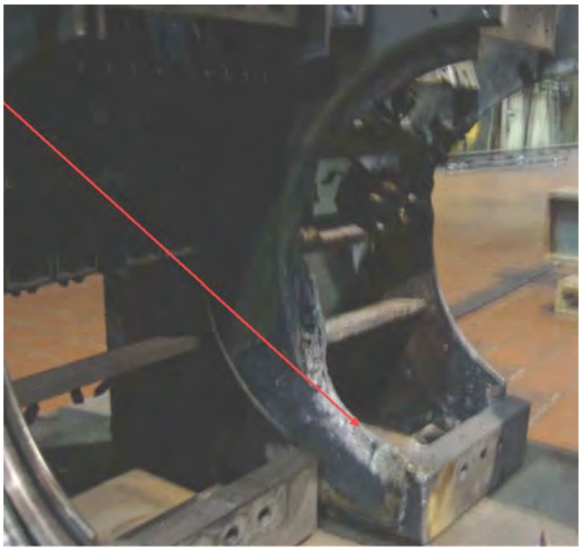


Figure 5: Flowing metal appearance

The reason the metal flows is because the burning takes place over a period of time. It is not an explosion. This effect typically misleads people in determining the root cause, as it appears to be the hottest spot. It is then assumed that the hottest spot is the source of the ring fire.

In fact, while investigating one recent fire, the initial point of failure was thought to be the terminal leads (Figure 6). Upon inspection it did appear that this area or region did have high temperatures, but understanding the torch effect and steps of failure in a collector ring fire, it became obvious from further inspection of the site and components that the source started with the loss of connection between the brush and collector ring of multiple brushes. When enough arcing is present a ring of fire will form all around the ring.

Figure 6: Burned area from the Torch Effect

The torch effect can also be misleading because the temperatures reached during a collector ring fire can be in excess of 930 °F (500 °C). As a result of this heat and airflow, it is very typical to see entire brush boxes melted away after a collector ring fire (Figure 7).

Figure 7: Molten Brush Holders

In some ring fires a secondary flashover (which would be a flashover caused by the ionizing of the air from the arcing or insulation failure) can take place, which is an instantaneous explosive type action with a phase-to-phase flashover or second ground being developed after a first ground has developed. The first ground won't create a flashover. The appearance of the damaged area in this type of flash over looks more like a "gouge" as opposed to flowing metal.

When both of these two appearances are present the ring fire with the flowing look MUST BE the cause because it takes time to develop. The explosive damage is instantaneous and cannot be followed by the ring fire that takes time to develop. The secondary flashover again most likely developed from the ionized conductive air or insulation breakdown as a result of the progressing ring fire.

Causes of Collector Ring Fires

Before listing the causes related to the components there are two problems that can be blamed to maintenance practices. The first maintenance error is letting the brushes get so short they no longer have a sufficient spring force to maintain the brush to ring connection. The second maintenance error is not positioning the brush leads correctly so that they come in contact with the top edge of the brush box, restricting the brush movement. Without positioning them correctly they can also come in contact with the constant force spring, which can cut the brush lead off.

The one component in the excitation system that has the most impact on this issue is the brush holder. We will next look at the various causes of ring fires that are associated with brush holder design and maintenance.

The number one common cause of ring fires is carbon deposits within the brush holder. These carbon deposits form over time within the holder and eventually prevent the brush from maintaining contact with the collector ring and can actually lock the brush in the holder (Figure 8 & 9).

Figure 8: Carbon Deposits, Plated Holder

Figure 9: Carbon Deposits, Un-plated Holders

Carbon deposits are definitely the most common problem that leads to ring fires but many times they are overlooked because they are small or because the brush can still be moved quite easily in the holder. It is thought that by exercising the brushes periodically they are not restricted, however, that is not the case. The side pressure from the ring rotation and the side pressure from a constant force spring will restrict the free movement of the brush and cause low spots to develop in the ring surface by electrical erosion from the arcing under the brush. The arcing is of course caused by the poor connection due to the brush restriction. One good way to easily check to see if there are brush movement restrictions from carbon deposits is to inspect the sides of the brush.

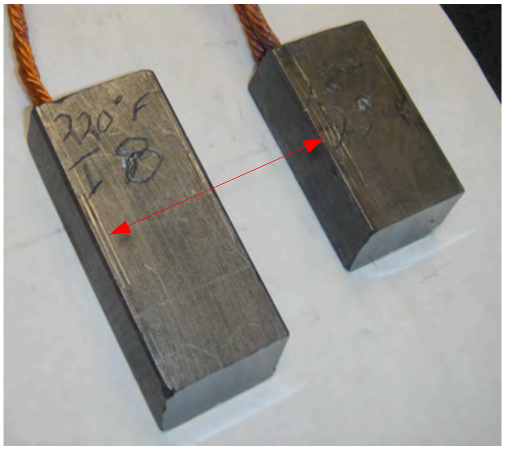
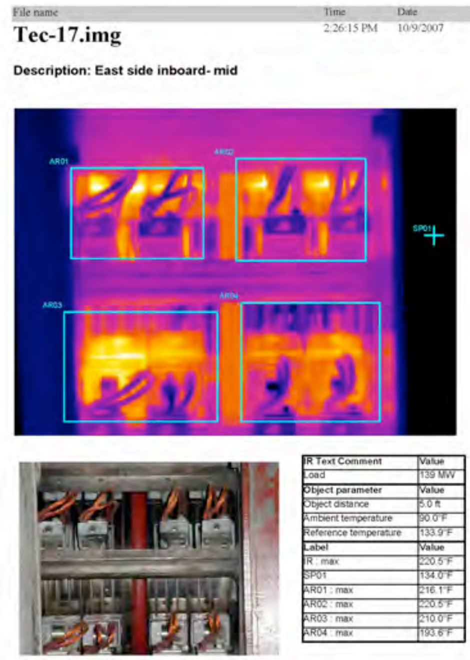


Figure 10: Carbon Deposit marks

In this photo (Figure 10) the carbon deposit marks were very evident in the brushes but the customer was distracted from this fact by the deceiving hot colors in the photos of thermal imaging (Figure 11). They believed that the high temperature was causing low spots to develop in the rings causing them to go out of round. Look again at the Figure 8A, there is no discoloration of the brush lead. The actual cause was the carbon deposits. The rings in this case needed truing every nine months from these deposit formations. These deposits formed on new bronze holders even though they had been plated.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Reference temperature	133.9°F
Label	**Value**
IR : max	220.5°F
SP01	134.0°F
AR01 : max	216.1°F
AR02 : max	220.5°F
AR03 : max	210.0°F
AR04 : max	193.6°F

Figure 11: Thermal imaging distraction

The second most common cause of ring fires is Brush Binding. Most Brush Binding is a result of the use of brush holders shorter than the brush, in holders using constant pressure springs. The springs exert side or lateral forces on the brush. This side force then causes the brush to bind on the top edge of the brush box opposite the spring clip side(Figure 12).

Figure 12: Example of Brush Binding

Carbon deposits form at pressure points so this binding of the brush in the holder increases the possibility of carbon deposits, which also increase the potential of the brush losing contact with the collector ring.

Figure 13: Plastic slides to control binding

Some holders are designed with a plastic guide that slides on a steel plate (Figure 13) to control the side pressure of the spring. This works well for a while until dirt gets embedded in the plastic creating yet another spring pressure restriction.

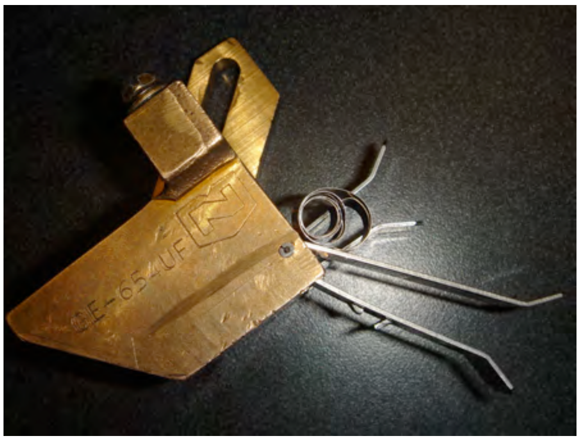

Figure 14: Severe Worn/Fatigued Spring

The third most common cause of the brush losing contact with the collector ring is low spring pressure (Figure 14 and 15). As the spring ages over time, it loses its tension and prevents the brush from making good contact with the collector ring. The springs also can weaken over time from conducting electricity or they can fail to work from fatigue. In some instances they can even crack, resulting in the brush failing to maintain contact with the collector ring. If during brush maintenance the spring is pulled up and bent backward the tension of the spring is also decreased.

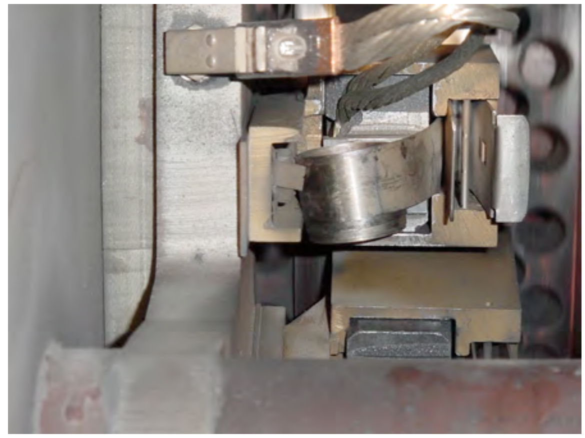

Figure 15: Low Spring Tension

The fourth most common cause is a poor terminal connection that results in a brush dropping out of the circuit, which reduces the number of brushes carrying current. This is typically evidenced by a discolored lead (shunt), <u>at the terminal end</u> indicating that a high resistance terminal connection has created enough heat to discolor the lead (Figure 16).

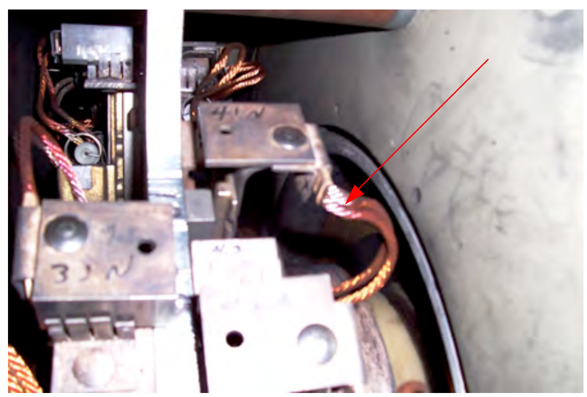

Figure 16: Poor Terminal Connection

A poor terminal connection in bronze or brass holders can also result in the current flowing through the brush box instead of the brush lead. The result is electrical erosion of the brush box due to arcing. This electrical eroding then creates a rough surface that causes brush movement restriction and the brush loses its connection to the collector ring (Figure 17).

Figure 17: Brush Box Erosion

Contamination as a Cause

Another contributor to collector ring fires is air contamination. Dirt and oil in the air in excess can cause the brush to ring contact to degrade as contaminates collect under the brush surface. This then leads to arcing and the progression toward a ring fire begins.

Another form of contamination is the introduction of a foreign object. A dropped tool or object can wedge itself into the brush rigging and apply plastic or other material to the surface of the ring. This creates an insulated barrier between the brush and collector ring causing a ring fire. For example: A dropped penlight, made of aluminum, could coat the ring causing a rough surface that could start arcing.

Selective Action as a Cause

Current readings on a brush will continually vary and sometimes by a significant amount. You will find some brushes consistently lower than others and some always higher than others. This is not a problem. One of the unique characteristics of carbon is that as the temperature of carbon increases, its electrical resistivity decreases. Most materials, including copper, have the opposite reaction to increased temperature. This is important in understanding selective action. The term "selective action" is used to describe an extreme movement of current load from one brush in the same circuit in relation to another. As one brush heats up from friction and current, the carbon becomes a better conductor. Under certain conditions this continues until the copper gets too hot and resists the current flow. At this point another brush that may have been carrying very little current becomes the better path.

This cycle in resistivity causes a chain reaction of dropping more brushes out of the circuit. Brushes begin to arc as the functioning ones are now overloaded and rapidly degrade. This scenario can increase to the point that eventually the energy starts arcing from the ring to the holders as the air is ionized from the arcing. Eventually it can arc to ground or to the opposite polarity causing a catastrophic explosion type failure. The voltage regulator senses the unstable current and reacts to the demand to maintain generator terminal voltage. In many instances the result is a generator trip due to exceeding maximum excitation limits. If the condition is sustained, the damage can be severe enough to open the circuit resulting in a loss of field trip

For an example of the sequence that could take place, in your mind look at a GE 7F generator that has the cooling air coming up from the bottom against the rings. Lets say the air coming in got contaminated by an oil leak and the face of the brushes took on a build up of the contamination. The lower brushes would pick up the contamination first and start dropping out of the circuit. As this progressed the top brushes, which weren't contaminated, would continually be carrying more of the current until the leads couldn't carry any more. Eventually that lead would burn off and the next best connection would start taking the current until its lead failed and so on down back to the bottom brushes. As brushes keep coming out of the circuit the arcing keeps increasing and the current path starts jumping from the holders direct to the ring, burning up the holders. The air blowing around in the compartment starts burning other parts like a blowtorch as the air "fans" the electrical fire (Figure 18).

Figure 18: Indication of Selective Action due to Lead Discoloration

This progression can literally vary from a matter of months (with rapid deterioration at the end) to minutes. Therefore it is important that when inspecting a generator, to look for indications that selective action may have occurred. If there is indication that selective action has taken place (Figure 19), proper actions can often be taken to prevent the potential of a collector ring fire.

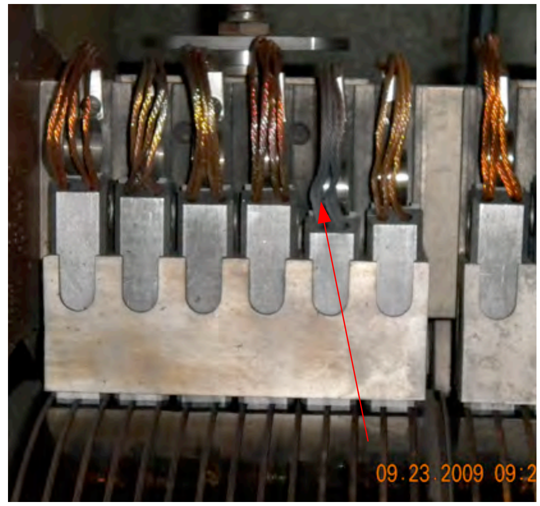

Figure 19: Black Lead indicates Selective Action has occurred

One sure way that selective action will occur is if the ring wears down enough that the helical groove disappears. A practice of measuring and recording the depth of the groove every time the unit is down should be adopted. It should be re-grooved by .035" depth (Figure 20).

Figure 20: Ring Re-Grooving (Cutsforth Inc. Patented process)

Other contributors to selective action would include uneven spring pressure and excessive variation in brush length.

Any one or combination of the previously listed causes will eventually result in the loss of brush to collector ring contact. In turn, the brushes begin to arc. The arc causes the rings go out of round as it electrically erodes the rings as the brush leaves the surface. More arcing ensues and the progression toward a catastrophic ring fire is well under way.

Warning Signs

As previously mentioned one of the early signs of problems is the presence of visible **arcing**. Arcing typically progresses slowly from small trailing pinpoints {that are hard to see unless in the dark) to significant arcing around all edges of the brush. Visual inspection of all brushes, if possible, is important in order to see the early sign of arcing. Arcing is the indicator of some problem it is not the cause.

Another early warning is the presence of **photographing** (also called foot printing or ghosting) on the ring surface (Figure 21).

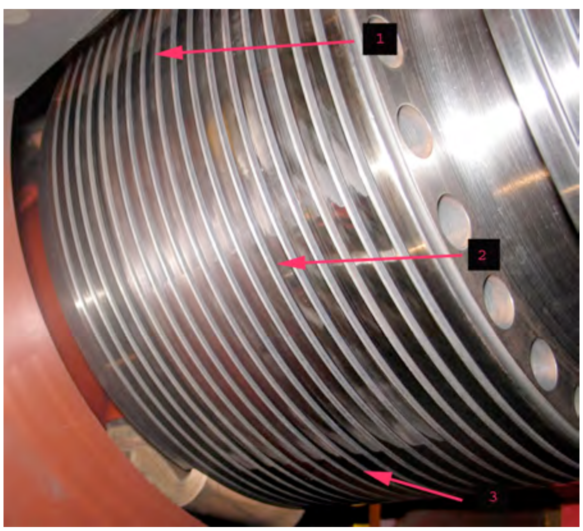

Figure 21 Ring photographing

This condition can develop on a ring that is very smooth if there are stuck or restricted brushes present. Some units are very prone to photographing. It can show up within days on a freshly ground ring, even with new holders. A ring with low spots does not cause photographing but if left it will develop lifting of the brushes and will make the rings develop low spots.

Figure 22 Truing GE 900 MW Rings

Load spikes and air contamination are also causes of photographing. The important thing is to immediately re-surface, “true”, the ring on-line (Figure 22). Inspect for deposits, eroded brush holders, spring problems, brush lead restrictions or brush binding from brushes being pushed against the top of the holder by the constant force spring on units that have a brush longer than the holder.

Discolored leads are the best visual check for presence of **Selective Action**. As previously shown in figure 19, discolored leads can be easily recognized as the copper discolors from excessive over heating. Taking an amp reading of the individual brushes can show the immediate degree of selective action as well.

Another sign would be increased **brush vibration** or movement. This is typically measured with an insulated probe, attached to a vibration analyzer.

There was an instance in Memphis where brush vibrations were up to 60 mils displacement with no visible arcing. Also looking at the ring with a strobe light did not show any photograph marks or discoloring of the ring but as truing of the rings was performed the low spots became very evident. The alarm for this plant was noticing that their brush springs were breaking. This unit was very close to a ring fire but there was very little visible evidence of the problem other than the brush movement.

As more and more brushes lose contact with the collector ring, the risk of a collector ring fire dramatically increases, jeopardizing operational reliability, operator safety, and ultimately component failure as a result of selective action.

Ways to prevent Collector Ring Fires

There are two ways to prevent collector ring fires. One is to keep brushes from losing contact with the collector rings and the second is maintaining sufficient groove depth of the spiral (helical) groove in the ring.

This can be accomplished by preventing the problems already mentioned; carbon deposits, brush binding, low spring tension, poor terminal connections, short brushes, poorly adjusted lead positioning and contaminated air.

Eliminate carbon deposits (which are the protruding bumps of carbon that attach to the inside of the brush box wall) to prevent the brush from being held up or movement restricted in the holder. This can be accomplished during down periods but is difficult for most holder designs while the generator is in operation.

Another problem is that carbon deposits develop very quickly back at the same spot where they were removed. These deposits can form in hours rather than days. The deposits may be thought to not be a problem because the brush can still be moved up and down but there are two factors to consider; 1) when the side force from constant force spring and the side force from ring rotation come into play the brush is held against the small deposits or eroded brush box inside surface. 2) The brush may be able to be pulled up away from the ring easily but that does not mean there are not deposits causing resistance of movement toward the ring as the brush wears.

As for brush binding, this cause is typically difficult to eliminate, as brush binding is an inherent problem with the design of the holder and is going to be a constant challenge. If possible, upgrade to a brush holder that eliminates brush binding all together by using a brush box that is as long as the brush itself.

Next, eliminate poor spring tension from the constant pressure spring used in the design of the holder. In most instances, this is easier said then done since the majority of OEM holders within the industry and many after market holders do not allow for the springs to be changed out easily during operation. The only way to prevent poor spring tension is to setup a periodic maintenance schedule so that the holders can be sent out at a consistent frequency for new springs to be installed. If possible replace the holder with a design that has an on-line replaceable spring.

Eliminate poor terminal connections from the holder to brush. Again, with some OEM holders, this is not easy to accomplish while the generator is in operation. But it is important on some OEM designs to ensure these connections are inspected thoroughly during every outage period and changed frequently. If it is not a bolted connection the spring portion of the quick disconnect connection is what fails. If possible, Install a holder and brush that has the spring portion of the connection attached to the brush and you should not have any more terminal related problems.

Other common problems and solutions include; the elimination of contaminated air; ensure that the spiral (helical) groove is not worn which is a cause of selective action; inspect for uneven spring tension; change out short brushes soon enough to avoid development of light spring tension, and check for proper brush lead positioning on each inspection of the brushes. Poor lead positioning is a very common problem and is the fault of poor maintenance.

There are also additional maintenance checks to take, in the prevention of collector ring fires. It is important to incorporate a routine frequency where brush amp readings are monitored and recorded periodically. This monitoring frequency should be increased if there are indications that selective action has occurred or is currently occurring.

It is also important to check amperage readings prior to changing brushes under load, especially when indications of selective action are present. Taking a reading before pulling the brush will ensure that a brush is not pulled that is carrying the majority of load, potentially tripping the unit. The fewer the brushes in service the more critical this is.

Amp readings can be an excellent means to monitor the brush holders' performance on maintaining proper contact between the brush and collector ring. In instances where low or no amp readings are determined for a particular brush, one can begin troubleshooting possible causes to prevent a potential collector ring fire from occurring.

Another good maintenance practice is to quarterly take brush vibration readings at one phase angle. Brush vibration readings will alert one that the collector ring is going out of round as a result of poor brush to ring connections that now has caused the collector ring to electrically erode.

Conclusion

It is vital to maintain the optimum brush to collector ring connection in order to prevent a collector ring fire. Proper maintenance conducted by trained personnel who understand the common problems and their signs are vital to preventing collector ring fires.

This can easily be accomplished by consulting with an expert in this region of the generator, conducting routine inspections, and have a thorough inspection conducted of the components within the system on a routine basis. Collector ring fires can normally be avoided, though in some instances they can develop very fast.

It is important to know that there are after market holders available that make maintenance safer and easier. Not all of these after market designs address the common problems discussed in this paper. To learn more, consult a Cutsforth Application Specialist by contacting sales@cutsforth.com.

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