Flashover of DC machines can occur for many reasons, the underlying cause being the voltage between commutator segments exceeding the safe minimum for stability of commutation at a specific operating point, either within the range of operating conditions covered by the design or as a result of this point being outside the design parameters.

Flashover of DC traction machines

There are a number of factors that influence the stability of this voltage and hence flashover. This article attempts to explain the problems of commutation and identify the factors that can give rise to machine instability and flashover. There is often a belief that a machine entering service and that subsequently flashes over after several months is as a result of bad workmanship at either the manufacturers or repairers. Whilst this and the possibility of latent defects should not be discounted bad workmanship is more likely to result in flashover/failure very soon after a machine enters service. This belief can result in only a cursory examination of a flashed over machine and little if any attempt to analyse the history/events prior to flashover. In order to start to understand the mechanisms behind flashovers the opportunity to examine each machine and look at records of incidences/events on the locomotive or motorcoach on which the flashover occurred should always be taken.

The problem of commutation

In the design and operating of the DC traction machine there are two major considerations when examining the problem of commutation. The achieving of no sparking or minimal sparking over the whole range of working loads and speeds for the application. Elimination of any tendency to flashover at the commutator when subjected to voltage jumps or surges, excessive mechanical disturbances or sudden changes in load due to interruptions or wild fluctuations in the supply. The first consideration is, initially at least, in the hands of the designer. The solution is invariably a compromise based on established design practise and experience in the particular application. “Fine tuning” usually takes place during design proving tests. Once in service the necessity for proper maintenance cannot be over stated and of utmost importance is the condition of the commutator surface. Apart from normal wear and tear there will be additional deterioration arising from mechanical sources such as inevitable overspeed situations, the effects of which will be compounded if a traction machine commutator is subjected to excessive sparking over part of its operation range. Eventually flats or depressions will develop caused by burning of the commutator bar surfaces. Once started, these have been known to develop at an alarming rate resulting in ever increasing levels of sparking and ultimately flashover. Similarly commutator deterioration will occur under wheelslip/wheelslide situations should the control system be defective or incorrectly set.

Let us now look at the second consideration and question what are the underlying factors giving rise to possible instability in a DC traction machine. Firstly, from the design aspect the ratio of field ampere turns per pole/armature ampere turns per pole is critical to the establishing of the maximum permissible average volts per commutator bar. The smaller this ratio becomes the more critical this voltage. Take for example motors that are operating in their weak field range. Any sudden disturbances, such as a mechanical shock or current swings, are liable to give rise to abnormal sparking at the brushes and this may in turn lead to a flashover round the commutator. This is just one possible scenario. There are many contributing factors to the instability of traction motors in service a number of which are inherent in those motors solidly suspended on the axle of a locomotive or multiple-unit train set. This is the case with the vast majority of DC traction motors operating on railways in Southern Africa. The commutation of frame mounted (or fully spring-borne motors) is less subject to the effect of mechanical disturbances since much of the mechanical shock from the track is damped by the suspension. Auxiliary machines such as motor/generator and motor/alternator sets are usually underframe suspended or body mounted and are not subject to the same severity of mechanical shock loading as are the bogie mounted traction motors. However they have their own set of problems notably those as a result of supply fluctuations, interruptions, etc., and techniques have to be applied to counter these. Their proper mounting on mechanical shock absorbing resilient mounts is obviously of great importance.

Factors contributing to the instability of traction machines and potential flashover.

Some of the many factors that can contribute to the flashover of traction
machines under in service operating conditions are:

- Development of a rough commutator surface due to excessive operating speeds, i.e. abnormal overspeed conditions, wheelslip or wheelslide with the resultant mechanical overstressing of the commutator.
- Poor commutation causing abnormal and rapid undetected or unchecked deterioration of the commutator surface.
- “Copper Dragging”, this term describes the condition whereby slivers of copper are drawn from the trailing edge of commutator bars, thus bridging the air gap between adjacent bars. This condition has been linked to high frequency vibration which results in the brushes having a hammering effect on the commutator surface.

A similar effect happens when thin slivers of copper break away from the edges of the commutator bars, again tending to bridge out adjacent bars. This can be the result of: sharp edges on commutator bars due to incorrect bevelling; inadequate cleaning out between bars following undercutting/bevelling and final turning /skimming of the commutator surface and operation with an unsuitable brushgrade at high operating speed. Even with the established brushgrade this may be compounded by operating motors unloaded and for traction motors this can result in serious commutation defects. The towing of dead locomotives or motorcoaches and the operation of either locomotives or multiple-unit trainsets with motors cut out even for short periods are examples. A further example is running with machines lightly loaded such that they draw only a fraction of their rated current for long periods. These operating conditions have a tendency to give a high glaze on the commutator surface and at high speed circumferential chattering of the brushes may occur.

- Insufficient tension in brush holder springs that allows the contact between brush and commutator to be lost. This will be compounded by bad rail conditions.
- Rapid fall in brush spring tension as brushes wear resulting in very low or, at the extreme, no contact pressure as the brush length decreases.
- Brushes sticking in their boxes.
- Build up of carbon and other contaminants on the commutator riser face between commutator bars and/or on the front ‘V-ring’ creepage band.

- Poor regulation of the supply. In the case of electric locomotives or motorcoaches from the sub-station via the pantograph/current collector. The pantograph itself can compound this if not correctly set/balanced. In the case of diesel electric locomotives disturbances can arise from the generator or alternator/rectifier, however, generally traction motors on diesel electric locomotives are less prone to flashovers as a result of supply problems. The reason for this is that the power input to the motors, in theory, is at all times limited to the generator or alternator output corresponding to the governed maximum power of the diesel engine. The result is that the supply voltage to the motors is automatically and very closely controlled to the value corresponding to the instantaneous speed of the locomotive. Therefore, unless wheelslip/wheelslide detection equipment fails it should not be possible for the traction motors on diesel electric rolling stock to be subjected to the sudden and often wide fluctuations in voltage that are common and to some degree unavoidable on most electrified systems. Advance in control technology has greatly improved the situation on electrified systems but there are still a large number of old technology locomotives and motorcoaches in service.

Instability may also result from winding defects, whether in the field system or armature and these are often accompanied by blackening of the commutator from burning and sparking. Examples of armature faults are defective joints at the commutator risers, main coils and/or equalisers if applicable, if applicable equaliser connections at non-commutator end on armatures of such design. The development of shorts within the winding is another possibility and early detection of shorts is essential if serious damage to a machine is to be avoided. Examples of field system faults are poor interconnections and the development of shortened turns. Failure as a result of a serious flashover usually occurs within a matter of days of a machine developing the type of faults mentioned above.

Finally, but not least, an unstable commutator will cause havoc and it is not always easy to pinpoint. During manufacture or repair strict attention should be paid to the ensuring of stability of the segmental assembly. Finally a spin seasoning cycle should be completed on either the completed commutator or wound armature assembly to ensure stability throughout the full operating speed range, an overspeed cycle should also be included. Unless stable before entering service it is unlikely for a commutator to settle down totally satisfactorily and a lot of costly maintenance will result with little if any real service benefit. The problem is that bars may move over only a part of the speed range and resettle over the balance of the speed range, hence, a profile (out of round) check may not reveal the full extent of a commutator being either stable or unstable.

**Discussion and summary**

There are many reasons and conditions that result in the flashover of a DC machine and the traction environment presents an extremely arduous set of operating conditions. The DC traction motor in particular is invariably a tight design in order to achieve maximum output within the space limitations between the rails and both mechanical and electrical clearances tend to be at a premium. The 3 000 V DC supply system that is widely used in South Africa results in machine insulation systems that have to be designed accordingly, taking into account the environment parameters (altitude, temperature, humidity - coastal to desert, etc.) The system must also be capable of handling varying supply conditions such as surges (supply induced, lightning, etc.) and fluctuations (short and long) taking this to 4 000 V DC. The insulation system must also be mechanically robust whilst displaying resilience (particularly in the case of the armature) in order to survive the mechanical stresses imposed by the environment. These insulation systems need space, have to be properly engineered and finally correctly implemented during manufacture or repair of machines. Failure to engineer and apply an insulation system to the proper standard, whilst not necessarily a primary cause of a flashover as discussed above is of primary consideration during machine design, upgrade and/or refurbishment programmes.

Many of the factors contributing to the instability of traction machines can be negated by giving due attention at the design stage and subsequently during manufacture or repair. Once in service a correct and effective maintenance
schedule is of prime importance and will greatly assist in the identification of any design and/or machine build limitations so that these may be rectified, by for e.g. modification, if necessary and practical to do so. However, often we have situations where the reasons for instability are inherent in the conditions of service under which the machine must operate. Examples of such conditions are, bad rail conditions, supply problems, poor maintenance standards and/or procedures, incorrect and/or worn mounting of traction motors in bogies, incorrect and/or worn mounting of auxiliary machines such as MG/MA Sets.

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