Case study on

EFFECT OF TG SHAFT VOLTAGE ON ROTOR EARTH FAULT CIRCUIT

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ABSTRACT

There are many reasons for generation of shaft voltage in turbo generator but this voltage is generated mainly due to Static charges developed in low pressure stage of the steam turbine because of impinging of wet steam on turbine blade at high speeds. The DC voltage generated due to these static charges can be of the order of 200V. It tries to discharge through the thin oil film damaging the bearing. Hence it becomes essential to ground the shaft through brushes. The brush contact deteriorates over a period of time and if not attended, shaft voltage may become abnormally high. This paper discusses the effect of Shaft Voltage on Generator Rotor Earth Fault monitoring system on the basis of actual site incident..

INTRODUCTION

Shaft voltage of a turbo generator is generated due to various reasons. Some of main reason are mentioned here after

a) Potential Applied Directly to the Shaft through Generator-Excitation System

State-of-the-art excitation systems supply generator field windings with D.C. voltage through rectification. The instantaneous magnitude of the D.C. voltage is not constant with respect to time because of a large A.C. component of ripple voltage. The excitation system rectifiers are supplied from a three-phase (120 or 360 hertz or as the case may be) voltage produced by a synchronous generator. The rectifiers produce a ripple dc output voltage. The generator field-winding insulation serves as a distributed capacitive impedance which couples a component of the applied ripple voltage to the rotor steel. Thereby, a component of the applied ripple voltage wave between the generator field winding and ground via generator rotor shaft may cause currents to flow through bearings when the bearings are not insulated by the lubricating oil, that is, when the bearings are in a conducting state. When the bearings are not in a conducting state the voltage from generator shaft to ground can be more than 100 volts peak to peak. Damage to bearings involving complete mechanical failure can occur when the generator shaft to ground voltage is high in magnitude. The profile of potential to ground is of essentially the same magnitude at all points along the entire length of the steam turbine generator shaft.

b) Dissymmetry Effect

The Dissymmetry effect is one of the cause of shaft voltage that arises through induced effects. The dissymmetry effects are due to unsymmetrical joints in the stator core with respect to the field winding poles and vary from one machine to another because of small differences in manufacturer's tolerances. Within ideal design conditions, if the generator could be constructed without dissymmetries so that the reluctance of the magnetic circuit is completely uniform around the stator core, a shaft potential would not be produced. Within the ideal generator the equalized magnetic flux patterns in the stator would be balanced, thus adding vectorially to zero. However, generator units being produced are not ideal machines and have inherent dyssymmetry effects associated with their manufacturing process.

c) Shaft Magnetization

The shaft magnetization effect is another source of shaft voltage. It is primarily due to an unbalance of ampere turns in the field circuit which surrounds the generator shaft. The unbalance of ampere turns causes the shaft to become magnetized by establishing a flux linkage which passes along the shaft, through the bearings, bearing pedestals and generator base. Once the magnetic circuit is established, a homopolar voltage will be induced in each bearing as the rotating shaft cuts the radial lines of flux passing from the shaft to the bearings. The induced homopolar voltages in the bearings will be exactly equal, provided the flux passing through one bearing is equal to the flux returning from the other bearing to the generator shaft. Therefore, induced homopolar shaft voltage will cause localized bearing currents to be produced within the bearings.

d) Electrostatic Effect

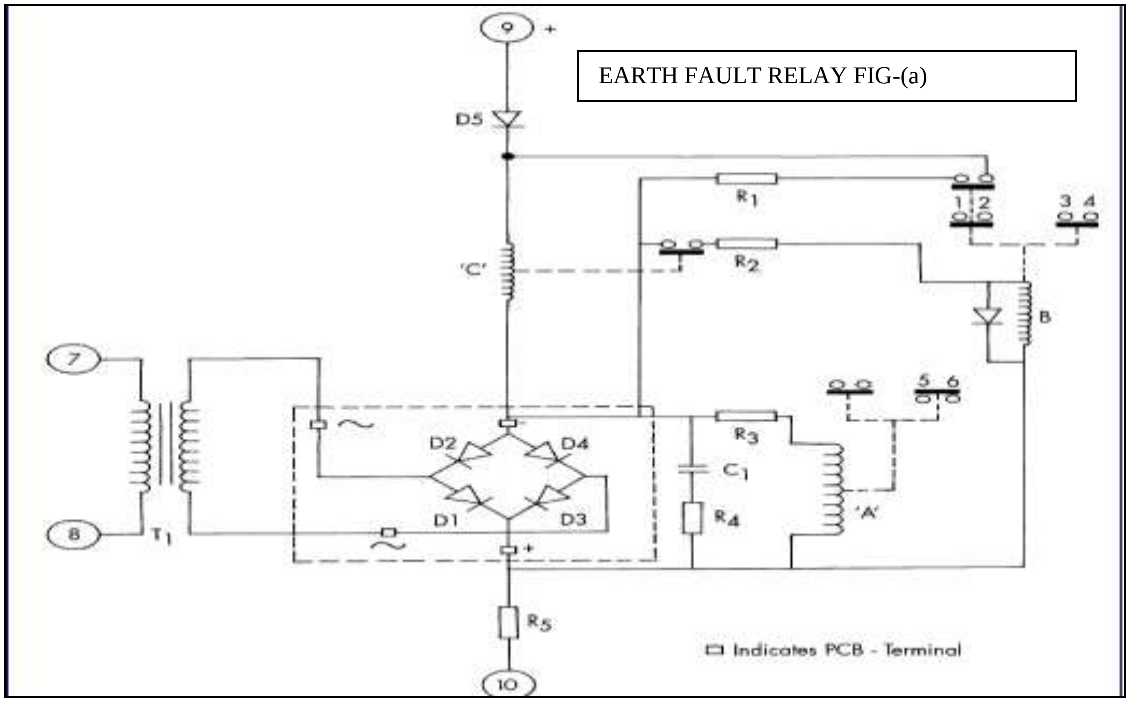
The electrostatic effect is another major source of shaft voltage. Unlike the alternating current produced by strict magnetics, electrostatic current is a constant or random pulsing direct current existing between the steam turbine shaft and ground. The shaft voltage produced as a result of electrostatic effects originates in a condensing steam turbine only. It has never been observed on noncondensing turbines which are predominately free from wet steam. The electrostatic effect is a particle charge build-up on the steam turbine-generator shaft, which is insulated from ground by a thin lubricating oil film on the bearing surface. If the bearings, shaft seals and gears on the steam turbine generator unit are non-conducting, the voltage will charge the distributed capacitance between the shaft and ground until limited by the leakage current, oil film insulation resistance, internal impedance of the voltage source or breakdown of the bearing oil film. When the capacitive voltage increases to a value high enough for voltage breakdown of the oil by piercing the thin film, the stored charge along the shaft is dissipated through the bearing causing a momentary flow of current whose magnitude is dependent on the quantity of stored charge. Even though the electrostatic effect is strictly a D.C. quantity yet if the source of the charge is maintained or continued, an alternate scheme of charging and discharging will occur giving the effect of variable frequency A.C. current. The variable frequency is due to the fluctuating time period occurring during the charging and discharging of the potential needed to pierce the oil film. The electrostatic effect in a steam turbine-generating unit is primarily due to impinging particles and charged lubrication oil which produce several of the characteristics which can be read in **Appendix- A**

REAL CASE ANALYSIS

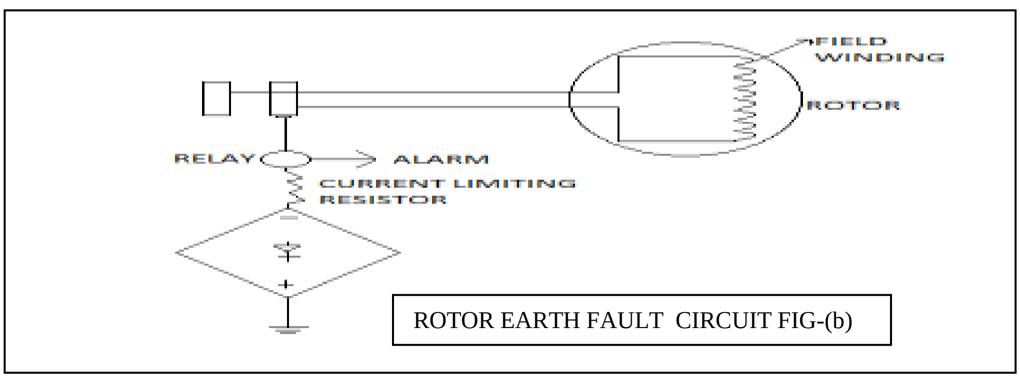
In one of the steam turbine generator unit with static excitation system, the Rotor Earth Fault monitoring system was provided through Alstom make VAEM21 RELAY. In this relay rotor earth fault is detected using the principle of negative potential biasing. The d.c. injection supply establishes a small bias on the alternator field circuit so that all points are negative with respect to earth (refer FIG (a)). The auxiliary transformer used in the biasing circuit is rated at 240 volts ac 50 c/s supply. For a 250 volts dc system, the bias voltage is 60 **-** 70 volts dc. The rectified output of transformer fed from the system L.V. supply provides a biasing potential, which is connected with positive terminal to earth. The negative terminal is connected through a long core unit ' **C** ' to the positive pole of the field circuit (refer Fig-(b)). In case of fault, current flows in the long core unit, when the leakage current goes above 1 mA which in turn actuates the relay '**A**' to give a REF-STG-I alarm. The scheme will operate only if ac supply is available. If ac supply fails, relay '**B**'. drops off and initiates an alarm for supply fail condition.

It was reported that rotor earth fault stage-I alarm was actuating and resetting. Frequent make-break of relay contact was observed . There was no malfunction from relay side as it was actually sensing the condition of rotor earth fault. Since the machine was at rated generation and synchronised with the grid, it was essential to identify the cause and rectify the problem online. No physical evidence was observed which may lead to such initiation of rotor earth fault. However, the behaviour of relay (frequent make and break of contacts) lead to suspicion that its cause could be build up and discharging of shaft voltages through bearings. On investigation it was noted that the shaft voltage of this machine was abnormally high and was around 150 V which normally remains in the order to 2 to 5 volts. Further checking revealed that the shaft earthing brush were not making proper contact with the turbine shaft due to jamming of brush in brush holder. This restriction in movement was because of deposition of oil and dust in the path of brush inside holder and this paste type mixture was obstructing the movement of brushes as its spring tension failed to overcome the friction offered by mixture of oil and dust. On readjusting the contact pressure of brushes the shaft voltage resumed to normal value of 5 Volt and rotor earth fault alarm got reset.

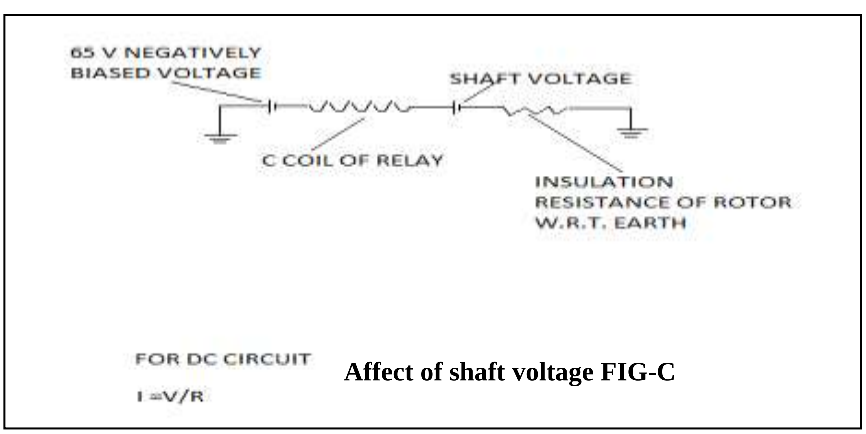
The effect of shaft voltage on rotor earth fault circuit is illustrated in fig -C through Single Line Diagram wherein this voltage gets added in series with Rotor Earth Fault Circuit and leads to REF STG-I alarm once the leakage current exceeds 1mA. Hence it was concluded that the cause of rotor earth fault relay actuation was not any actual deterioration in IR value of generator rotor but was effect of shaft voltage.



EARTH FAULT RELAY FIG-(a)



ROTOR EARTH FAULT CIRCUIT FIG-(b)



Affect of shaft voltage FIG-C

Conclusion :

Monitoring of effectiveness of shaft earthing system is vital and shall be done regularly by shaft voltage measurement. Higher shaft voltage interferes with rotor earth fault monitoring circuit and may initiate spurious operation of rotor earth fault relay leading to unit outage. Any incidence of rotor earth fault relay initiation shall also be investigated from shaft voltage point of view.

REFERENCES

[1] Steam Turbine-Generator Shaft grounding- by Bernard Michel Ziemianek

[2] Rotor Ground Fault Protection of generator with static excitation System - By Z. Elecshova, A. Belan, D. Gasparovsky

[3] Controling Shaft Voltage -by James S. Bothwell , www.Powermag.com

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- The impressed voltage between the steam turbine-generator shaft and ground is a direct current value.
- The magnitude of the voltage is not constant, but varies between high and low values thereby giving the effect of A.C. and D.C. components without reversing polarity.
- The maximum voltage observed by an oscilloscope is 250 volts peak-to-peak value.
- The rate of rise of shaft voltage is in the range of 200 volts per 1/60 second or 12 kV per second.
- The voltage rate-of-decay (or time of sparking) is less than 0.1 milliseconds.
- The minimum voltage impressed on the shaft is less than one volt.
- The average voltage magnitude is in the range of 30 to 100 volts peak-to-peak.
- The voltage polarity is usually positive.
- The potential is essentially of constant magnitude along the shaft
- The maximum magnitude of current through a grounding resistor between the steam turbine-generator shaft and ground is approximately 1.0 milliamp. The current magnitude is the same regardless of how small a resistor value is used.

Steam turbine-generator parts become charged by the process of neutral particle charging or direct contact of already charged particles. These processes are influenced by charges resulting from moisture particles in wet steam which is usually found in the low pressure turbine stage directly ahead of the condenser. When a stream of neutral particles strike an object, such as the case when wet steam at high temperature, pressure and velocity comes in direct contact with the steam pipes, pumps, boiler tubes, rotor blades, etc., a percentage of the neutral particles of the steam rebound with a positive and negative charge. The particles undergoing a collision each leave charges of the opposite polarity on the object which has been struck. The magnitude of electrostatic charge developed by contact of solid substances to the dielectric constant is given by the following equation:

Q = k (K1 - K2)

where: Q - is the electrostatic charge in electrostatic units (esu) per sq. cm.
k is the proportionality constant equal approximately to 4.4 in magnitude.
K1 and K2 are the dielectric constants of the two contacting mediums.

Electron theory explains that electrons travel from an uncharged material of higher K value to an uncharged material of lower K value. The overall number of particles which become charged, the final balance of positive and negative charges and the distribution or placement of the charges at post collision depend strictly upon the properties of the steam, piping system, rotor blades, etc., and upon the conditions of temperature and pressure under which impact takes place. Steam particles charged in the foregoing manner will ultimately give up their charge to any surface with which they come in contact.
For analysis, if the metal steam turbine blades are assumed to have a dielectric constant of 3.0 and dry steam of 1.0, the difference in magnitude of the dielectric constants is given by:

$\Delta K = Kl - K$
$= 3.0 - 1.0$
$\Delta K = 2.0$

The very small difference in magnitude of the dielectric constants accounts for the positive polarity of the electrostatic charge on the rotor blades of the high pressure end of the steam turbine. This condition will exist when the inlet superheated dry steam contacts the shorter turbine blades in the high steam pressure section. If the dry condition of the steam existed throughout the entire sections of the turbine without becoming moist in the low pressure section, the dry steam will then generate a positive electric charge on the rotor shaft. The electrostatic voltage on the shaft can be defined by the following equation:

$V = Q/C$

where: Q - is the electrostatic charge of the turbine shaft in coulombs.
C - is the electrostatic capacitance of the turbine shaft to ground in farads.
V - is the potential in volts of the turbine shaft to ground.

If the metal steam turbine rotor blades are again assumed to have a dielectric constant of 3.0 but wet steam of an unrealistic amount and condition is now analyzed with a dielectric constant of 80.0, the difference in magnitude is given by:

$\Delta K = K1 - K2$

$= 3.0 - 80.0$

$\Delta K = -77.0$

The high wet steam condition will produce an electrostatic charge of negative polarity on the rotor shaft.

It must be noted that a very high wet steam condition is being used for the example of negative potential on the rotor shaft. If the high wet steam condition existed within a turbine, then the associated turbine shaft to ground potential would be in the order of several thousands of volts. However, the shaft potential will be limited to the breakdown voltage of the lubricating oil film. Wet steam of this magnitude is highly improbable even under the worst operating conditions of an actual turbine. It is also interesting to note that at a potential of a few thousand volts, it is possible for sparking to take place between the highly charged rotating turbine blade tips and the grounded stationary blade tips within the turbine frame.

On an actual condensing steam turbine at full load, the high pressure rotor blades have a net positive polarity imposed on them by the dry inlet steam. However, as the steam exhausts out of the turbine via the low pressure section into the condenser, the steam becomes slightly wet thereby imposing a large negative charge on the larger low pressure turbine blades. Since the charge on the low pressure blades is larger than the associated charge on the high pressure blading, the net overall potential developed on the shaft is negative in polarity. However, if a light megawatt load is on the same steam turbine unit with dry inlet and exhaust steam, a net positive charge of potential on the turbine blading will be predominate. The potential will be of a very small magnitude and due to a summation of positive charge in the high, intermediate, and low pressure sections of the turbine unit. Oil used for closed cycle lubrication in the steam turbine-generator undergoes a similar charging effect as that of water and steam. However, lubrication oil used on steam turbine-generator units is a poor conductor of current. The molecules of the lubricant have an electrical behavior similar to a balanced or neutral material. That is, the positive and negative charges are electrically balanced. As the lubrication oil passes through piping and various filter systems made up of small passages, the molecules of the lubricant become charged. Since the lubricant is a non-conducting medium, a portion of the molecules remain charged after passing through a long length of the grounded piping system. The charged lubricant is then deposited on the journal or the bearing. When the developed potential at this location becomes high in magnitude, the capacitor stored potential is discharged through the bearing oil film to ground. As discussed earlier, the discharge through an oil film creates a random pitting on the surfaces involved.