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ROTOR GROUND FAULT PROTECTION OF GENERATOR WITH STATIC EXCITATION SYSTEM

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This paper deals with the influence of harmonics produced by the static excitation system of generator on the rotor ground fault protection of synchronous generator. The report brings measured courses of field voltage and current flow through insulation system of field winding during generator failure-free operation. There is analysed potential impact of static excitation system on correct function of rotor ground protection based on AC injection method.

Key words: rotor, generator, static excitation system.

The synchronous generator is one of the most important and the most complicated elements of power system. It is main source of electrical energy. It is essential to know everything about its steady states but mainly about its fault states. Various fault states can occur during generator operation. We distinguish between internal and external failures of generators.

The first ground fault of field winding belongs in internal failures of generator rotor. The single ground fault on the field winding is not hard fault state for synchronous machine. But there is probability of occurrence of the second ground fault which presents short circuit with very large currents, dynamic and thermal stress of filed winding and rotor armature [1].

The Faults on Synchronous Generator Field Winding. Synchronous generator excitation system is insulated DC electrical system. Rotor of generator, like a rotating part, has higher probability of single ground fault occurrence than stator. Rotor winding damage is frequently, mainly on turbogenerators where rotor winding insulation is fairly stressed effected by centrifugal forces [9].

Ground fault of field winding. The first rotor ground fault causes just a little fault current, although it stresses the insulation in portions of the winding where the fault is. The real danger is the second ground fault which can cause significant forces. During dual ground fault can draw large currents which may cause extensive damage to rotor winding and armature.

It is important to detect the first ground fault, thereby preventing a serious failure. The first ground fault is signalizing only. Generator is tripping and damaged winding is repairing. In this way it can prevent large damages which could be during the second ground fault. Backup protection against the second ground fault is loss of excitation protection.

Field winding short circuit. Shorted turns in the generator field winding can cause distorting the field across the air gap. This is due to the unsymmetrical turn current of magnetomotive force in different parts of the field winding. The accrued much distorted forces can effect rotor deformation or severe vibrations which can destroy machine bearings. The machine can be protected before serious damage by vibration detector which can alarm or trip unit. Shorted winding is often due to rotor ground faults at two different places.

Open field winding. Field winding open circuit is rare. But rapidly detection of this fault is required, because it can be accompanied with arcing that can do great damage to the rotor body. Open field winding can be detected by loss of excitation protection.

Rotor Ground fault protection. The rotor ground fault protection should protect whole field circuit of generator in cause of ground fault. In regard to the second ground fault is non-permissible, the protection which signalize the first ground fault must be high reliable and shouldn't incorrect act, because every protection alarm of the rotor first ground fault is necessary checkup.

The protection, which controls field winding insulation by injection of auxiliary voltage, is the most frequently used for detecting of rotor ground fault of generator. According to injected voltage the rotor ground fault protections are based on AC or DC injection method.

The new rotor ground fault protection uses injected low-frequency squarewave voltage.

AC injection method. AC injection method is showed in fig. 1. This method is based on injection of AC auxiliary voltage to field winding through a capacitor. When any point of field winding is grounded, circuit will be complete and the protection signalizes the rotor ground fault. This system has no blind point [9].

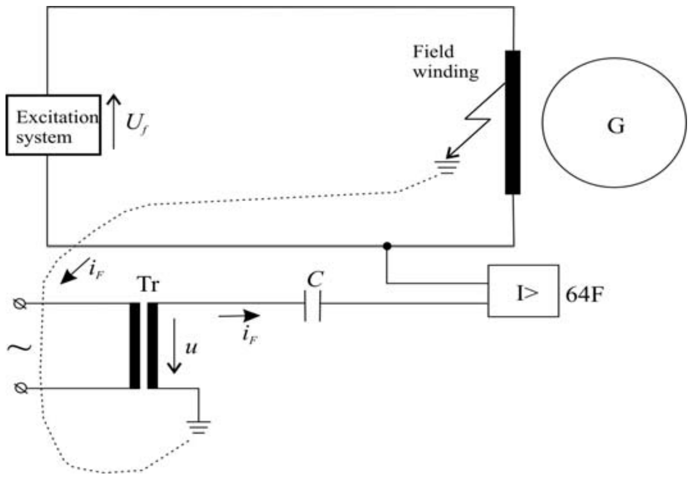

Fig. 1. Rotor ground fault protection of generator – AC injection method.

DC injection method. DC injection method is showed in fig. 2. Protection based on this method uses DC voltage. The DC output of the rectifier is connected to the positive side of the field circuit and the second output is grounded. Every point of the field winding grounded closes circuit through current relay [5].

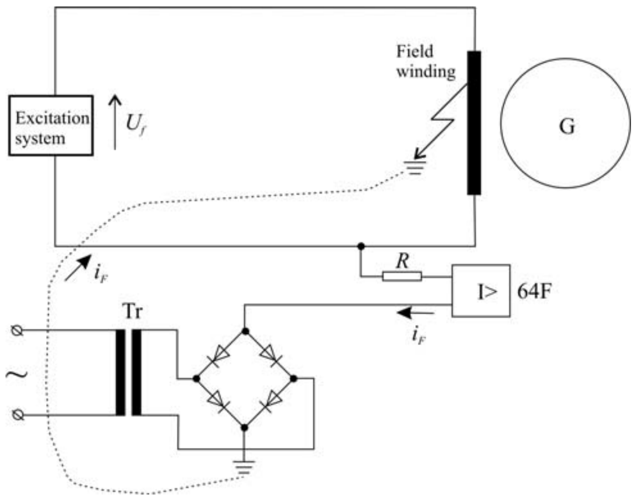

Fig. 2. Rotor ground fault protection of generator – DC injection method.

Rotor ground fault protection with squarewave auxiliary voltage. Fig. 3 shows principle of rotor ground fault protection with squarewave auxiliary voltage [1].

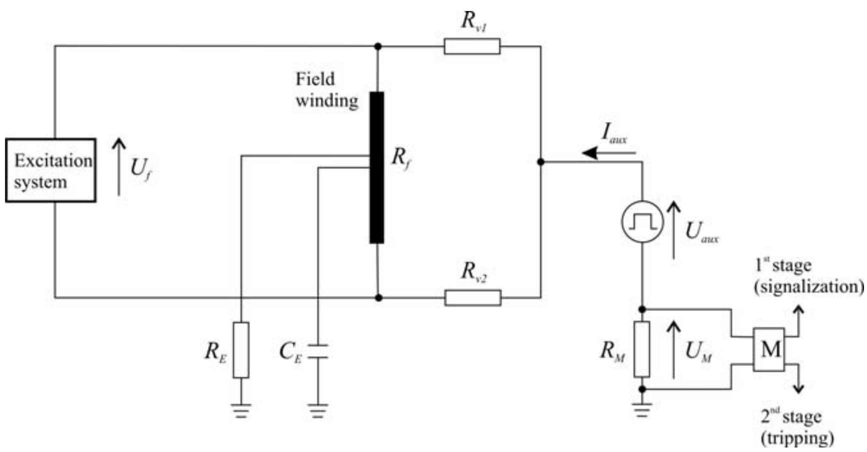

Fig. 3. Rotor ground fault protection of generator – low-frequency squarewave voltage injection.

Measuring circuit M is connected to rotor winding through the high resistance R_{v1} and R_{v2}. The squarewave auxiliary voltage U_{aux} causes an auxiliary current I_{aux}. The value of auxiliary current is given

$$I_{aux} = \frac{U_{aux}}{R_E + R_v + R_M}, \tag{1}$$

where

$$R_v = \frac{R_{v1}R_{v2}}{R_{v1} + R_{v2}}. \tag{2}$$

If $R_M << R_v$ then measured voltage U_M is

$$U_M \approx \frac{U_{aux}R_M}{R_E + R_v}. \tag{3}$$

For a consideration of measured voltage course and value protection evaluates the leakage resistance value and state of rotor insulation system.

Flow current through the rotor ground fault protection measurement. The goal of measurement was to find out and analyse influence of the static excitation system on correct function of rotor ground fault protection. The measurements were made on the synchronous machines with static excitation system and rotating exciter too. The generators were 110 MW, 32 MW and 28 MW. The rotor ground protections of these machines are based on the AC injection. The measurements were aimed at determining of harmonic contents in voltages and currents of generator, in voltages and currents in front of static excitation system, in field voltage, mainly in current flow through rotor ground fault protection in failure-free state with different value of field current.

The measurement on 110 MW generator with static excitation system. This generator had analogue rotor ground protection based on the AC method.

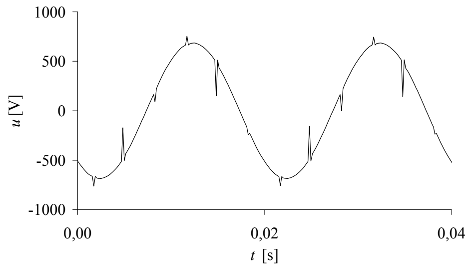

Fig. 4. The voltage in front of the static excitation system.

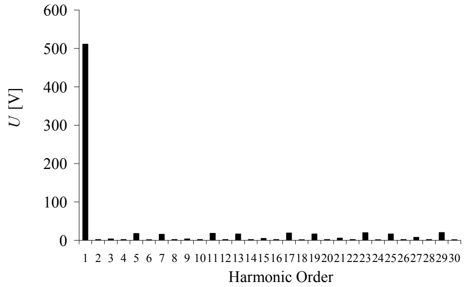

Fig. 5. The harmonic content of voltage in front of the static excitation system.

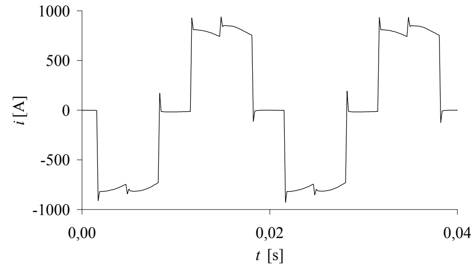

Fig. 6. The current in front of the static excitation system.

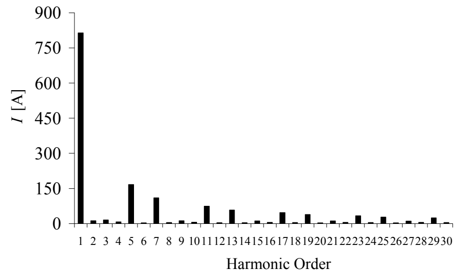

Fig. 7. The harmonic content of current in front of the static excitation system.

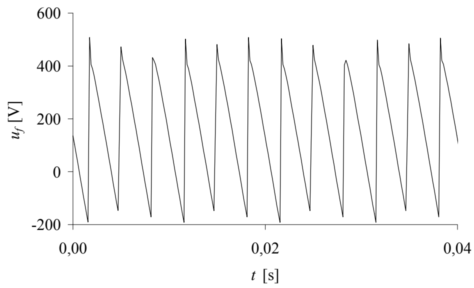

Fig. 8. The field voltage.

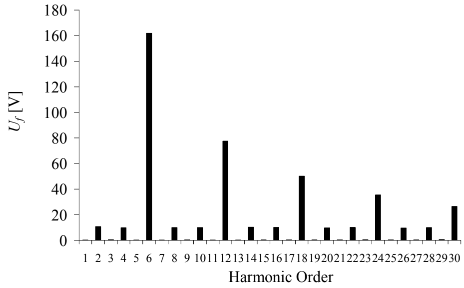

Fig. 9. The harmonic content of field voltage.

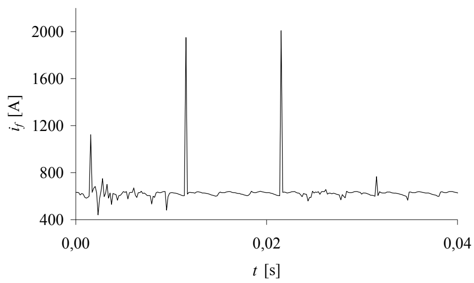

Fig. 10. The field current.

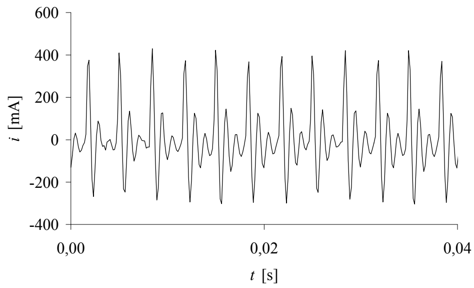

Fig. 11. The current flow through rotor ground protection.

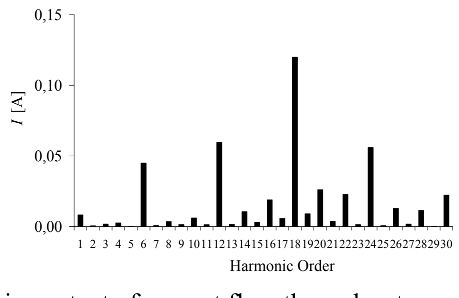

Fig. 12. The harmonic content of current flow through rotor ground protection.

From the field voltage course (fig. 8) can see that this voltage isn't DC voltage. That is way we did harmonic analysis of this voltage. In the field voltage are specific harmonics (the 6^{th}, 12^{th}, 18^{th} etc.) which are multiples of the number of rectifier impulse [6].

In histogram of harmonic content of voltage and current in front of the static excitation system (fig. 5, fig. 7) we can see impact of six-impulse rectifier too. On the rectifier AC side in the voltage and current are specific harmonics (the 5^{th}, 7^{th}, 11^{th} etc.) which are given [8]

$$n = k \quad p \pm 1\,, \tag{4}$$

where p – the number of impulse; n – the harmonic order; k – the natural number.

From measured course of current flow through protection (fig. 11) is to see that harmonic content is marked. The instantaneous values of this current achieve more than 400 mA. This is more than setting value at the protection (15 mA).

The current flows through the protection contents mainly higher harmonics (it's shown in histogram of content harmonic – fig. 12), the magnitude of the fundamental of the current is cca 9 mA, this is bellow the current nominal value of relay. Till the 6^{th} harmonic magnitude is larger than 15 mA.

In spite of this the rotor ground protection didn't act false during measurement (with fluent field voltage changing). The analogue protection has connected parallel to current relay two capacitors which eliminate higher harmonics from the current flows through this relay. It means higher harmonics haven't negative impact on the protection function.

The measurement on 28 MW generator with static excitation system. This generator had the analogue rotor ground protection based on the AC method. In respect of size of synchronous generator (28 MW) in compare with 110 MW generator (smaller value of field winding capacitance) the magnitude of current flows through the protection is markedly smaller. Fundamental harmonic magnitude is cca 5,5 mA and magnitudes of the other higher harmonics are smaller. In this case the rotor ground protection shouldn't act false.

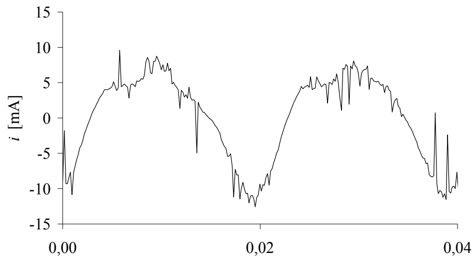

Fig. 13. The current flow through rotor ground protection.

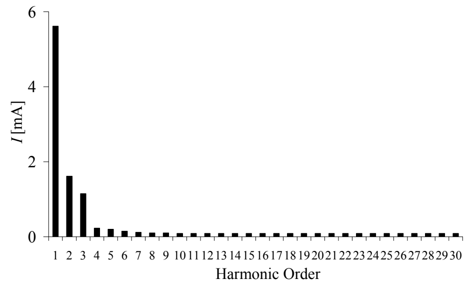

Fig. 14. The harmonic content of current flow through rotor ground protection.

The measurement on 32 MW generator with the rotating exciter. This generator had the digital rotor ground protection based on the AC method. Because this generator had the rotating exciter – dynamo, the field voltage is really DC and the injected auxiliary AC voltage of protection isn't deformed. There wasn't possible to measure the current flows through the rotor ground protection because this current had too small magnitude – non-measurable by the measuring instrument.

The measurements on the generators with the rotor ground protection based on the AC injection method and with the static excitation system were made at the instance of generator operator to find out the static excitation system impact on this protection correct function. Because the rotor ground protection on 110 MW machine signalizes rotor ground fault in express terms in spite of rotor insulation system was sound.

The measurements on 110 MW generator with the static excitation system and with the rotor ground protection based on the AC injection show the impact of six-impulse thyristor rectifier on course and harmonic content of voltage and current in front of the excitation system, of field voltage, but also of current flows through rotor winding insulation (and rotor ground protection too) during failure-free and steady state operation of generator.

From the measurements is result that during steady state of synchronous generator the rotor ground protection didn't act false in spite of the instantaneous values and higher harmonics magnitudes of the current flows through this protection are greater than setting value on protection. As mentioned above harmonics of current flow through parallel connected capacitors and don't through protection current relay.

It means that seemingly "easy solution" – to replace the analogue protection by digital haven't enough because in this case the harmonics aren't causer of the rotor ground protection incorrect acting.

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ЗАХИСТ РОТОРА ГЕНЕРАТОРА ЗІ СТАТИЧНОЮ СИСТЕМОЮ ЗБУДЖЕННЯ ВІД ЗАМИКАНЬ НА ЗЕМЛЮ

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Описано вплив гармонік, генерованих статичною системою збудження генератора, на роботу захисту від замикань на землю синхронного генератора. Наведено способи вимірювання напруги збудження і струму, який протікає через систему ізоляції обмотки збудження під час нормальної роботи генератора. На підставі методу введення змінного струму проаналізовано потенційний вплив статичної системи збудження на правильність роботи захисту від замикань на землю.

Ключові слова: ротор, генератор, статична система збудження.

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