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EPSR-4731; No. of Pages 9
ARTICLE IN PRESS
Electric Power Systems Research xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Electric Power Systems Research
journal homepage: www.elsevier.com/locate/epsr

Detection and location of a ground-fault in the excitation circuit of a 106 MVA synchronous generator by a new on-line method

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ARTICLE INFO

Article history:
Received 27 July 2015
Received in revised form 10 April 2016
Accepted 9 June 2016
Available online xxx

Keywords:
Fault Location
Power system protection
Hydroelectric power generation
Generators
Rotors

ABSTRACT

In this paper, the influence of the rotor capacitance in the detection and location of a ground-fault in the excitation circuit of a 106 MVA static excitation synchronous generator by a new on-line method is presented.

In this generator, numerous rotor ground-fault trips took place always about an hour after the synchronization to the power system. Nevertheless, when the field winding insulation was checked after the trips, there was no failure. The rotor ground fault relay was verified and the operation was correct.

Therefore the data indicated that the faults in the rotor were caused by centrifugal forces and temperature. A new on-line rotor ground fault detection and location method, was employed in this generator. Unexpectedly, the failure was located in a cable between the excitation transformer and the automatic voltage regulator.

After the location of the ground fault, thanks to numerous intentional ground faults tests along the field winding with different fault resistance values, the influence of the capacitance of the rotor is analysed. It can be concluded that the location method has an acceptable accuracy and the rotor capacitance has not a significant influence. However the detection method could produce unwanted trips due to the capacitive current in non-faulty conditions.

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1. Introduction

The excitation field circuit of synchronous generators is isolated during normal operating conditions. The field winding is exposed to mechanical and thermal stress cycles as a result of the rotation speed and the temperature increase [1].

In addition to the normal stress, the field winding can be exposed to abnormal mechanical or thermal stress because of overspeeding, vibrations [2], excessive field currents, poor cooling or stator negative sequence currents, among others. This may result in a breakdown of the insulation between the field winding and the rotor iron at the points where the stress has the highest value [3].

In synchronous generators of pumped storage power plants, the insulation failures occur more often [4,5] since they are operated generally from stopped to rated power operating condition in a short time. This causes the temperature of the insulation to alter very fast and frequently, increasing the possibility of an insulation failure.

As the excitation system is isolated, a single ground fault can cause a negligible fault current, which does not represent any immediate danger. However, if a second ground fault occurs, high fault currents and severe mechanical unbalances may arise quickly and lead to serious damage [6]. In some cases the field current, flowing through the rotor iron, could generate enough heat to melt it [7,8]. It is essential, therefore, that the first insulation failure be detected [9–11], and the generator be removed from service in order to check the insulation [12].

Currently, fault diagnosis is an active research field in induction motors [13–17], permanent magnet synchronous motors [18–20] and synchronous machines [21,22].

Regarding the synchronous generator, there are several techniques for detecting faults in rotor windings [23–28]. Some of these techniques are useful for ground fault detection, and they are based on AC or DC voltage injection [29,30]. New ground fault detection [31] and location [32] methods, without using voltage injection, have also been proposed recently for static excited generators.

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http://dx.doi.org/10.1016/j.epsr.2016.06.011
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Please cite this article in press as: M. Pardo, et al., Detection and location of a ground-fault in the excitation circuit of a 106 MVA synchronous generator by a new on-line method, Electr. Power Syst. Res. (2016), http://dx.doi.org/10.1016/j.epsr.2016.06.011

Nomenclature

f	network frequency
V	grounding resistor voltage
V_f	field voltage
V_{ph}	phase voltage in the low-voltage side of the excitation transformer
R_G	grounding resistor
R_F	fault resistance
$V_{ph,f}$	AC component of phase voltage in the low-voltage side of the excitation transformer
$V_{AC,f}$	fundamental frequency AC component of grounding resistor voltage
$V_{AC,3f}$	third harmonic AC component of grounding resistor voltage
V_{DC}	DC component of grounding resistor voltage
V_{fAC}	AC component of the excitation voltage
V_{fDC}	DC component of the excitation voltage
V_{DC0}	max. value of V_{DC} of of the field winding (0%)
x (%)	rotor winding position expressed in percent

This paper presents tests of a new on-line field-winding location method, performed in a 106 MVA synchronous machine of a storage pumped power plant.

Starting in May 2011, sporadic alarms of the rotor ground-fault protection went off in the plant under study. After a few months, the ground-fault rotor protection caused trip commands. Numerous rotor ground-fault protection trips always occurred about an hour after the synchronization to the grid. However, after the protection trips, when the field winding insulation was checked, no failure was found. All the evidence seemed to indicate that the fault in the rotor was caused by the simultaneous effects of centrifugal forces and temperature, because the trip occurred an hour after the synchronization, and no evidence of a defect was found when the machine was stopped.

Because of these trips, a non-programmed extraction of the rotor was planned just for locating and repairing the fault, however using the application of this new detection method the ground fault was located.

In order to carry out this method, the neutral of the low voltage side of the excitation transformer was grounded through a high value resistor. The voltage registered at this grounding resistor was analysed following this novel fault location algorithm, and the ground fault was located in the AC side of the excitation system.

On the other hand, once the generator was repaired, the owner of the plant allowed the authors to perform several intentional ground faults in the field winding, in order to test the accuracy of the method in the location of ground faults on the DC side. The results of these tests were acceptable and the capacitive current through the rotor winding does not have a significant influence.

Moreover some tests in healthy conditions were carried out and the influence of the field winding capacitance could produce unwanted trips because according to the algorithm the measurements indicated a ground fault in the midpoint of the rotor winding.

2. Brief description of the rotor ground fault location method

This section is a brief description of the method used for rotor ground fault location. The detailed method description is in the reference [31,32]. Firstly this method allows discriminating whether the ground fault is in/on the AC side or on the DC side of the excitation system. In addition, if the fault is located in the DC side, it is possible to provide an estimation of the ground fault location along the field winding.

As additional equipment, only a high value grounding resistor is required at the neutral of the excitation transformer low-voltage side. The grounding resistance value should be calculated in order to limit the ground-fault current to a very low value; in the experience described in this paper, the voltage between the neutral and ground, when the fault occurred, was almost 100 V and a 10 kΩ grounding resistor was utilized to limiting the fault current to 10 mA

The waveform of the voltage measurement at the grounding resistor (V), in the field winding (V_f) is analysed to detect and locate the ground fault (Fig. 1). In the Measurement Wave Analyzer block,

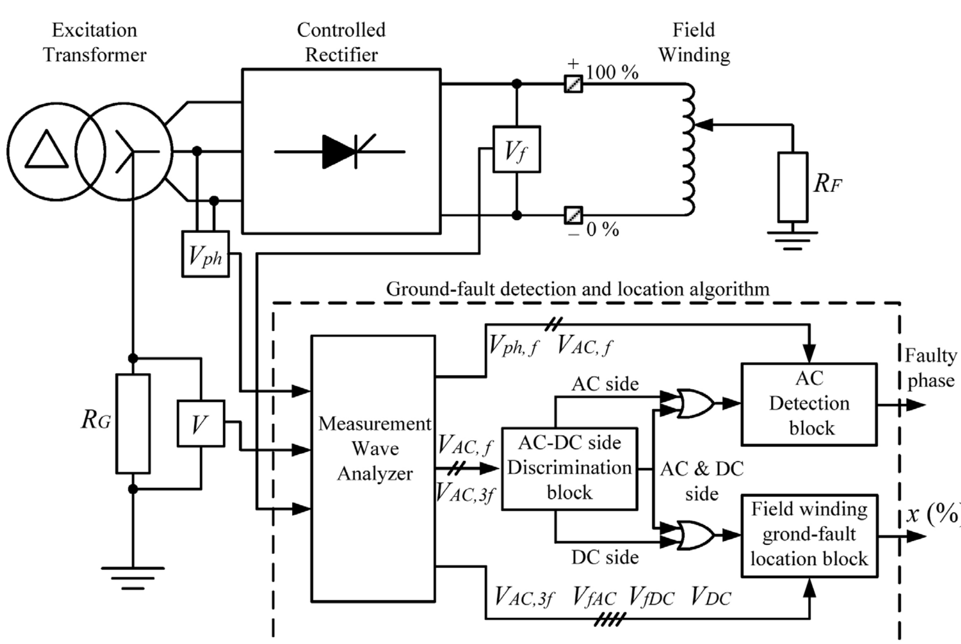

Fig. 1. Rotor ground fault detection system layout.

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