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Design and Analysis of Neutral Grounding Transformer for Hydro Alternators

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Abstract— Power Generators of high KVA rating especially that of hydropower plant are very much prone to the ground faults. Stator ground faults are the most common winding failure in generators. During stator ground faults, short circuit currents flow from the damaged phase to ground through the stator core. Experience has shown that stator ground fault damages are proportional to phase-to-ground fault current as well as fault duration.

For that reason, Generator Neutral Grounding must be applied in order to;

I. Limit phase-to-ground fault current.
II. Provide a means of stator ground fault detection.

There are various generator grounding classes and types available. In this paper, high-resistance grounding has been chosen. High-resistance generator neutral grounding scheme based on a grounding transformer with a secondary resistor

The advantage of the distribution transformer resistor combination is that the resistor used in the secondary is of comparatively low ohmic value and of rugged construction as compared to obtaining the same result by installing a high-ohmic, low-current resistor directly in the generator neutral.

This research introduces some important and applicable practices which came from few years of practical as well as theoretical studies and discussions with some national and international power system experts. The research was made on the hydro power plants installed at Tarbela generating unit. The important parameters concerning the high impedance grounding of the generator were calculated. These results will be a kind of ready references for neutral grounding transformer design calculations and analysis.

Keywords— NGT (Neutral Grounding Transformer), KVA Rating (Kilo Volt Amperes), Secondary Resistor, Tarbela Generating Unit.

I. INTRODUCTION

One of the important parts of the power system is generators. They are basically the in charge of the uninterrupted power supply to the consumers hence it's very crucial that it works in its normal conditions. The compromise on their reliability can possibly result in the blackouts and affects not only the power system but also the customers. Usually, if the generators get damage then they are returned to the manufacturer to rewind or re-stack them because utility normally is incapable to rewind the damaged generator. This fixing cost is normally very high hence it is also very important to protect the generator against abnormal situations and the faults [1].

Currently, in the modern era, the rate of overall failure of the generators and other machines is very low as compared to the past 10-20 years. The main reason is because of the improved materials and the design practices that effectively reduces the faults. Unfortunately, the rate of failure is never zero but is reduced because of improvements made in the design and technology. It is important to recognize the faults and effectively isolate it, thus allowing minimum damage to occur. The abnormal conditions include overload, over speed, winding faults, loss of excitation, out of step condition, excitation loss, sub-synchronous oscillations, and un-balance current conditions. These all conditions do not require that generator will be tripped, in many conditions, the tripping is not necessary. For every hazard, the operating conditions, cost of maintenance and extent of protection must be weighed against the associated risks for no protection. The degree to which protection should be applied depends upon the importance and size of generator [1-2].

The protection system for the generator should be robust and reliable. It should not interrupt the while power system for the non-serious or minor faults and those schemes, on the other hand, should be capable to protect the generator against all types of faults in the windings of the generator thus providing a high degree of the seriousness. If the generator protection is sensitive and robust, the generator will not shut down the whole system for minor fault and prevent the generator from the damages against the faults [2, 3]. The generator needs to be protected against internal and external faults. Generators are being protected against the faults (external) by means of the circuit breakers which interrupt and switch off against the faults in the network (lines, buses, and transformer, etc.)

One of the internal faults of the generator is the stator ground fault. The faults of the stator ground are generally caused by the degradation of the insulation as well as influences of the environment such as oil or moisture in combination with the dirt that usually is present on the surface of the coil outside the slots of the stator. This can eventually result in discharges of the electrical tracking in the end winding that punctures the ground well [1, 3].

II. LITERATURE REVIEW

A. *Differential Protection*

For the systems which are grounded by low impedance or ungrounded, the short circuit currents are typically of very large value ranging from 400 A to 1200 A of the primary current. It is very high value which can damage the equipment as previously mentioned. This fault can also be detected by the differential protection scheme which depends on the phase current on the neutral and terminal side of the machine. As the level of the fault current is very high, the secondary amperes can be much higher than the relay trip settings. For example, in case of the 6kV 10 MVA current transformer, the value of the phase-to-ground current is limited in range of the 2 to 6 A, the protection should detect the difference in the value of the current.

B. *Machine Connection*

Many machines typically generators have y-connected winding. The 3 relays which are coupled to they-connected CT gives the phase and in few of the cases (depending on the system grounding and the neutral) ground fault protection. Figure 2.5 gives the protection system for the delta generators. In this system, the winding of delta should be brought out such that CTs can be inserted inside the delta [4, 6].

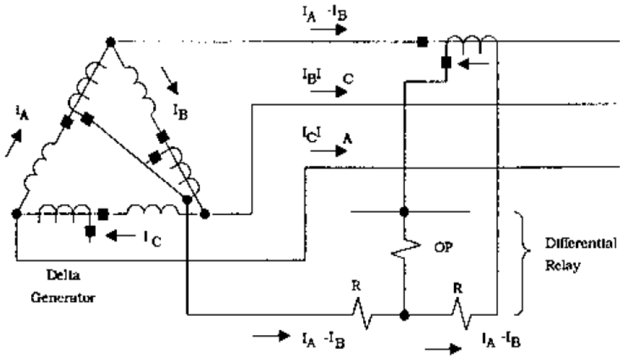

Figure 2. 1: Differential relay schematic for the delta connected machine

C. *Split Phase*

The generators having the winding of the split phase can be possibly be protected by using the differential relay sets as depicted in figure 2.4 and 2.6. This sort of configuration prevents against the fault types which exits internally typically including the open circuited or short-circuited. This arrangement can further be extended for accommodating the other types of winding arrangements that particularly involve the more than 2 equal winding per phase. The arrangement of figure 2.6 should be equipped with the auxiliary transformers for providing the balance in the normal working [7-8].

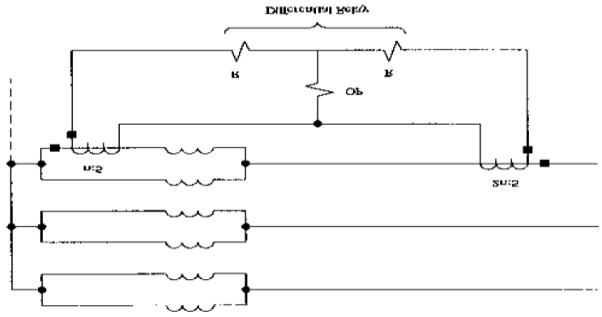

Figure 2. 2: Configuration for single phase with split phase winding

D. *87N3(Neutral to Ground Protection of Fault)*

Figure 2.8 depicts the phenomena for detecting the neutral to ground fault in machine. This fault is not hazardous. The occurrence of the second fault of the ground at the machine, eventually causes the phase to ground fault which is not limited to the neutral impedance. This magnitude of the fault current will increase from the value for which it is designed causing the destruction. The figure 2.7, compare the 3rd voltage of harmonic present between the ground and the machine neutral at the line terminals [9-10].

E. *Toroidal Transformer along with Differential Relay*

When the generator ratings are not too high, then some scientists have presented a solution based upon the 3-phase current and the neutral lead coupled with the toroidal transformer as depicted in the figure 2.9. Such scheme generates magnitude of the current of the secondary winding of the transformer similar to the internal fault of generator, and false trip of the relay is thus avoided when external fault occurs.

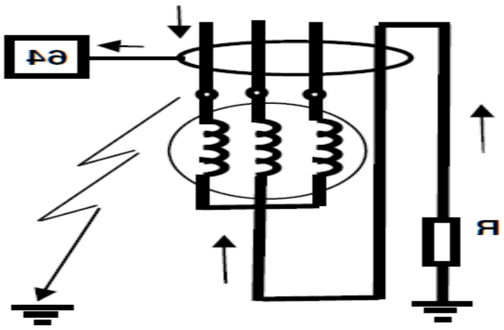

Figure 2. 3: Differential Over-current relay along with toroidal transformer

It has some limitations as it is only applicable for the generators having smaller ratings and leads of the cable on the terminal and the small section to be cabled via window of the toroidal transformer.

There are many issues of the relay settings as it should be adjusted according to the unbalance current that is calculated on the secondary winding of the toroidal transformer. The average tripping time which is present in literature for this relay is 300 ms to 1 second, particularly 500ms for avoiding occurrence of any external faults

III. WORKING PRINCIPLE OF NGT

The basic method for detecting the ground faults is to couple the over-voltage relay for monitoring the voltage impressed across the resistor as depicted in figure 2.17. It is observed that the high value of the harmonics is generated by the generator. Such an element should be made for measuring the fundamental component of the voltage and to filter or attenuate the harmonics [1, 5].

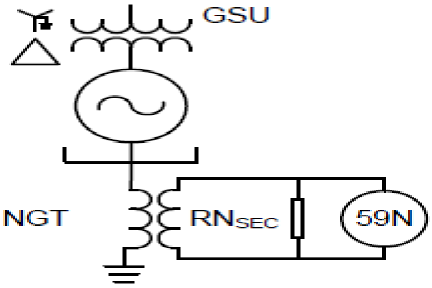

Figure 2. 4: Generator having the fundamental neutral over-voltage (59N)

The high value of the impedance grounded generators is coupled to the power system through the delta connected GSU. It is observed that under the operating conditions, no basic current flow through NGT and fundamental across the 59N and the grounding resistor is zero. During the stator ground faults, the fault current of the ground flowing through the NGT thus causes the voltage which is impressed by the grounding resistor. The over-voltage function relay is for measuring the magnitude of the fundamental voltage and hence detect the faults of the ground in the winding of the stator [11-12].

IV. METHODOLOGY

The calculations of the obtained data are shown in this chapter. The rating of the generator is depicted in table 4.1 and table 4.2 depicts the data of the GSU transformer, whereas that of 4.3 represents the capacitance values of the Generator;

TABLE 4. 1: GENERATOR RATED VALUE

Generator type	Abbreviations	Synchronous generator with salient poles
Rated power output	SGen	522 MVA
Rated stator voltage	UGen	18 kV
Operating range of stator voltage		+/- 5 %
Ext. operating range of stator voltage		+/- 10 %
Rated current	IGen	16743 A
Rated Frequency	F	50 Hz
Stator winding capacitance	CGen	2.46 µF

GSU Transformer:

TABLE 4. 2: GSU TRANSFORMER RATED VALUE

Rated power output	SGSU	3 x 174 MVA
Rated Voltage primary	UGSU,prim	500 kV
Rated Voltage secondary	UGSU,sec	18 kV
Capacitance HV-LV	CGSU, HV-LV	2.248 nF
Capacitance HV-E	CGSU, HV-E	3.983 nF
Capacitance LV-E	CGSU, LV-E	35.320 nF

The sum 1ph-to-ground capacitance is calculated according to following table. The main values are the capacitance of the generator winding and of the protection capacitors.

TABLE 4. 3: SINGLE PHASE TO GROUND VALUES ARE CALCULATED ACCORDING TO THE FOLLOWING TABLE

Equipment	Phase Capacitance to Ground (C0)	Remark
Generator	CGen = 2460.000 nF	
Capacitor, Main Transformer side	CCap = 100.000 nF	
Capacitor, Generator side	CCap = 50.000 nF	acc. to arrangement
Main IPB 65 m 100 kA IPB @ 114.7 pF/m	CIPB = 7.456 nF	
Main transformer LV/Earth	CGSU, LV-E = 35.320 nF	
Main Transformer Delta IPB 12.5 m 100 kA IPB @ 76.32 pF/m	CGSU,Delta = 0.954 nF	acc. to arrangement draw
Sum 1ph-to-ground capacitance	C0 = 2653.74 nF	

V. CALCULATIONS

Impedance criteria:

$$\acute{R} \leq \frac{1}{3\omega C_0} \quad \text{(Equation 4-1)}$$

$$= \frac{1}{3.2.pi.50.2.65e-6}$$

$$= \mathbf{400.4\ ohm}$$

Current criteria:

Resistive current component will be:

$$I_R \leq \frac{U_{norm}}{\sqrt{3}.\acute{R}} \quad \text{(Equation 4- 1)}$$

$$= \frac{19.10^3 V}{\sqrt{3}.400.4}$$

$$= \mathbf{25.95A}$$

Capacitive current component will be:

$$I_C = \frac{U_{nom}}{\sqrt{3}.\frac{1}{3\omega C_0}} \quad \text{(Equation 4- 2)}$$

$$= \frac{18e3\ V}{\sqrt{3}.\frac{1}{3.2.pi.50.2.65e-6}}$$

$$= \mathbf{25.95\ A}$$

Short circuit current will be:

$$I_{SC} = \sqrt{I_R^2 + I_C^2} \quad \text{(Equation 4- 3)}$$

$$= \sqrt{25.95^2 + 25.95^2}$$

$$= \mathbf{36.70\ A}$$

Grounding Transformer Design Ratio:

$$\mathrm{N_{GT}} = \frac{\mathrm{U_{GT,prim}}}{\mathrm{U_{GT,sec}}} \quad \text{(Equation 4- 4)}$$

$$= \frac{18\ \mathrm{kV}}{\sqrt{3}}\mathrm{VA}$$

$$= \mathbf{381.4\ kVA}$$

Transformer Data:

18kV /V3 /500V; 381.4 kVA

Secondary Resistor Design

$$\mathrm{R} = \frac{\mathrm{\acute{R}}}{\mathrm{N^2}_{\mathrm{GT}}} \quad \text{(Equation 4- 5)}$$

$$= \frac{400.4}{20.78^2}$$

$$= \mathbf{927\ m\Omega}$$

Resistor Data:

R=927 mΩ; V= 500V

Impedance criteria:

$$\mathrm{X_{C0}} = \frac{1}{\omega \mathrm{C_0}} \quad \text{(Equation 4- 6)}$$

$$= \frac{1}{2.\mathrm{pi}.50.2.65\mathrm{e}-6}$$

$$= 1201.2\Omega$$

$$\mathrm{X_{cg}} = \frac{\mathrm{X_{C0}}}{3} \quad \text{(Equation 4- 7)}$$

$$= \frac{1201.2}{3}$$

$$= 400.4\ \Omega$$

$$\boldsymbol{\grave{R} = X_{cg} = 400.4}\Omega$$

Current criteria Short circuit current will be;

$$I_{SC} = I_R + jI_{Xcg} \quad \text{(Equation 4- 8)}$$

$$\acute{R} = X_{cg}$$

$$I_{SC} = I_R.(1 + J + 1)$$

$$= I_R.\sqrt{2} = \frac{\frac{U_{Gen}}{\sqrt{3}}}{\acute{R}}.\sqrt{2}$$

$$= 36.71\ A\ \rightarrow > 20\ A$$

Secondary Resistor Design:

$$\mathrm{R} = \frac{\mathrm{\acute{R}}}{\mathrm{N^2}_{\mathrm{GT}}} \quad \text{(Equation 4- 9)}$$

$$= \frac{\acute{R}}{\left(\frac{18.e3}{\sqrt{3}.500}\right)^2}$$

$$= 927\ m\Omega$$

$$\mathrm{I_{sec\ max}} = \frac{\mathrm{U_{sec\ max}}}{\mathrm{R}} \quad \text{(Equation 4- 10)}$$

$$= \frac{\frac{\mathrm{U_{Gen}}}{\sqrt{3}}.\frac{\mathrm{U_{GT,sec}}}{\mathrm{U_{GT,sec}}}}{\mathrm{R}}$$

$$= \mathbf{539.4A}$$

$$P = I_{sec\ max}^2.R \quad \text{(Equation 4- 11)}$$

$$= \boldsymbol{269.7\ kW}$$

Resistor Data:

R=927 mΩ, 269 kW, V=500V

Grounding Transformer Design:

$$\mathrm{N_{GT}} = \frac{\mathrm{U_{GT,prim}}}{\mathrm{U_{GT,sec}}} \quad \text{(Equation 4- 12)}$$

$$= \frac{18\ \mathrm{kV}}{\sqrt{3}}.\frac{1}{500V}$$

$$= 20.78$$

$$\mathrm{S} = \mathrm{U_{GT,sec}}.\mathrm{I_{sec,max}} \quad \text{(Equation 4- 13)}$$

$$= \mathbf{500V.539.4A = 269.7\ kVA}$$

CONCLUSION

In this thesis, the technique of neutral grounding transformer for the hydro-generators was analyzed. It was observed that grounding is very important for saving the generators from the stator to ground faults. These types of faults severely damage the generator stator’s winding thus generator is prone to permanent damage.

The challenges which are faced during the no grounding, low resistance grounding and high resistance grounding are briefly discussed in the thesis. There are certain advantages and disadvantages of every technique. Moreover, the problems which are faced during the 3rd harmonic injection are also discussed. The ground coupling capacitance was observed to be had a major effect on the stator to ground faults. The capacitance value thus controls the capacitive current that is flowing from the winding to the ground.

The study includes the case study of the Tarbela Hydro Power Plants. The grounding techniques of the generators were observed, and certain values were calculated which were depicted in the chapter 4. In literature there are few standards that should be adopted while designing the grounding transformer. The design made by opting the standards provide the optimum results. It is recommended that to use modern techniques for sensing the stator to ground faults. From the literature study it is obvious that various intelligent deep learning and machine learning techniques can effectively detect the faults and provide the better results than the traditional techniques.

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