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100% Stator Ground Fault Protection of Alternators by Low Frequency Injection and Using Real Power Signal

Md Mizanur Rahman , S M Salim Reza, Sajib Chakraborty, Wahidul Hasan, Dilshad Ara Hossain

Abstract*- In this paper, 100% stator ground fault protection by application of low frequency (20 Hz) injection for 6.6/132 KV alternators have been investigated. Here, different types of faults of alternators and possible protections by conventional means have been discussed. It is shown why conventional method by differential relay protection is not adequate. Modern approach of alternator fault protection is reviewed and effective methods of 100% stator ground fault protection of alternators have been applied. In this work, it is focused protection of alternators based on sub-harmonic injection method using low frequency band pass filter. The design of stator ground fault protection consists of 20 Hz signal generator, band pass filter, 20 Hz current relay and protection system model includes alternator, total capacitance to ground of stator winding, grounding transformer turns ratio, and neutral resistor. PSPICE simulation of the protection scheme is performed and analyzed.

Keywords—Alternator; Generator; Filter; Stator; Pspise simulation

I. Introduction

An undetected stator ground fault on a large turbine generator can cause millions of dollars in damage and a larger amount of lost operating revenue during the time the generator is out of service being repaired. Synchronous generators are very important elements in power systems since they are in charge of providing an uninterrupted power supply to the consumers.

Md Mizanur Rahman
Department of Electrical & Electronic Engineering, Primeasia University (PAU)
Dhaka, Bangladesh

S M Salim Reza
Assistant Professor, Faculty of Science & Technology, Bangladesh University of Professionals (BUP)
Dhaka, Bangladesh

Sajib Chakraborty
Department of Electrical & Electronic Engineering, Independent University
Dhaka, Bangladesh

Wahidul Hasan
Department of Electrical & Electronic Engineering, Independent University
Dhaka, Bangladesh

Dilshad Ara Hossain
Dhaka, Bangladesh

Therefore their reliability and good functioning are crucial. The construction as well as maintenance costs are high depending on the complexity and the size of the generators. Moreover, damaged generators usually have to be returned to the manufacturer to restack and rewind because it is not common that companies using generators have the skills to repair them. [1] The important role of generators in the power system and the cost of fixing them in case of damage require a protection system against faults, which means, they must be protected against the damage caused by irregular situations in the electrical network or in the generator itself. [2-3].

Protection system used for generator protection should be robust to extent that it will not interrupt the system for non-serious faults and on the other hand should be sensitive enough to detect all kinds of faults in the generator windings with different degrees of seriousness. Therefore, if the generator protection system is robust and sensitive, the generator will not be unnecessarily shut down but it would in case the generator is damaged. Thus, generators have to be protected against external faults and internal faults. It's like a local fault in one of the coil. The protection scheme to cover stator inter turn fault is simply basis the theory of differential theory. In normal condition, the two coils or multi coils individually carry same magnitude of current but with a phase displacement.

II. Stator Protection

Differential protection is used for protection of the generator against phase to earth and phase to phase fault. Differential protection is based on the circulating current principle. In this type of protection scheme currents at two ends of the protection system are compared. Under normal conditions, currents at two ends will be same. But when the fault occurs, current at one end will be different from the current at the end and this difference of current is made to flow through relay operating coils. The relays then closes its contacts and makes the circuit breaker to trip, thus isolate the faulty section. This type of protection is called the merz price circulating current system [5]. Limitations of this method: The earth fault is limited by the resistance of the neutral earthling. When the fault occurs near the neutral point, this causes a small current to flow through the operating coil and it is further reduced by the neutral resistance. Thus this current is not sufficient to trip the circuit breaker. By this protection scheme, one can protect only 80 to 85 percent of the stator winding [6-7].

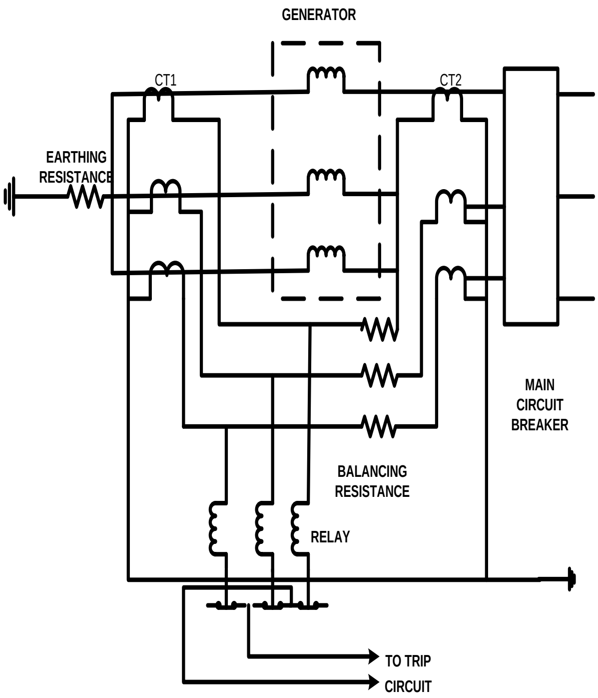


Figure 2. Differential protection for generators

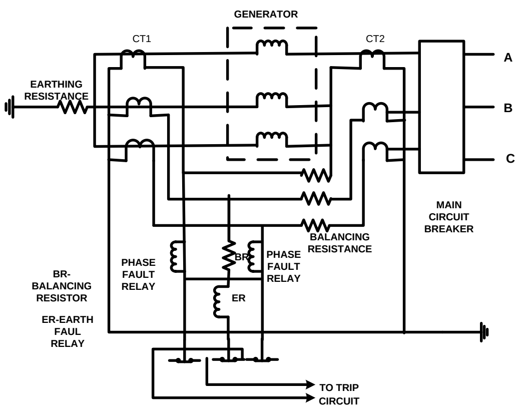


Figure 3. Modified differential protection for the generators

III. Result, Discussion and Analysis

One hundred percent stator ground fault protection is provided by injecting a 20 Hz voltage signal into the secondary of the generator neutral grounding transformer through a band-pass filter. The band-pass filter passes only the 20Hz signal and rejects out-of-band signals. The main advantage of this protection is 100% protection of the stator windings for ground faults including when the machine is off-line (provided that the 20 Hz signal is present.) Fig.7.1- Illustrates a typical application. A 20 Hz voltage signal is impressed across the grounding resistor (R_N) by the 20 Hz signal generator. The band-pass filter only passes the 20Hz signal and rejects out-of-band signals. The voltage across the grounding resistor is also connected across the voltage input (V_N) of the 64S relay. The current input (I_N) of the 64S relay measures the 20 Hz current flowing on the grounded side of the grounding transformer and is stepped down through a CT. It is important to note that the relay does not measure the 20 Hz current flowing through the grounding resistor. The 20Hz current increase during ground faults on the stator winding and an over current element that operates on this current provides the protection [4].

A. 20 Hz Subharmonic Alternator Schematic Diagram, Parameter Calculation for Analysis

The following shows how to calculate the 20Hz voltage and current measured by the 64S relay.

Here, Grounding Transformer Turns Ratio (N):

Assume that the turns ratio of the grounding transformer is equal to:

$$N = \frac{8600}{240} \qquad \text{(i)}$$

Capacitive Reactance: The total capacitance to ground of the generator stator windings, bus work and delta connected transformer windings of the unit transformer is expressed as C_0. Generator step up transformers have delta connected windings facing the generator so capacitance on the high side is ignored. The corresponding capacitive reactance is calculated as follows:

$$X_{co} = \frac{1}{2\pi f_o C_o} \qquad \text{(ii)}$$

The capacitive reactance for 1 micro-Farad is equal to:

$$X_{co} = \frac{1}{2\pi(20Hz)(10^{-6}F)} \qquad \text{(iii)}$$

$$= 7{,}985\ \Omega \text{ primary}$$

Reflect the capacitive reactance to the secondary of the grounding transformer:

$$X_{co} = \frac{7985\Omega}{N^2} \qquad \text{(iv)}$$

$$= \frac{7895\Omega}{(8000/240)^2} = 7.162\ \Omega$$

Grounding Resistor (R_N): The ohmic value of the grounding resistor can be sized as follows so as to avoid high transient over voltage due to Ferro-resonance:

$$R_N = \frac{X_{co}}{3} \qquad \text{(v)}$$

$$= \frac{7.162\Omega}{3} = 2.387\ \Omega \text{ secondary.}$$

A value of 2.5 Ω secondary is used for this example. 20 Hz Signal Generator and Band-pass Filter Characteristics:

Assume that the 20 Hz signal generator outputs 25 volts. The band-pass filter has a resistance equal to 8 Ω.

V = 25 volts
R_{BPF} = 8 Ω secondary

Stator Insulation Resistance R_S: R_S is the insulation resistance from the stator windings to ground. A typical value for non-fault condition is 50,000 ohms primary.

$$R_S = \frac{50000\Omega}{N^2} \quad \text{(vi)}$$

$$= \frac{50000\Omega}{(8000/240)^2}$$

= 45 Ω secondary

Current Transformer: The current input (I_N) of the 64S relay measures the 20 Hz current flowing on the grounded side of the grounding transformer and is stepped down through a CT.

CTR = 80/1

Grounding Network: Now there are all of the elements needed to mathematically represent the grounding network and determine the 20 Hz signals measured by the 64S relay.

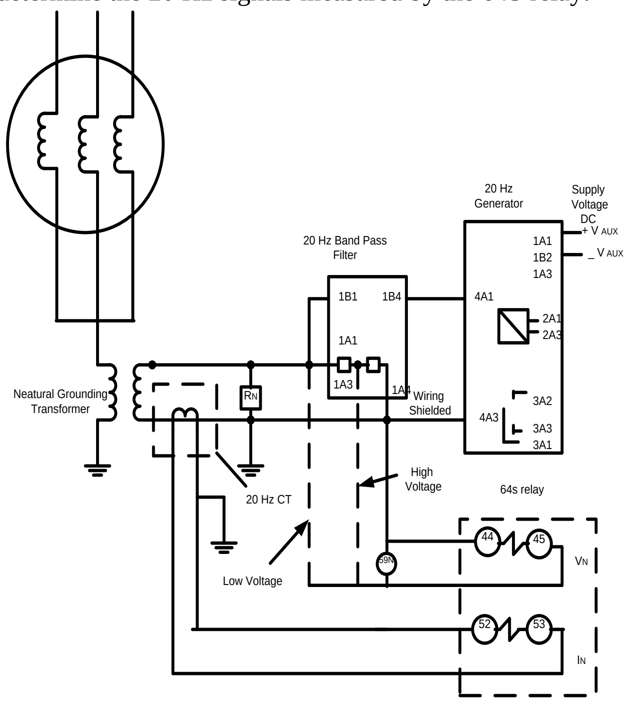


Figure 4. Schematic diagram and 20 Hz injection grounding network

B. Total 20 Hz current Supplied by Signal Generator

The 20 Hz signal generator looks into the band-pass filter resistance (R_{BPF}) which is in series with the parallel combination of the following:

- Z_{c0}
- R_S
- R_N

Therefore, the total loop impedance of the 20 Hz grounding network can be expressed as follows:

$$Z_T = R_{BPF} + (R_N // R_S // Z_{co}) \quad \text{(vii)}$$

$$= 8 + 2.5 // 45 // -7.162j$$

= 10.135-0.706j Ω secondary

The total 20 Hz current supplied by the signal generator is determined as follows:

$$|I_T| = \left| \frac{V}{CTR \times Z_T} \right| \quad \text{(vii)}$$

$$|I_T| = \left| \frac{25}{80 \times (10.135 - 0.706j)\Omega} \right|$$

= 30.759 mA

C. Equivalent Circuit of 20 Hz Alternator Model for Analysis

The 20 Hz current measured by the 64S relay is the ratio of the total current that flows into the primary side of the grounding network (Z_{co}//R_S):

$$|I_N| = \left| I_T \times \frac{R_N}{R_N + Z_{co} // R_S} \right| \quad \text{(viii)}$$

$$|I_T| = \left| 30.579 \times \frac{2.5}{2.5 + (-7.162j) // 45} \right|$$

= 9.779 mA(Non-Faulted)

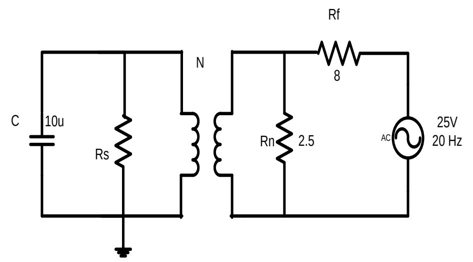
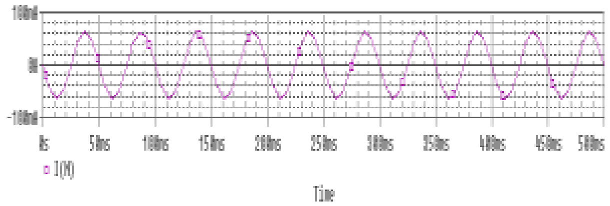


Figure 5. Equivalent circuit for 20 Hz grounding network - referred to primary of grounding transformer



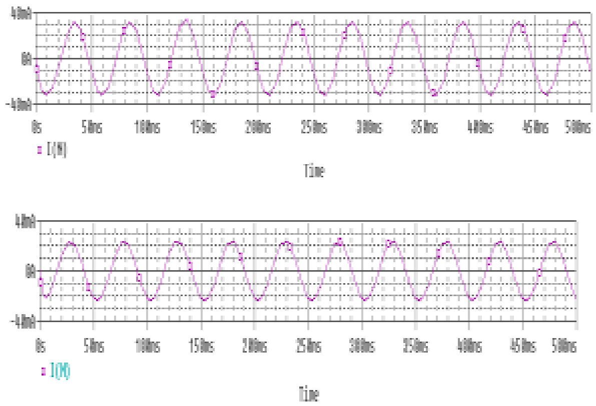


Figure 6. Neutral current measurement of equivalent circuit of 20 Hz grounding network for low capacitance

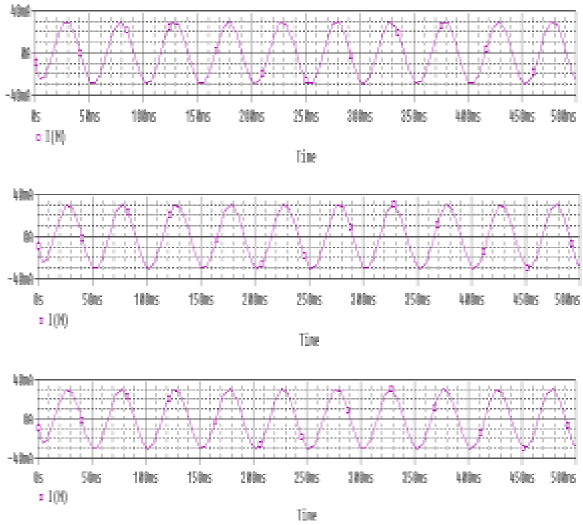


Figure 7. Neutral current measurement of equivalent circuit of 20 Hz grounding network for high capacitance

D. 20 Hz Current Measured by Relay during Ground Fault on Stator Windings

A typical value to represent the insulation resistance of the stator winding breaking down during a ground fault is 5,000 ohms primary. If the calculations for a fault resistance equal to 5,000 ohms primary (4.5 ohms secondary), then the 20 Hz current measured by the relay is as follows:

$$|I_N| = 13.486 mA (5{,}000\Omega \text{ primary ground fault})$$

If the calculations for (7) through (9)are repeated for a fault resistance equal to 1,000 ohms primary (0.9 ohms secondary), hence the 20 Hz current measured by the relay is follows:

$$|I_N| = 26.640 \text{mA} (5{,}000\Omega \text{ primary ground fault})$$

Table 1 summarizes the 20 Hz current measured by the relay for Non-faulted and faulted conditions.

TABLE I. 20 Hz CURRENT MEASUREMENTS FOR LOW CAPACITIVE CIRCUIT (1uF)

Rs (primary)	I_N(Peak)	Condition
1000 Ω	62 mA	Fault
5000 Ω	33 mA	Probably Fault
50000 Ω	23 mA	Non Fault

Set the pickup of the 64S relay over current element above the current measured during normal operating conditions but below the current measured for a ground fault equal to 5,000 ohms primary.

E. PSPICE Model for Simulation

Transformer model is not available directly in PSPICE. Mutually coupled inductor of PSPICE has been used to model transformer, the parameters of which are calculated below,

$$\frac{L_1}{L_2} = \left(\frac{N_1}{N_2}\right)^2 \qquad \text{(xi)}$$

Here L_2=5H, N_1=8000, N_2=240 equating these value at Eq. xi, the value of L_1=5500H. Transformer magnetic coupling (primary-secondary) coefficient is assumed 0.9999.

III. Conclusion

The simulation shows that 100% coverage of the stator windings for ground faults including when the machine is off-line is possible. The total capacitance-to-ground of the generator stator windings, bus work and delta-connected transformer windings of the unit transformer is a very important factor and must be known to ensure the protection settings are correctly determined. There are cases when it is hard to distinguish between normal operating conditions and an actual ground fault unless special steps are taken in the design of this protection. A good rule of thumb to decide if the real component of 20 Hz current is necessary is when C_0 is greater than 1.5 micro-Farads and the grounding resistor is less than 0.3 ohms secondary. The real component of the 20 Hz current measured by the relay for these cases has been applied before. But from this thesis work it has been found that, power relay can be used for distinguish the difference between normal and fault condition. So 100% stator protection for ground fault condition by using power relay is the new possibility for generator protection system.

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About Author (s):

Mizanur Rahman has completed his B.Sc. Engg in EEE from Bangladesh University of Engineering and Technology (BUET).He has been serving as a lecturer in the Dept. of EEE of Primeasia University, Bangladesh (PUB), Dhaka, Bangladesh.

S M Salim Reza has been serving as Assistant Professor of the Department of ICT, Faculty of Science and Technology (FST) in Bangladesh University of Professionals, Mirpur Cantonment, Dhaka, Bangladesh

Sajib Chakraborty received his Bachelor of Science in Electrical and Electronic Engineering from Independent University, Bangladesh. Currently, he is studying Master of Science (Power) in Independent University, Bangladesh. His research interests include hybrid power system, sustainable energy and high voltage engineering.

Wahidul Hasan has completed his B.Sc Engg in EEE from Independent University, Bangladesh (IUB) and he is doing his MS in EEE at same institution. Presently, he has been working as Research Assistant (RA) in the Dept. of EEE of Independent University, Bangladesh (IUB), Dhaka, Bangladesh.

Dilshad Ara Hossain is a CSE graduate from Bangladesh. She worked as ICT Teacher in GCSE Level on Dhaka. Her research interest includes ICT, Telecommunication, Electronics, Cyber Security and International Cyber Law.