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Online neutral grounding resistor monitoring for unit-connected generators with hardware validation

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ABSTRACT

Neutral grounding resistors are used to control transient overvoltages and overcurrents in power systems. Failure of these critical assets revives many disadvantages of ungrounded and solidly grounded traditional systems. Therefore, monitoring the neutral grounding resistors is necessary. A new continuous monitoring technique is proposed for such a resistor located at the neutral of unit-connected generators. It detects resistor failure by comparing the third harmonic of neutral and residual voltages. This proposed scheme demonstrates reliable operation under various conditions of the system and resistor as observed by PSCAD in conjunction with MATLAB. Further performance validation has been carried out using an industrial generator protection relay as well. In contrast to existing methods, this scheme does not require any additional measurement instruments. Thereby, it is easily retrofitted to installed unit-connected generator protection infrastructures. Moreover, this continuous monitoring technique prevents maloperation of the generator stator ground protection due to the neutral grounding resistor failure.

1. Introduction

Neutral Grounding Resistors (NGR) are used to limit overcurrent, and control transient overvoltages in power systems. Thereby, the thermal and electromechanical stresses are suppressed to a safe level [1–4]. However, NGRs fail due to outdoor environmental incidents such as striking light, corrosion, vibration due to earthquake, etc. Degradation of these key assets results in many challenges that have been reported by ungrounded and solidly grounded traditional systems [5–7]. Consequently, NGR monitoring is necessary as mandated by Canadian Electric Code (CEC) in section 10 and National Electric Code (NEC) in article 250 [8,9].

Well-designed power systems do not experience noticeable energy flow in the neutral earthing system unless a ground fault occurs. Since identifying a defective NGR is mainly required during normal (unfaulted) condition to guarantee a safe operation during an impending ground fault [6], the aimed monitoring suffers from insufficient voltage and current of the neutral system.

Existing monitoring schemes are classified into three categories: passive, active, and passive-active. Passive methods assume that the neutral system always experiences a minimal current, in the order of milliamperes, due to inherent asymmetry of the power system components [10]. They use either a sensitive CT or a zero-sequence-current-sensor to provide wide range current measurement. Their only challenge is the measurement of the neutral voltage. Using neutral voltage and current, they benefit from two logics called impedance supervision and neutral current supervision. The neutral voltage is measured different ways resulting in various passive monitoring approaches. The simplest sort of passive monitoring method relies only of the neutral current. It supervises the presence or absence of the neutral current, and detects the disconnected NGR conditions. This method is not known as a NGR monitoring method since it only detects the disconnection of the neutral circuit. Therefore, the advanced type of passive monitoring methods were proposed that offer a better performance using the neutral current and voltage. These methods use both of the neutral current supervision and NGR impedance supervision logics. Their only difference is the neutral voltage measurement mechanism that results in different operation principles. The second method uses the neutral sensitive CT and neutral PT. The minimum accuracy limit of the neutral PT is 10%. Therefore, it relies on NGR impedance supervision only when the neutral voltage is higher than 10%. Otherwise, it employs the neutral current supervision logic. The only issue with this concept is

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that the neutral voltage is not as high as 10% in normal operation condition, where the NGR monitoring is most required. Therefore, the enhanced version of this method was proposed in [11,12], which is the third passive monitoring method. This method uses the residual voltage, obtained by three-phase line PTs, instead of neutral voltage obtained by neutral PT. The minimum accuracy limit of the residual voltage is 1%, which results in wider range of NGR impedance supervision and better performance compared to the previous method. Yet, it is believed that the neutral voltage is most likely very low, even less than 1%, in normal operation condition. Thus, the fourth passive method came to the picture which uses the resistive potential divider with minimum accuracy limit of as low as 0.1%. The only issue is the sampling resolution required for such a measurement accuracy, e.g., 12bits or 4096 for having less than 10% error over 0.1–500% of neutral voltage in a MV system [13]. The last sort of passive monitoring methods uses the sensing resistor which guarantees error-less measurement of the neutral voltage in normal operation condition. The sensing resistor is nothing but a high resistance resistor in series with a Transient Voltage Suppressing (TVS) diode. Accordingly, the NGR resistance is obtained with less than 10% error. However, this method cannot obtain the NGR resistance in presence of the ground faults. But, it still can monitor the connectivity of the neutral-to-ground circuit using the neutral current supervision logic [6,10,14]. The last sort of the passive methods only use the neutral voltage for NGR failure detection by comparing the frequency spectrum of the measured voltage with pre-saved archived data [15,16]. These two methods effectively distinguish the ground faults from NGR failure for unit-connected generators. Along with the mentioned issued, none of the passive methods can monitor the NGR in de-energized condition. That is why the active methods came to existence.

The second category of monitoring methods, called active methods, inject an AC/DC signal to neutral to monitor the NGR. The first active method relies on the continuity of the injected signal to detect the shorted or disconnected NGR conditions [17–19]. These methods employ only the neutral current supervision logic to detect the presence or absence of neutral current which means they cannot identify partial failures of the NGR. The more advanced types of active methods rely only on impedance measurement [20,21], which makes them stronger than passive methods. However, the additional instruments required for both signal injection and metering cause extra expense. Moreover, monitoring ceases during ground faults since the injection system needs to be decoupled from the neutral system. Further, the monitoring system itself needs to be monitored adding to the complicity of these methods.

As may be realized, the combination of active and passive methods results in the best performance. There exist methods that use this concept, which are called passive-active methods. The active concept is used when the neutral voltage and current are very low which means that the system is healthy, and the injection system can be connected to the neutral. Otherwise, the injection system is decoupled from the neutral, and the existing neutral voltage and current of the neutral system are employed, which is the passive concept [22,23].

This paper proposes a new monitoring method applicable to the high resistance NGR located at neutral of Delta-Wye or Delta-Delta grid-connected generator configurations. The proposed technique does not inject any signal or require any additional metering instruments, which are significant advantages. Moreover, it solves the undesired operation of generator stator ground protection due to failed NGR. Fundamentals of the proposed technique are explained in Sections 2 and 3. In Section 4, the performance of the method is investigated for various failures of the NGR considering different conditions of the system, by PSCAD in conjunction with MATLAB and hardware validation using an industrial generator protection relay. Lastly, conclusions are presented in Section 5.

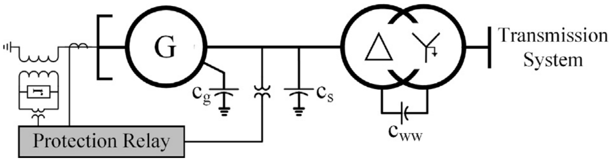

Fig. 1. High-resistance-grounded unit-connected generator.

2. Fundamentals and concepts

The proposed technique monitors the NGR located at neutral of unit-connected generators as shown in Fig. 1. As known, generators are often connected to the system through a delta-wye transformer. This configuration, called unit-connection, provides a unique feature which is the third harmonic and zero sequence isolation. It means that the ground faults in transmission system will not have any effect on neutral and residual third harmonic voltages of the generator. Moreover, if the ground fault occurs at generator side, the high voltage system will not feed the third harmonic into the ground fault except through the transformer interwinding capacitance which is very small. However, this concept does not apply to wye-wye transformer. Under this condition, the transformer bank must be high resistance grounded, or ungrounded which is not a recommended practice. In Fig. 1, the c_g and c_s are generator and generation-side-system phase-to-ground capacitances, respectively. The c_{ww} is the inter-winding or primary-secondary capacitance of the step-up transformer.

Since the proposed technique employs the third harmonic of the neutral and residual voltages, the third harmonic model of the system is needed, as depicted in Fig. 2.

In this figure, $-jX_{CG}$, $-jX_{CS}$ and $-jX_{CWW}$ are capacitive reactances related to c_g, c_s and c_{ww}, respectively. The $-jX_{CG}$ is divided between two ends of the generator stator. Moreover, $E3$ and $e3$ are phasor quantities that refer to third harmonic voltages generated by the generator and step-up transformer, respectively. The $e3$ is generated at star side of the step-up transformer and affects the delta side through $-jX_{CWW}$. Using superposition theorem, the third harmonic of neutral-to-ground voltage phasor, $VN3$, and that of the residual voltage phasor, $VR3$, are derived as below.

$$VN3 = \frac{Z_N}{Z_N + Z_T}E3 + \frac{Z_N||Z_T}{Z_N||Z_T - jX_{CWW}}e3 \tag{1}$$

$$VR3 = \frac{Z_T}{Z_N + Z_T}E3 - \frac{Z_N||Z_T}{Z_N||Z_T - jX_{CWW}}e3 \tag{2}$$

These parameters are normalized with respect to $E3$ considering that the magnitude of $-jX_{CWW}$ is remarkably greater than that of the $Z_N||Z_T$, based on data presented in [24]:

$$\overline{VN3} = \frac{VN3}{E3} = \frac{Z_N}{Z_N + Z_T} - \frac{Z_N||Z_T}{jX_{CWW}}\frac{e3}{E3} = A - B \tag{3}$$

$$\overline{VR3} = \frac{VR3}{E3} = \frac{Z_T}{Z_N + Z_T} + \frac{Z_N||Z_T}{jX_{CWW}}\frac{e3}{E3} = C + B \tag{4}$$

where the bar symbol indicates the normalization in respect to $E3$. In

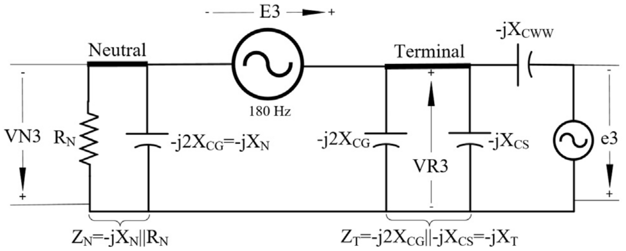

Fig. 2. Simplified third harmonic equivalent network of the system.