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Suppression of geomagnetic induced current using controlled ground resistance of transformer

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ABSTRACT

Geomagnetically induced currents (GICs) in power systems can cause transformer-overheating malfunction of protective relays, tripping of protective devices, and voltage instability. This article presents a new approach by using a controlled resistance to suppress the GIC flowing through the neutral of transformers. The performance of the proposed method is compared with that of the currently adopted method, i.e., the fixed-capacitor method. In this work, a power network consisting of a single synchronous machine connected through a step-up delta/wye transformer, a double run transmission line and another step-down transformer to an infinite bus, is considered. The GIC is modeled as DC voltage pulses inserted in series with the line. The MATLAB/SIMULINK software is utilized to carry out simulations. Simulation results show that the proposed method is able to stabilize the system under GIC events. In addition, the new technique helps mitigate the zero sequence current flowing through the neutral of transformers during unsymmetrical faults. Moreover, the performance of the proposed method is better than that of the conventional method.

1. Introduction

Plasma clouds of high energy are produced by solar disturbances. Those clouds generate geomagnetic disturbances (GMDs) when they interact with the earth magnetic field. Those virtual conductors are called electrojets. During GMDs, electrojects magnetic field variations (nT/minute) induce a very low frequency quasi-dc current (less than 1 Hz) in long conductors, such as transmission lines, pipelines, and railways. These currents are commonly referred to as geomagnetically induced currents (GICs) [1,2]. As per the history of GIC events [3], the Hydro Québec power system collapsed on March 13–14 of 1989, as a geomagnetic storm hit the earth with a magnitude of 500 nT/min. This storm resulted in the collapse of the entire Québec grid in 90 s. Seven online static var compensators (SVCs) tripped, resulting in voltage drop of 0.2 pu. The interconnections to Montréal tripped due to loss of synchronism; hence, the networks got separated [1]. The blackout did not reach the USA. However, there were many reports of lines being tripped and other power system problems. Also, irregularities were recorded around the globe during the next 24 h period, and a large transformer located at nuclear plant in New Jersey was damaged and taken out of service [4]. The lead-time (production time) of a high-voltage transformer is between 12 and 24 months. So, if several of these key transformers were taken out of service, long-term power outage is anticipated.

Fig. 1 illustrates the effects of GIC on power systems components [1]. It is clear that power transformers are the most affected by the GIC. Transformers generate unusual even and odd harmonics under GIC conditions [5]. These harmonics are capable of improperly triggering the relays, heating up transformers, and generators, which result in the improper operation of the system's components, and might trip them right away and may cause damage in the long term.

Since the GIC flow will saturate the positive cycle of the AC exciting current (Half-cycle saturation) [6], their reactive power consumption increases critically and generates higher order harmonics which in turn trips shunt capacitors and SVC, and eventually leads to a voltage collapse [4,7].

GIC has a significant impact on high voltage transmission lines as well as power transformers. Considering long transmission line circuit (> 250 km), in order to control the voltage level along these high-voltage transmission lines reactive compensators such as SVCs and static synchronous compensator (STATCOMs) are required. Under the GIC presence, as mentioned earlier, some compensators will trip and the voltage-drops of the line increases, hence other compensators trying to regulate the voltage drop with reactive power will be overloaded. This might destroy the fixed capacitors from overcharging as well, which leads to an even more severe voltage sag [7,8].

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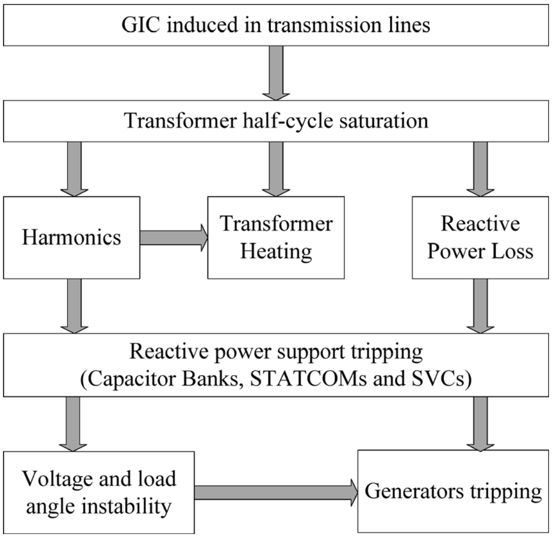

Fig. 1. GIC impact on power system's components.

The ability of various mitigation methods to block/partially block the GIC is investigated in the literature [9–15]. GIC blocking means can be both passive devices, such as linear resistors [9], capacitors with non-linear resistors (Varistors/MOV) with capacitors [10], polarizing cells [9], neutral capacitors [11], or series capacitors [13]. In [14], the authors have proposed a neutral switching circuit, where the circuit consists of a gate-turn-off (GTO) switch that converts the system from grounded wye to ungrounded wye. GIC mitigation devices can be active devices placed in-line or inserted in the neutral of the transformer to cancel the DC currents directly [15]. Active devices also can be placed in the tertiary winding to generate magnetomotive force opposing to the generated by the GIC [9].

Although these methods are reported effective during testing and simulation, they have practicality and reliability issues. For instance, polarizing cells have a very low dc voltage blocking limits, so high-voltage power system would require a long string of cells to block the neutral voltage under GIC effect. When using a capacitor in the neutral, any close line-to-ground faults can generate transient overvoltage which leads to surge protection devices associated with the blocking device to fail, thus a very large capacitor is required to support fault current or through bypassing the capacitor to discharge the neutral capacitance, via parallel resistors, spark gaps, vacuum switch, MOV, or interrupting protection circuit [12], which would add complexity and bulkiness to the neutral solutions and increase the cost as well. Furthermore, an issue with using capacitive blocking whether it is series in-line or neutral is the series resonance and ferroresonance, which may also occur and must be calculated for design. Unbalanced fault currents increase due to the zero sequence impedance cancelation when capacitor is employed [16]. Based on the above, adding a resistance to the neutral in order to minimize the GIC currents unlike the capacitor reduces system's complexity [9], suppress GIC flow and minimize the fault current [17].

This work proposes a new method by using controlled ground resistor to mitigate the GIC. The novelty of this work is summarized in the following:

- The controlled ground resistor is also designed to suppress the zero sequence current. So, the device can protect the transformers from a) GIC events, b) unsymmetrical faults, and c) faults during GIC event.
- The resistor was selected large enough to limit any zero sequence current flowing through the neutral of transformer during any unbalanced faults in the network.
- The controlled ground resistor is introduced at the neutral at *adjustable duty cycles*. Therefore, the effective resistance is *varied* according to *the severity* of the current. This work is different from the idea proposed in [9] that is adding a *fixed* resistor *constantly* during the GIC.
- Our method is also different from the circuit proposed in [14], which is using GTO switch at the neutral. The switch would transform the system from solidly grounded into ungrounded wye system.
- The authors in [14] did not intend their proposed device to tackle any kind of fault currents. They have added a protection circuit against faults composed of a parallel resistor (50–100 Ω) and a surge arrester to drain the transient voltage during transition of circuit breakers and an Earth Switch (ES) to temporally by-pass the GTO switch while circuit breakers operate.

Another salient feature of this work is that the performance of the proposed method is compared with that of the conventional fixed-capacitor connected to the neutral method. The validity of this work was tested on a single machine infinite bus power system under the events of GIC (6 v/km), single line to ground fault (SLG) and double lines to ground faults (2LG). Simulations were performed by using the MATLAB/SIMULINK software.

2. Modeling of system under study

In this work, the GIC effect on transmission lines is modeled by series dc voltage sources as seen in Fig. 2.a. Further, details on modeling and computing the GIC is given in [18]. In Fig. 2.a, the three-phase system model consists of a 2000 MVA synchronous generator connected to an infinite bus via two step-up (11/765 KV) and step-down (765/20 KV) delta/wye transformers, and a double run transmission lines. The GIC voltage source is placed at the high side of the generators transformer. The injected DC voltage is assumed to be 3000 v based on electric field of 6 v/km and the lines length of 500 km. The fault is placed at the point F1 and the circuit breakers (C.B) shown will open to clear the fault according to grid standards. To add more practicality to the model, transformers' saturation was implemented and designed using the MATLAB/SIMULINK saturation and hysteresis tools.

Fig. 2.b demonstrates the equivalent DC circuit for the GIC flow. The GIC in the electric transmission system depends upon the induced dc voltage in the transmission lines and the resistance of the system components. Since the GIC is fundamentally a dc, systems reactance has no contribution to the GIC magnitude. So, basically only resistive system components determine the GIC including the resistance of the transmission lines, the resistance of the coils of grounded transformers, the resistance of the series windings, and the substation grounding resistance. It is to note here that, for the GIC analysis, the per-unit principle plays no role. Thus, all resistance, currents, voltages must be given in ohm, ampere and volt, respectively.

3. Proposed control method

3.1. Controlled ground resistance topology

The proposed method as shown in Fig. 3 measures the current through solidly grounded neutral (during normal operation) and detects any alteration in the system operation. The measured value is regulated via proportional-integral (PI) controller in order to set the duty cycle value for the insulated-gate bipolar transistor (IGBT)