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Impact study of short-circuit calculation methods on the design of a wind farm's grounding system

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ABSTRACT

Safe operation of a wind farm (W/F), under fault conditions, requires a grounding study to ensure protection against developed voltages (step and touch). A key stage in the design of a wind farm's grounding system is to determine the maximum ground fault current. The aim of this work is to examine how different short-circuit calculation (SCC) procedures affect the calculation of developed voltages (step and touch) at a wind farm and therefore the provided level of safety. For this purpose, the response of the interconnected grounding system of an actual wind farm is calculated, under fault conditions, using three alternative SCC methods and the results obtained concerning violation or not of safety criteria are presented.

1. Introduction

The grounding system of a wind farm should ensure the protection of both human life and installed equipment, in case of power system fault. W/Fs in Greece are usually situated on mountainous areas with rocky ground, where the soil resistivity takes high values and the area available for the grounding system is usually limited. For these reasons mainly, in most cases, it is not possible to construct a grounding system at each wind turbine, with low grounding resistance. The main concern, therefore, when designing an effective grounding system should not only be the minimization of the W/F grounding resistance, but also meeting the safety criteria, as defined by the Standard ANSI/IEEE Std 80-2000 [1].

According to the Standard [1], the determination of the maximum ground fault current is a key factor in designing a safe grounding system. The SCC is generally of critical importance for the design and safe operation of an electrical power system or installation (e.g. electrical equipment sizing, setting protection devices, earthing system design etc.), thus justifying the development of numerous SCC methods. This paper focuses on SCC methods adhering to the American Standard ANSI C 37.010 [2], its European counterpart IEC 60909 [3] and that based on the principle of superposition.

The question that arises is how different SCC methods affect the calculation of the developed voltages (step and touch) in typical wind farm installations and, therefore, the provided level of safety. For the purposes of this paper, the response of the interconnected grounding system of an existing wind farm is calculated, under fault conditions, using three different SCC methods whereas a parametric safety study against developed voltages is carried out. Last, but not least, it should be made clear that it is not the intent of this work to either criticize or endorse any of the three SCC methods.

2. Short – circuit current calculation methods

In the international scientific and technical literature there are several methods for calculating short-circuit currents, some of which have been included in international standards, because of their comparative excellence concerning the accuracy of estimated current values, the method's complexity and the computational burden entailed. The comparative superiority of computational methods contained in IEC and ANSI Standards has made the latter as the most used, at international level, for calculating fault currents.

2.1. IEC 60909 standard

The European Standard IEC 60909 [3] is applicable to all networks, radial or meshed, up to 550 kV at a nominal frequency of 50 or 60 Hz. Therefore, short-circuit calculations according to IEC Standard are extensively performed for evaluating the design short-circuit capacity of a power system network related to the thermal and mechanical withstand capability of the electrical equipment and also to the switchgear selection and protection

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coordination. The IEC Standard adopts the method of equivalent voltage source to calculate fault currents. According to this method, an equivalent voltage source $c\tilde{U}_n/\sqrt{3}$ is placed at the fault point and the equivalent impedance $\tilde{Z}_k$, as seen from the fault point, needs to be determined. The voltage factor c takes into account the variations of the pre-fault voltage at the fault point, from its nominal system value, and it is given depending on the voltage level at the short-circuit location (LV/MV/HV) and the fault current type (maximum/minimum). Synchronous and asynchronous machines are replaced by their internal impedances (positive, negative and zero sequence), although the application of certain correction factors is also deemed necessary, while the static (non-rotating) loads are neglected. Doubly-fed induction generators (DFIG), extensively used nowadays in variable speed WTs, need to be considered also when calculating short circuit current contributions in power distribution networks with wind energy penetration. Despite the presence of the converter in their rotor circuit, their maximum fault current contribution resembles that of the directly connected induction generators. Hence, the IEC Standard equivalent impedance representation of induction generator may be applied in this case, using a ratio of locked-rotor to rated current of $I_{LR}/I_{RG} = 8$ and a duration Δt of contribution limited to 3–5 cycles [4].

2.2. ANSI C 37.010 standard

The American Standard ANSI C 37.010 [2] applies to electrical networks of nominal voltage above 1 kV and it is oriented in the selection of medium and high-voltage circuit breakers rated on a symmetrical current basis. *ANSI* short-circuit current calculation is based on the application of the simplified E/X method, which determines rms symmetrical fault current values (E/X), as a basis for the selection of circuit breaker ratings. According to this method, the electrical network is reduced separately to an equivalent R and X network, as seen from the fault point. The machine impedances used for the calculation of driving point impedance are mainly sub-transient reactances scaled using impedance correction factors, which differ according to the machine type (size and speed) and the fault current duty type under consideration. The ANSI Standard neglects pre-fault loads assuming unloaded network conditions.

2.3. Superposition method (conventional fault analysis)

The steady-state non decaying SCC (Conventional Fault Analysis-CFA) is based on the superposition method, consisting of three successive stages [5]:

Step 1: Calculate the pre-fault load flow conditions of the network (i.e. the pre-fault current flow and pre-fault voltage at the fault location).
Step 2: Determine the Thevenin equivalent of the initial network as seen from the fault location with all voltage sources ignored (short-circuited). The only active voltage source is the pre-fault voltage at the fault location with opposite sign.
Step 3: The conditions of the previous two steps are superimposed giving the fault current.

The reasons for selecting this method are the low input data and computational requirements, compared with the above mentioned SCC methods [6]. The key feature of this method is that it entails load flow analysis of the pre-fault state of the network thus, giving an insight into the new steady-state operating conditions of the network, after the fault transients, in case of outage occurrence (contingency analysis).

3. Short – circuit current duty types

The IEC 60909 Standard considers four types of duties for short-circuit currents:

1. *Initial* symmetrical short-circuit current (I''_k): rms value of ac symmetrical short-circuit current flowing immediately after the fault occurrence, taking into account only the sub-transient reactance of rotating machines.
2. *Peak* short-circuit current (I_p): maximum instantaneous value of short-circuit current after the fault occurrence.
3. *Breaking* short-circuit current (I_b): rms symmetrical short-circuit current flowing through the first phase to open when contact separation occurs in the circuit breaker.
4. *Steady-state* short-circuit current (I_k): rms symmetrical short-circuit current after all fault transients have died away.

The ANSI/IEEE C 37.010 Standard calculates, also, four short-circuit current duty types:

1. *First Cycle* current (first cycle time duty): rms symmetrical fault current at ½ cycle after short-circuit inception, which allows the evaluation of stresses during the first cycle.
2. *Momentary* current (closing–latching time duty): rms asymmetrical fault current at ½ cycle after short-circuit inception. This rms current is used to examine the circuit breaker's capability to remain closed until tripped.
3. *Interrupting* current (contact parting time duty): rms asymmetrical fault current at the parting of the circuit breaker poles.
4. *Time delayed* current (time delay duty): rms symmetrical fault current at a point in time (> 6 cycles) when the motor contribution can be safely omitted and generators are represented by their transient or greater reactances.

The above mentioned fault current duty types are listed for both Standards in Table 1 [7].

4. W/F grounding system design methodology

The methodology used, extensively, in the design process of wind farm grounding systems in Greece consists of the following steps [8,9]:

1. Determination of the maximum ground fault current
2. Measurement of the soil resistivity, using the Wenner method, at each prospective installation location of wind turbine (W/T) or Control Center (C/C)
3. Calculation of the soil model, based on soil resistivity measurements, for each prospective installation location
4. Calculation of the maximum allowable step and touch voltages, as defined by the ANSI/IEEE Std 80-2000
5. Design of default grounding grid for each W/T or substation
6. Calculation of the grounding resistance of individual grounding systems
7. Calculation of the allocated ground fault current to individual grounding systems

Table 1
Duty types per ANSI and IEC.

IEC 60909 duty type	ANSI C 37.010 duty type
initial	first cycle
peak	closing latching
break	contact parting
steady state	time delayed