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Effects of high frequency modeling & grounding system parameters on transient recovery voltage across vacuum circuit breakers for capacitor switching in wind power plants

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ABSTRACT

This paper investigates the transient recovery voltages across vacuum circuit breakers used for the switching shunt capacitor bank in wind power plants, which are connected to the power system. Consideration has been given to high frequency models of all power system components, such as, the transformer, wind power plant generator, cable, surge arrester, vacuum circuit breaker and grounding system. The initial phase of study reproduced the results of previous work. In the second phase, the influence of different parameters, such as, the grounding system network, current injection point location to the grounding system, soil resistivity, grounding system length segment and soil ionization phenomena in the grounding system on transient recovery voltage, have been investigated via EMTP-RV. The results show that consideration of the high frequency behavior of the grounding system in wind power plants for prediction of transient recovery voltages is very important.

1. Introduction

The use of wind power plants for energy production is growing and many attempts have been made to improve the reliability of this type of energy production plant through effective grounding systems. Normally the system of grounding is through generators and transformers neutral points. Proper grounding systems will reduce excess transient overvoltages and hence increase the reliability and safety as well as reducing damage to the interfaced electrical equipment to the plant [1,2].

The switching overvoltage is considered to be an important cause of insulation breakdown in the windfarm. Zhang et al. [3] report that there is a relationship between the switching overvoltage and the length of the feeder cable and the number of feeders that have been energized. Wu et al. [4] discuss simulation results obtained from a number of switching scenarios in one of the Fuhai offshore wind farms in Taiwan. These switching scenarios include breaker closing or opening with wind-farm cable and substation transformer at no-load conditions, breaker opening when single-phase or three-phase faults appears in the cable of the offshore wind farm. In general one cause of over-voltages in power plants is capacitor switching [5]. Shunt capacitor bank switching is used for reactive power compensation, voltage regulation and power factor adjustment. Typically shunt capacitor bank switches are equipped with a series-connected inductor, which limits the inrush current during capacitor energization and the outrush current during capacitor bus faults [5]. A common application of this configuration is when two capacitor banks are connected to the same bus bar or located within the same vicinity. This is generally called back to back switching [6]. Switching is performed via circuit breakers, and hence, to achieve reliability, knowledge of the transient recovery voltage across the vacuum circuit breaker is necessary for determination of the breaker's dielectric withstand capability. A number of researchers have investigated issues related to the connection and disconnection of VCBs comprehensively in both time and frequency domains [7,8] and [9]. The effects of different capacitor bank structures on transient recovery voltage across power systems' vacuum circuit breakers has been investigated by Badrzadeh [10] using PSCAD software. In a further investigation Badrzadeh et al. [11] report that the stray capacitor of elements plays an important role on the Transient Recovery Voltages (TRV) at high frequencies. More recently Ghafourian et al. [12] investigated the vacuum circuit breaker switching over voltages in an offshore wind farm. This work deals with the impact of VCB parameters (e.g. stray capacitance and withstand voltage ability) and cable length on the transformer terminal voltage during closing operation.

In this paper the reduction of Transient Recovery Voltage (TRV) across a Vacuum Circuit Breaker (VCB) will be studied. In section II, high frequency models of all elements of power systems are considered

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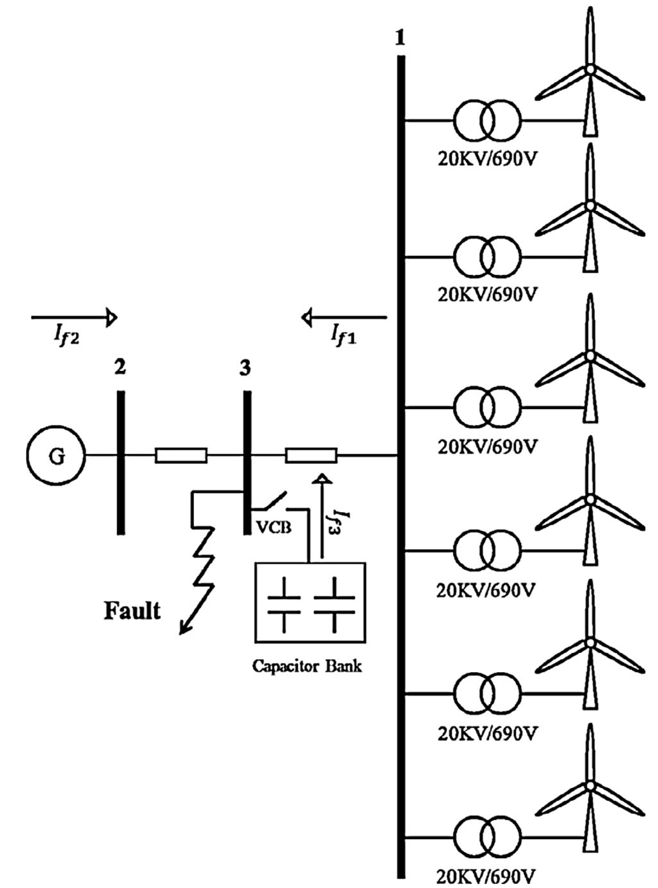

Fig. 1. System under consideration [10].

for this investigation within an EMTP-RV environment. Simulation results are composed of two parts. Part A-III shows a reproduction of the results of a previous work [10], which are used here as a bench mark. The bench mark paper investigates TRV across VCB which is the result of disconnection of capacitor banks to the plant. Part B-III reports the contribution of this paper where the results demonstrate that consideration of the high frequency model of the grounding system will lead to a more accurate prediction of TRV across VCBs for protection of plant equipment. Then in conjunction with the developed high frequency grounding system model investigated the impact of soil ionization phenomena on TRV magnitude which has previously not been considered.

2. System under consideration

The simulation is carried out on a wind farm which is composed of six identical wind power generators. Each generator has a rating of 2 MW. The layout of this model is shown in Fig. 1. Step-up transformers (2.2 MVA, 690 V/20 kV) are installed in the vicinity of the wind turbine towers. All step-up transformers are connected to the grid (20 kV) via a two Km three phase single core underground (details shown in Appendix A). The grid is simulated as a voltage source behind impedance. The surge arrester is placed with the two capacitor banks which are rated 1.67 and 3.34 MVAr respectively. The function of the capacitor banks is to provide reactive power to the plant when needed and to be disconnected in the event of a fault. The fault is assumed to be a three phase to ground fault occurring at bus 3 (midpoint of grid and wind-farm connection) at time zero and clearing at 60 ms. Also, the first opening attempt by the vacuum circuit breaker is initiated at 80 ms.

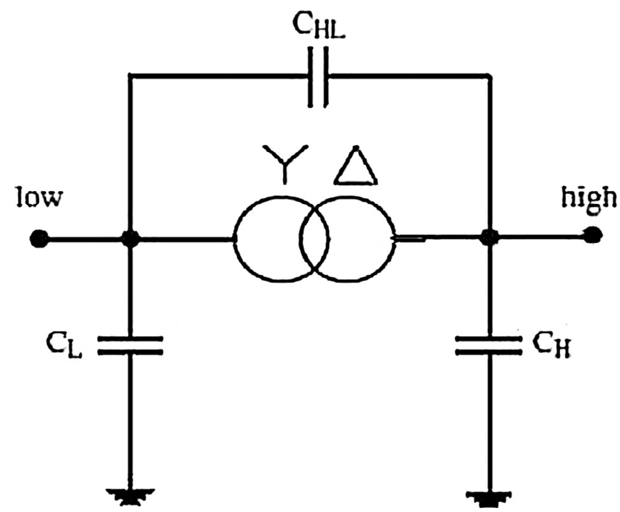

Fig. 2. Model of transformer [13].

2.1. Model of asynchronous generator

It is well known that the influence of stray capacitance is more significant at high frequencies. In general the main stray capacitors of an induction machine include the following:

C_{sf}: Stator winding to frame capacitance
C_{sr}: Stator winding to rotor capacitance
C_{rf}: Rotor to frame capacitance

The calculated capacitance between the windings and the stator frame C_{sf} is typically in the order of 30–100 times higher than the capacitance between the winding and the rotor C_{sr}. Eq. (1) is generally valid:

$$C_{sf} \gg C_{rf} \gg C_{sr} \tag{1}$$

It is therefore justifiable to neglect the stator winding to rotor and the rotor to frame capacitances which have a significantly smaller value compared to the capacitance between the winding and stator frame [11].

2.2. Model of transformer

In the transient study that involves frequencies up to a few kHz, inclusion of the transformer stray capacitances in the transformer model is essential [13]. These parameters can often be determined by measurement from the actual transformers. Transformer capacitances have been represented by CH, CL, and CHL as shown in Fig. 2 where:

C_H: Capacitance of HV winding to ground
C_L: Capacitance of LV winding to ground
C_{HL}: Capacitance between HV and LV windings

Wang et al. [14] suggest that the values of CL and CHL are greater than those of CH, as shown by Eq. (2). This is due to the fact that the high voltage side requires more separation between windings and between windings and the core [15].

$$C_{HL} > C_L > C_H \tag{2}$$