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Designing and modelling of temporary and transient over voltages in a wind farm

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ABSTRACT: Under the event of energization, deenergization, fault occurrence and fault clearing in a wind farm switching transients are initiated by the action of circuit breaker. In this paper an analytic study of temporary and transient overvoltages has been carried out by using modelling methodology of all componentsin a wind farm. This study also focused on the frequency relation of different components of wind farm which takes place during transients. For analysis of effectiveness of system grounding we use Coefficient of grounding(COG).

Index Terms: Wind farms, transient overvoltage, temporary overvoltage, grounding transformer, coefficient of grounding (COG).

I. INTRODUCTION

In a power system we can classify overvoltages into 1) transient overvoltages 2) temporary overvoltages

Transient overvoltage may be defined as "highly damped, oscillatory or non oscillatory overvoltage for short duration, having few mille seconds or less." Transient overvoltage can be classified into lightning, switching and short duration very fast front. An oscillatory overvoltage at a specified positionforcomparatively long time period (seconds, even minutes) may be known as temporary overvoltages. It is undamped and weakly damped. Fault clearing operations and switching are major causes for temporary overvoltage.In a wind power plant switchingtransients including energization and deenergization of system elements are main reasons for overvoltages. Due to switching on and off of capacitor banks, overvoltages may initiate in a power system. Hence, for studying and analysing these transients and overvoltages initiated from thesetransients, detailed modelling of system components is essential. Many papers are available in literature that describes equipment modelling and transient analysis of wind power plant.This paper explores the consequence of temporary overvoltages and switching transientsin a practical wind farm.

II. SYSTEM DESCRIPTION AND EQUIPMENT MODELING

The power system we consider here for study and analysing is a practical wind power plant located at Gujarat, India. There are total 20 double fed induction generators (DFIG) in this wind farm.All DFIG rating is 2.6 MW, 0.65 kV each, having total generation capacity of 55.2 MW.The DFIG can keep power factor between 0.95 (capacitive) and 0.9 (inductive) at terminal by variable reactive power. Each generator is connected to 32.5kV underground cable feeders through a 2.7MVA transformer. The WTG transformers step up voltages from 690V to 34.5kV. Three arrays of which 2 collecting 7 WTGs and one collecting 6 WTGs are connected to a collector bus at the low voltage side of a main transformer which further steps up the voltage to 138kV. The power will be transferred via an underground collection system at 34.5kV to the substation. A 34.5/138kV substation is built to step-up the generation to 138kV. All system modelling and analysis is done in PSCAD software.

A. Generator Modelling

For studying switching transients the source is always modeled as an ideal sine wave source i.e., each generator is modeled as a voltage source behind a (sub-transient $R + jX''$) thevenin impedance assuming to generate constant real and reactive power before switching transient occurs in system. Here we neglect the effect of power electronic converters used in DFIG.

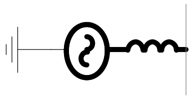

Fig. 1. Representation of source.

B. Transformer Modelling

For modelling high frequency transformer model we must consider nonlinear characteristics with hysteresis losses and eddy current losses. Due to inter-turn capacitance and winding capacitance, high frequency model demands capacitive couplings between windings of transformer.

In this system we consider two transformers, one turbine transformer having 2.7MVA, 0.69/34.5kV rating with impedance 8.45% whileanother one is the main transformer having 40MVA, 34.5/138kV rating with impedance 9%. Transformer terminal capacitances are calculated from the transformer oscillation frequency when a fault on the one side of the transformer is cleared from other side.The effective terminal capacitances can be determined based on the frequency of oscillation of each winding by using

$$C = \frac{1}{(2\pi f)^2 L_T}$$

Where f is oscillation frequency of each of the windings in Hertz andL_T is the transformer leakage inductance in Henries.

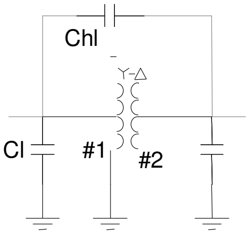

Fig. 2. Model of transformer.

Calculated transformer inter winding capacitances are shown in Table 1.

Table 1: Transformer inter winding capacitance.

Capacitance	Main Transformer (*nf*)	Turbine Transformer (*nf*)
High Voltage Winding	3.5180	1.10
Low voltage Winding	12.695	2.85
Inter Winding	6.4410	1.60

C. Cable Modelling

For transient overvoltage (TOV) studies, it is required that the cable systems should be modeled accurately because a simple pi section does not simulate reflections in cables, and it is thus usually used only for steady state studies. The TOVs, propagating in cable systems and impedances of the cable systems are highly frequency dependent. Therefore, for high frequency transient studies, frequency dependent model is used. The idea of this section is to accurately model an actual cable in PSCAD.

$$\rho' = \rho * \frac{R_2^{2}\pi}{A} = 3.55*10^{-8}\,\Omega\text{m}$$

ρ is the conductor resistivity (2.83*10-8Ωm), R2 is the conductor radius+ conductor shield (6.54mm), A is the nominal cross sectional area of the conductor (107.22mm^2),ρ' is corrected resistivity (Ωm).

Permittivity actual conversion is done by using:

$$\varepsilon_r = \varepsilon_{r,ins} \frac{\ln(R_4 / R_1)}{\ln(R_3 / R_2)} = 2.828$$

R_1 core radius (5.842mm)

R_4 core+ conductor shield+ insulation+ insulation shield (16.446mm)

R_2 insulation inner radius (6.54mm)

R_3 insulation outer radius (15.176mm)

The flux density B_{sol}caused by this solenoid effect is approximately given by$\mu_{ins,\,r}$is the relative permeability of the insulation. N is the number of turns per meter of the cable (3turns/m).

$$B_{sol}(r) = \mu_{ins,r}\mu_0 NI$$

The associated inductance is given by

$$L = \mu_{ins,r}\mu_0 N^2 \Pi(R^2{}_4 - R^2{}_1)$$

Table 2: Cable Constants Obtained in PSCAD.

Cable	500MCM	750MCM	4/0AWG
R_0	70.1	65.2	138.7
X_0	25.9	24.2	33.2
R_1	42.5	30.4	86.3
X_1	39.6	37.0	46.1

D. Transmission Line Modelling

The most efficient and accurate transmission line models are distributed parameter models based on the travelling time and characteristic impedance *Zc* of the line. Modeling of transmission line can be done in several ways in PSCAD, however taking into effect the frequency dependence effect using the frequency dependent phase model has been selected.

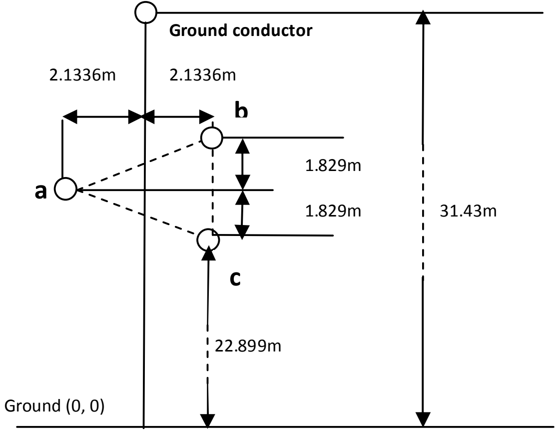

Fig. 3. Transmission line model used in PSCAD.

E. Grid Modelling

The utility is modeled using a 3-phase and 1-phase short circuit MVA ratings. Based on these MVA ratings and respective X/R ratios the positive and zero-sequence impedances are calculated. The terminal voltage is kept constant at 138 kV with positive sequence impedance being Z1 = 1.0856119 +j 8.215911Ω and zero sequence impedance being Z0 = 3.490777 +j 12.06413Ω.

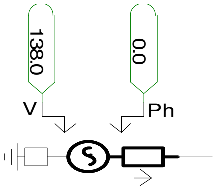

Fig. 4. Grid model used in PSCAD.

III. SYSTEM STUDY AND OBSERVATIONS

Here we consider two types of transient phenomena i) energization phenomena and ii) de-energization of the system elements. The former category includes energization of transmission lines or cables, transformers, reactors, capacitor banks etc.

The latter category includes fault clearing and load rejections.

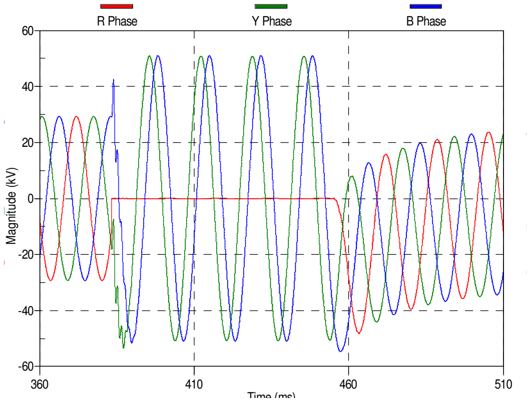

Fig. 5. Voltage across generator(G1) with SA.

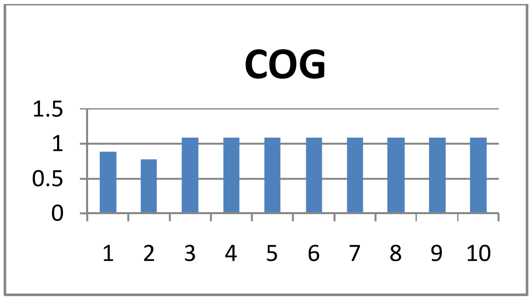

Fig. 6. COG Variation at different locations.

From above graph we can see COG in each case where fault occurred is 1.07 to 1.08 but according to standards COG for a perfectly grounded system should not exceed 0.8. This indicates that surge arresters are not capable to suppress the rise in TOV due to fault occurrence. This demands the use of Grounding Transformer on the MV bus to provide some degree of system grounding to avoid extreme TOV.The impedance of the grounding transformer must be chosen so that the unfaulted phase voltages during a ground fault, and subsequent cable isolation, are within the temporary overvoltage capability of the surge arresters.

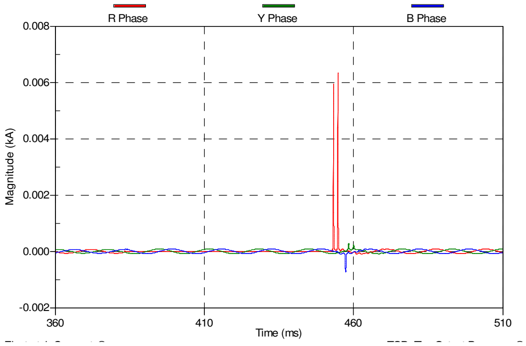

Fig. 7. Surge arrester current at main transformer due to SLG at PCC.

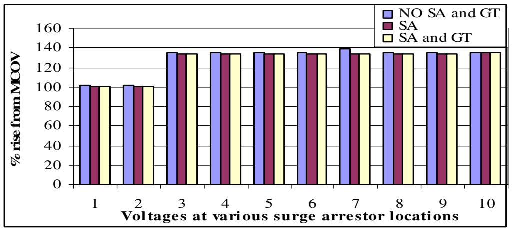

Fig. 8. % Rise from MCOV (PCC with no load transformer and cables).

Here we can see in above Figure the effect of GT is almost negligible as % rise from MCOV with and without GT is the same because the effect of grounding comes in case of only zero sequence currents hence the GT can be considered here to be open circuited. Also we can see the % rise from MCOV is almost well within limits. We also that rise of temporary overvoltages due to energization of circuit elements will not lead to any potential failures within system since rise of voltage is within the limits compared with Maximum Continuous overvoltage of Surge Arrester indicating efficiency of surge arrester to mitigate overvoltages. (Here the grounding transformers effect is mostly zero but they were considered to be active in operation).

IV. CONCLUSION

In this paper, analytic study of overvoltages due to the effect of switching in a practical wind farm is done. Simulation of major possible state of overvoltages in a wind farm is done in PSCAD and respective results are discussed. For finding the effective grounding system, possibility of coefficient of grounding (COG) is also discussed by using grounding transformer case. Under the consideration of using small length cables in a wind farm with respect to other farms,it is found that the magnitude of resultant overvoltage's are very less.

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