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Revision of TRV requirements for the application of generator circuit-breakers

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ABSTRACT

The requirements imposed on generator circuit-breakers greatly differ from the requirements imposed on other transmission and distribution circuit-breakers. Due to the location of installation between the generator and the associated step-up transformer, a generator circuit-breaker must meet high technical requirements with respect to rated normal currents, short-circuit currents, fault currents due to out-of-phase conditions and transient recovery voltages. The question whether the transient recovery voltage requirements laid down in IEEE Std C37.013-1997 (R2008) and in IEC/IEEE 62271-37-013 are adequate for the application of generator circuit-breakers in modern power stations is considered in the present work.

In order to quantify the transient recovery voltage requirements for the application of generator circuit-breakers a comprehensive survey of different fault conditions occurring in several power stations has been performed. The fault transients' simulations have been performed by means of the Electromagnetic Transients Program (EMTP).

1. Introduction

The requirements imposed on generator circuit-breakers (GenCBs) greatly differ from the requirements imposed on general purpose transmission and distribution circuit-breakers. Due to the location of installation, high technical requirements are imposed on GenCBs with respect to rated normal currents, short-circuit currents and fault currents due to out-of-phase conditions. Furthermore, the currents of very high magnitude which GenCBs have to deal with are associated with very steep transient recovery voltages (TRVs).

According to the international standards, the stresses imposed on GenCBs in case of faults differ from the stresses imposed on general purpose circuit-breakers mainly in the following aspects:

- the relatively long d.c. time constant of the system-source short-circuit current results in a high degree of asymmetry at contact separation;
- the generator-source short-circuit current may exhibit a degree of asymmetry higher than 100% thus leading to delayed zeros;
- the rate-of-rise of the TRV (RRRV) appearing after the interruption of a system-source short-circuit current may be as high as 6.0 kV/μs and the corresponding time delay (t_d) as short as 1 μs;
- the RRRV appearing after the interruption of a generator-source short-circuit current may be as high as 2.2 kV/μs and the corresponding t_d as short as 0.5 μs.
- a GenCB shall be capable of interrupting fault currents due to out-of phase conditions with extremely severe TRVs.

The out-of-phase conditions are abnormal circuit conditions due to loss or lack of synchronism between generator and power system at the instant of operation of the GenCB. The phase angle difference between rotating phasors representing the generated voltages on each side of the GenCB may exceed the normal value and may be as much as 180° el. [1,2].

The test quantities given for general purpose transmission and distribution circuit-breakers for the short-circuit and out-of-phase current switching tests do not adequately cover the above requirements. The only standards which cover the requirements for GenCBs are IEEE Std C37.013-1997 (R2008) and IEC/IEEE 62271-37-013 [1,2]. These standards in particular cover the requirements imposed on GenCBs regarding the degree of asymmetry of the fault

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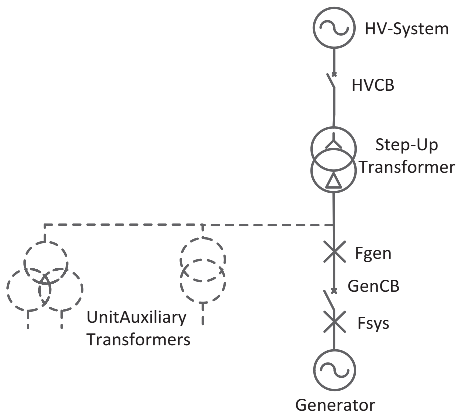

Fig. 1. Power station layout with one generator connected to a two-winding step-up transformer.

currents and specifically addresses the phenomenon of delayed current zeros.

The installation of a GenCB between the generator and the associated step-up transformer, where its performance directly influences the output of the unit, places high demands on its reliability. The required equipment quality and reliability can only be achieved by exhaustive testing of all the relevant aspects. The question whether the requirements laid down in [1,2] are adequate for the application of GenCBs in modern power stations is considered in the present work.

In order to quantify the requirements for the application of GenCBs a comprehensive survey of different fault conditions occurring in 185 power stations has been performed. Technical parameters of power station equipment have been collected from combined cycle, gas turbine, conventional thermal, nuclear, conventional hydro and pumped storage power stations.

The fault transients' simulations have been performed by means of the Electromagnetic Transients Program (EMTP) [3]. The parameters peak value (E_2), RRRV and t_d of the resulting TRVs have been analysed.

2. Power station equipment models adopted for the simulations

A typical power station layout used for this investigation is depicted in Fig. 1.

The system-source short-circuit current is the short-circuit current to be interrupted by the GenCB in case of a three-phase fault occurring between the generator and the GenCB. This fault location is identified by "Fsys".

The generator-source short-circuit current is the short-circuit current to be interrupted by the GenCB in case of a three-phase fault occurring between the step-up transformer and the GenCB. The source of this current is the generator through no power transformer. This fault location is identified by "Fgen".

As recommended in published literature, for the range of frequencies involved in this type of duty, generator, power transformers and busduct have been modelled with distributed parameters [4–7]. Both, the generator and the power transformers have been modelled with distributed parameters according to the model presented in [8]. This type of model has been tested for the interruption of fault currents and the results have been compared to measure values. They have shown to fit very well with the results of measurements. The power station components considered are:

- generator;
- step-up transformer;

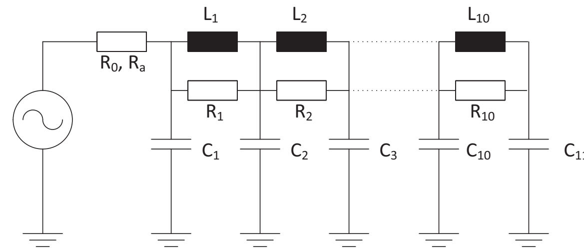

Fig. 2. Model of generator.

- connection between generator and GenCB;
- connection between GenCB and step-up transformer;
- connection between unit auxiliary transformers and GenCB;
- GenCB;
- unit auxiliary transformers;
- voltage and current transformers;
- HV-system.

The generator model consists of 10 inductance modules per phase paralleled by resistance elements and 11 capacitance-to-ground elements (see Fig. 2). The number of modules adopted has been validated with tests for the interruption of fault currents. The model has been deduced from measured TRVs of generators [8].

The corresponding model of the power transformer again consists of 10 modules per phase (see Fig. 3). Each module is made of a single-phase transformer with short-circuit inductance, capacitances to ground at each side of the transformer and coupling capacitances between the high-voltage and the low-voltage sides. The mutual inductive coupling between the coils does not need to

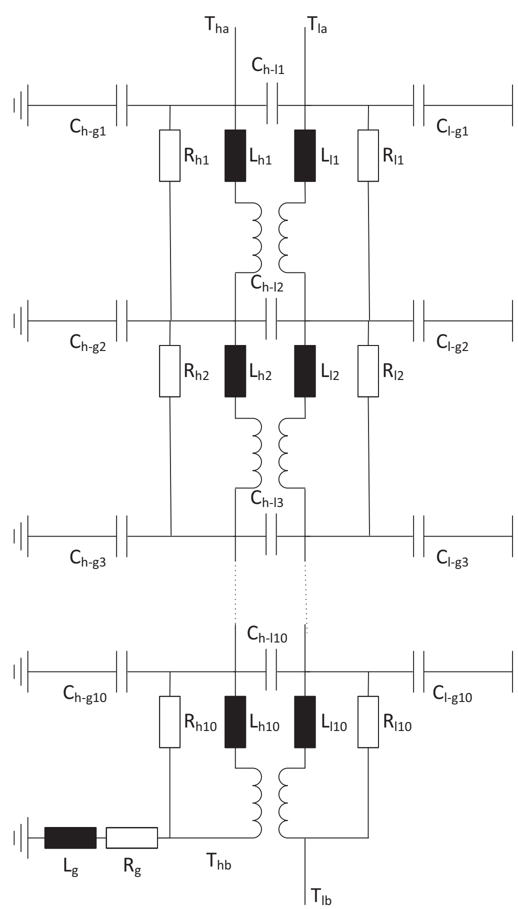

Fig. 3. Model of power transformer.