PERSPECTIVE GENERATOR CIRCUIT BREAKER

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ABSTRACT

This paper deals with the essential function of generator circuit breaker in power plant. The aim of the paper is to analyse very demanding current and voltage conditions which are directly influencing the reliability of energy generating process. The development in the field of circuit breakers has reached nowadays status of superiority of SF_6 based circuit breakers. There are analysed performance capabilities of possible generator circuit breakers for perspective nuclear power plant in the Czech Republic.

KEYWORDS

Generator circuit breaker, SF_6, Recovery voltage, Delayed current zero, Nuclear power plant Temelín

1. INTRODUCTION

With respect to growth of energy consumption in the world, the mankind is facing serious threat – lack of energy. More frequent outages with serious consequences, e.g. destabilisation of economy can be expected in not far perspective. Therefore, very intensive political discussion and especially engineer action is needed. The situation in the world, including EU seems to be, after decades, again nuclear energy friendly.

The vision of CZ energy concept is based on the renaissance of nuclear power plants. Total production from this pure source is estimated 50% of total consumption in 2030. The construction of new blocks is also crucial for energy independence on coal and gas and thus important step for energy safety and is suitable for health energy production mix. Existing blocks in Temelín nuclear power plant are operating with air blast generator circuit breakers. For future units is better option – SF_6 based circuit breakers.

Figure 1 – Temelín nuclear power plant 2020 visualization [6].

2. GENERATOR CIRCUIT BREAKER

These technical solutions can be included in group of large scale units of big output, each approximately 1000MVA.

In case of large generators circuits consideration must be given to:
Generator Circuit Configuration
High Continuous Current Levels
Unique Fault Current Conditions
– System-Source (Transformer-fed) Faults
– Generator-Source (Generator-fed) Faults
Unique Voltage Conditions
– Very Fast Rate of Rise of Recovery Voltage (RRRV)
– Out-of-Phase Switching

Generator circuit breaker is switchgear in the high-current connection between generator and generator transformer. The electrical requirements on generator circuit breakers are higher in many aspects than for breakers in the network. These requirements are specified in the (unique in the world) "IEEE" C37.013 standard in detail (ANSI).

2.1. Generator circuit breaker performance capabilities

Generator circuits are typically designed for high efficiency in order to minimize the watts loss of the system. Therefore the generator circuit breaker may be located very close to both the generator and transformer, connected by short conductors with a large cross-section, resulting in minimal circuit impedance. Applications with high continuous current levels require connections with very large conductors of very low impedance for optimum efficiency.

This circuit configuration and the operational application of generator circuit results in special voltage and current conditions that must be taken into account.

Generator circuit breakers must be able to carry high continuous current levels for extended periods of time. For larger units, continuous current is going up to 24 kA without cooling and 38 kA with forced cooling.

Generator circuit breaker performance capabilities – current conditions

The two key unique fault current conditions encountered by generator circuit breakers are shown in Figure 2.

- Faults at location "a" are called "System-source Faults" or "Transformer-fed Faults".
- Faults at location "b" are called "Generator-source Faults" or "Generator-fed Faults".

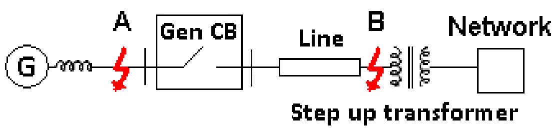

Figure 2 - Generator circuit breaker connection.

The transformer-fed fault current can be very high because the full energy of the power system feeds the fault. The low impedance of the transformer and the short, very lowloss buses connecting the generator, generator circuit breaker, and transformer, limit only a little the fault current because of their very low impedance. To interrupt these kinds of faults, generator circuit breakers must be tested and proven capable of interrupting not only the high symmetrical fault current, but also the higher asymmetrical fault currents resulting from extreme DC components of fault current.

Generator-fed fault currents are lower in magnitude, but they are subject to another type of very demanding condition called "Delayed current zeros". This unique characteristic of the fault current comes from the very high X/R (inductive reactance to resistance) ratio of the circuit and the operating conditions of the generator, which can combine to produce a DC component of the fault current exceeding 100%. This means the asymmetrical fault current peak becomes so high, and its decay so slow, that the first current zero can be delayed for several cycles. Since circuit breakers rely on current zero crossing in order to interrupt, generator circuit breakers must be able to withstand longer arcing times and greater electrical, thermal and mechanical stresses when interrupting this kind of fault.

Generator circuit breaker performance capabilities – voltage conditions

As previously mentioned, in the typical generator circuit configuration, two large and very expensive components, each with highly inductive impedance, are connected through the generator circuit breaker with very short conductors, of minimal impedance. The resistance and stray capacitance of the generator circuit is typically much less than a normal distribution circuit. These characteristics combine to produce very high natural frequencies (up to 40kHz) of the circuit and in turn result in extreme transient recovery voltages (TRV) with high rates of rise (RRRV).

This means that during the interruption, just after the interrupter has been subjected to a 50,000 degree plasma arc, it must re-establish dielectric strength across the open gap in order to withstand this fast-rising TRV. In the first phase to clear, the peak value of this TRV is nearly double the line-to-line voltage of the circuit, and the circuit produces that peak voltage within microseconds following the current zero. If the interrupter is able to withstand that voltage, then the interruption is successful. If not, the gap will break down again, and the fault current will continue to flow until the next current zero, when there will be another opportunity to interrupt. Here it is important to note that the critical parameter is how fast the TRV rises across the recovering gap after the current zero. This is measured by the RRRV, which is proportional to the peak value of the transient voltage in kV, divided by the time it takes the voltage to reach that peak value in microseconds, so that the RRRV is measured in units of "kV / μs".

Although generator circuit breakers and standard distribution circuit breakers are bothsubjected to TRVs during interruption, the rates of rise are quite different. RRRV values for typical 15 kV standard distribution circuits are in the range of 0.4 to 1 kV /μs, while RRRV values for generator circuits are about 3.5 kV / μs.

These TRV conditions are so severe that even the world's best high power laboratories cannot construct direct test circuits to prove this capability. The only way to prove this capability by high power testing is with the synthetic test method, where two separate sources are used, one to provide the required short-circuit current and the other to produce the required transient recovery voltage.

Generator circuit breaker performance capabilities – reliability

Specifically, the use of modern SF_6 generator circuit-breakers positively affects power plant availability in three ways:

- The use of generator circuit breakers allows the plant auxiliary supplies to be drawn directly from the high-voltage transmission system at all times, i.e. also during the critical start-up and shut-down phases of the plant operation. Supply from this source is considerably more reliable than that from a local sub-transmission network and results in improved plant auxiliary equipment availability.
- The rapid interruption of generator fed short circuit currents reduces the resulting fault damage and shortens repair times, thereby also contributing to an increased power plant availability. Although they have a low probability of occurrence such outages have a substantial effect on the availability of a generating unit and on the overall performance of an operating utility.
- Compared to high-voltage circuit-breakers modern SF_6 generator circuit-breakers exhibit higher maintenance intervals as they are especially designed for a high mechanical and electrical endurance. Depending on the application the down-time of an unit due to circuit

breaker maintenance can therefore be significantly reduced when a generator circuit breaker is used.

3. CONCLUSIONS

The generator circuit breaker is located between generator and step-up transformer. This localization directly influences energy output and therefore is crucial for its reliability. Advanced design, as well as accurate construction, high quality components and thorough testing are basic elements of success. Electrical and mechanical requirements highly exceed demands on standard distribution circuit breaker. Not only IEC 62271-100 norm must be taken into account when comparing distribution and generator circuit breaker. The capability to withstand extreme values of transient recovery voltage must be in compliance with ANSI/IEEE Standard C37.013. New models made by ABB which are designed for large units (> 1000MW) fully correspond needs of future III+ generation nuclear power plant.

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ACKNOWLEDGEMENT

This paper is worked out with the support of Project 1M 06059 Research Centre MŠMT Prague.

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