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Comprehensive dimensioning of series braking resistor for transient stability improvement

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ABSTRACT

This paper addresses comprehensive dimensioning of series braking resistors designed to improve transient stability of the power system. Since dynamic braking is one of the most cost-effective ways to improve transient stability, the applications of shunt and series braking resistors have recently expanded in the power industry. To find an effective algorithm for controlling series braking resistors appropriate resistor dimensioning should be performed first. This paper addresses the problem of dimensioning of series braking resistors. To solve that problem a mathematical model is employed for different operating states of the system equipped with a series braking resistor. This paper describes and discusses in detail the impact of series braking resistors on: power angle characteristics, intensity of dynamic braking in terms of transient stability improvement, voltage dynamic response during and after a fault, and turbo-generator shaft fatigue. Based on the analysis performed, criteria for the dimensioning of series braking resistors are formulated. Theoretical considerations are supported by simulation tests for nonlinear models of single-machine as well as multi-machine test systems.

1. Introduction

Transient angle stability is a necessary condition for a secure operation of any power system. The process of deregulation of the energy industry started several decades ago. It has increased importance of the power systems security, including stability [1,2]. Insufficient development of transmission network compared with development of power generation has made stability in many cases a critical criterion for the assessment of the power system performance.

Connecting and operating generating units with high rated power may cause problems with power system stability [3]. These problem can occur especially when the construction of new transmission lines is delayed and then a new generating unit is being connected to the weak transmission network.

To improve power system stability an excitation controller for a synchronous generator can be used. These generator which is equipped with an additional control loop, i.e. a power system stabilizer [4]. Power system stability improvement can be also achieved by adequate control of regulated devices connected to the transmission network defined as a Flexible AC Transmission Network (FACTS) [5] or High-Voltage Direct Current transmission links [6].

The stability of the power system is evaluated by analysing credible and extreme contingencies, i.e. when a fault occurs and is subsequently cleared by protection [7,8]. In many cases in order to meet the performance standards of a power system, including stability, Special Protection Systems (SPS) may be necessary [9,10]. In general, actions taken by SPS can include, among others: system reconfiguration, generation rejection or runback, load rejection or shedding, reactive power or braking resistor insertion, and DC fast ramping [11]. In recent years there has been a growing interest in braking resistor (BR) to improve power system (PS) performance in transient states [12]. This is due to the fact that BRs have been recognized and used as a cost-effective way to improve transient stability [13].

A proper application of shunt braking resistor (ShBR) or series braking resistor (SeBR) to improve transient angle stability of a power system requires: (i) selecting the parameters of the resistor, (ii) selecting the algorithm to control the BR. The literature on the topic is mainly focused on which algorithm should be used to control a shunt or series resistor [13–16]. These papers studies usually discuss the problem of how to select parameters for a BR very briefly or incompletely. This paper has been written with the intention to fill this gap. The analysis and considerations discussed here apply to the selection of parameters for series BRs. It is shown that

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parameters for SeBR should be selected comprehensively, taking into account both the problem of stability improvement and how the resistor affects the operation of power system components.

This paper is organized in the following way: Section 2 reviews the applications of dynamic braking in power systems briefly. Section 3 presents the options for connecting SeBR to power plant substation. Section 4 provides a mathematical model of a power system with a series BR as one of its components. Section 5 describes and discusses the factors which should be considered when selecting the size of a series resistor. Section 6 describes the results of simulation tests for single-machine and multi-machine test systems.

2. Dynamic braking

Dynamic braking with BRs is widely used in the power industry. As an effective way to improve the performance of a power system in transient states, dynamic braking is used for such applications as:

1) Angle stability improvement in power systems (both large generating units and distributed generation) [13,17];
2) Damping of shaft torsional oscillations in large steam turbo-generators [18];
3) Controlling (braking) motor drives [19];
4) Handling low voltage ride through (LVRT) conditions (VSC-HVDC transmission systems — by applying a chopper resistor) [20].

Braking resistors can be installed in the power plant (to improve transient stability and damp local power swings) or in the transmission network (to damp the area and inter-area power swings and to improve dynamic response of the busbar voltage) [21]. Dynamic braking is often employed as a component supporting wider automation systems designed to protect power systems, e.g., fast valving [22], automatic voltage control [23], or to support other FACTS devices [8].

If used for angle stability improvement of power system, on which this paper focuses, BRs are usually switched on/off using mechanical circuit breakers [24,25]. To improve transient angle stability, if a fault occurs, BRs are switched on for a short time in the power plant substation to increase the real-power load for generators which would otherwise significantly accelerate risking the loss of synchronism. Based on how they are connected to the grid, there can be ShBR or SeBR. ShBRs have been used to improve the stability of power systems for many years. Example systems and control methods are described in [13,24–27]. SeBRs, which are addressed in this paper, have also attracted interest for many years. Examples include publication [28]. In recent years, this interest has revived in the context of low-inertia generators installed in distribution networks [29] and turbo-generators [16] whose tripping following a grid fault provides a very serious disturbance to the power system.

3. Series braking resistor

Three-phase faults in transmission lines near power plant substations, which are cleared with a delay due to the malfunction of the main protection or stuck breaker and the operation of the breaker failure protection, are regarded as extreme contingencies [7] which risk the loss of synchronism of synchronous generators. Switching on a SeBR for a short time can be an effective method for preserving synchronism in such contingencies, and thereby this can improve transient stability.

There are several ways to connect a SeBR to generator unit circuits. Two of them are shown in Fig. 1. The method depicted in

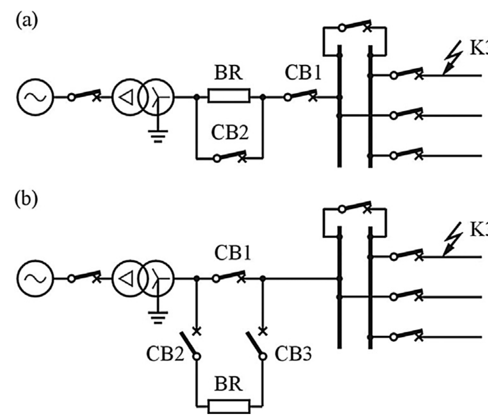

Fig. 1. Switching diagram for a series braking resistor with (a) one circuit breaker, (b) two circuit breakers.

Fig. 1a is the simplest case. To switch the resistor on, the CB2 circuit breaker should be opened, and to disconnect the resistor from the circuit, the CB2 circuit breaker should be closed. The drawback of this solution is that the resistor is always in the circuit when the generating unit is running. If the resistor is damaged, the generating unit must be switched off. The method shown in Fig. 1b provides that the resistor is disconnected in its normal state. To connect the resistor, circuit breakers CB2 and CB3 should be closed, and circuit breaker CB1 of the generating unit should be opened. To disconnect the resistor from the circuit of the generating unit, circuit breaker CB1 should be closed and circuit breakers CB2 and CB3 should be opened. The drawback of this solution is that two additional circuit breakers are used.

The effectiveness of angle stability improvement using a SeBR depends on proper dimensioning selection of SeBR and on the control algorithm mechanism applied. The following sections discuss comprehensively the dimensioning of SeBR in terms of parameters selection.

4. System model with a SeBR

4.1. Single-machine infinite bus approach

Systematic analysis of the criteria for the selection of SeBR requires formulating and testing the mathematical relationships describing the system model. In doing this, both the short-circuit state near the busbars of the power plan substation and the state after the short circuit is cleared should be considered.

Transient stability of power systems is a challenging issue mathematically, because it involves strongly nonlinear and highly dimensional formulations [8,30]. Attempts to overcome the above-mentioned challenges have led to an approach whereby, as the first step, analysis are conducted for an equivalent multi-machine system, being a single-machine infinite bus system (SMIB). A SMIB system provides a means to describe mathematical relationships between variables and to formulate algorithms and hypotheses. Then, as the second step, the algorithms and the results of first step are verified using simulations in a multi-machine system. Such accepted approach [8,31–35] is also applied in this paper.

Despite the considerations relating to the SMIB system case they may be useful for the case where a power plant is composed of several synchronous generators. The individual SeBR for each machine can be considered in case of both a multi machine power plant and a typical layout of power plant substation. The installation of common SeBR is also possible but it requires adjustment to a substation layout which, in turn, can have influence on substation operation and reliability.