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Investigation of Transient Recovery Voltage Across a Circuit Breaker with Presence of Braking Resistor

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Abstract: This paper presents a study of Transient Recovery Voltage (TRV) of a Circuit Breaker (CB) connected to transmission line with presence of Braking Resistor (BR). In order to effectively control the transient stability of the synchronous generator during the dynamic period, the BR unit is located at the generator terminal bus through the thyristor switching circuit and near the circuit breaker. It is shown in this paper that, when a fault occurs in the transmission line and circuit breaker acts, existence of breaking resistor and its natural performance during instability eliminates TVR in the circuit breaker completely. The simulations are implemented by using the Electromagnetic Transients Program (EMTP/ATP).

Key words: Transient Recovery Voltage (TRV), Circuit Breaker (CB), Braking Resistor (BR), EMTP/ATP.

INTRODUCTION

Braking Resistor (BR) is known to be one of the very effective methods for transient stability improvement. Braking Resistor uses the concept of applying an artificial electrical load during a dynamic period to control the active power output of generator and thereby control rotor oscillations. BR can be utilized for variety of functions: Prevent transient instability during the first power system swing cycle; damp subsynchronous resonance (SSR) resulting from series capacitor com pensation; reduce and rapidly damp subsynchronous shaft torques. A BR can often be the lowest cost, and a simple, highly reliable FACTS Controller. The best location for a BR is near a generator that would need braking during transient instability conditions (Hingorani *et al*. 2000). When a fault occurs on a system, variable rotor speed of the generator is measured and the firing-angle for the thyristor switch is determined from the BR controller. By controlling the firing-angle, BR can control the accelerating power in generator and thus improves the transient stability.

After interruption of a short-circuit current by a high-voltage fuse or a power circuit breaker, a transient recovery voltage (TRV) appears across the terminals of the interrupting device (Sluis. 2001). Circuit breakers can fail to interrupt fault currents when power systems have TRV characteristics which exceed the rating of the circuit breakers (Lin Ye *et al*. 2007). Some research has been done to evaluate the TRV of a circuit breaker with presence Flexible AC Transmission System FACTS controllers. In (Lin Ye *et al*. 2007)–(Liu *et al*. 2009) impact of different types of FCLs on power switch TRV have been investigated. In (Lin Ye *et al*. 2007), a case study of HTS resistive superconducting FCL in electrical distribution systems is investigated; the studies include the circuit breaker TRV analysis. The work in (Calixte *et al*. 2005) looks at the mathematical expression of the rate of rise of recovery voltage (RRRV) across a circuit breaker connected with FCL as a function of the limiting impedance Z_{FCL} and the limited current when a fault occurs at a distance near the load-side terminals of the FCL. The investigation in (Li *et al*. 2008), presents analytical basis and theoretical reference for optimal parameter design of inductive FCLs and reliable selection of the interrupting characteristics of HV circuit breakers. The work in (Liu *et al*. 2009) presents the impact of inductive Fault Current Limiter (FCL) on the interrupting characteristics of high-voltage CBs.

In this paper, BR is modeled in ATP environement. Then impact of BR on power switch TRV is investigated. The results show that, existence of BR when CB acts cause the elimination of TRV.

Modeling of System and BR:

For the simulation of transient stability and TRV, the model system (Mohd *et al*. 2007), as shown in Fig. 1, has been used in this paper. The model system consists of a synchronous generator (SG) feeding an infinite bus through a transformer and double circuit transmission line. CB in the figure represents a circuit breaker.

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The CB1 is modeled as an time-controlled switch and a shunt capacitance (C_P) which is shown in the figure. In order to show TVR phenamena, re-strike phenomena which occurs after opening the switch is neglected in simulations.

In order to effectively control the power balance of the synchronous generator during a dynamic period, the BR unit is located at the generator terminal bus (Hingorani *et al*. 2000). Automatic Voltage Regulator (AVR), Excitation System Stabilizer (ESS) and governor (GOV) control system have been included to make the system closer to practical systems. Parameters of the system are completely listed in (Mohd *et al*. 2007). The Braking Resistor (Fig. 1) is a shunt-connected thyristor-switched resistor (usually a linear resistor). Speed deviation of synchronous generator ($\omega = \omega - \omega_0$, in which ω is the actual generator speed and ω_0 is the steady state generator speed) is the basic control parameter.

The phase 'a' related to BR which is modeled in EMTP/ATP is shown in Fig. 2. The Thyristor block in Fig. 2 also contains a series R_s-C_s snubber circuit that can be connected in parallel with the thyristor device. The firing-angle α, for the thyristor switching circuit is calculated from the output of the PI controller. PI controller for the BR is shown in Fig. 3. In normal operation the value of ω in the generator is negligible and the output of the controller is 180 degrees. In other words both thyristors are out of circuit it means that the breaking resistor is not operate. In presenence of any possible fault in the transmission line, an unbalance will be created in the input mechanical power and generator electrical power which lead to a ω in the generator rotor. Comencerate with this ω, breaking resistor operates and improves the transient stability of the generator.

Simulation Results:

The simulation is implemented by using the electro-magnetic transients program (EMTP/ATP). Alternative Transient Program (ATP) is one of the EMTP versions and ATPDraw is a graphical pre-processor to ATP and is used to create and edit circuit files which are used in the simulations carried out in this paper. ATP (Alternative Transients Program) is considered to be one of the most widely used software for digital simulation of transient phenomena of electromagnetic, as well as electromechanical nature in electric power systems. The severity of a circuit breaker duty is generally determined by the value of the short-circuit current together with the shape and the recovery voltage. For the short-circuit current, a symmetrical three-phase-to-ground short circuit was assumed to occur because the estimation of the MVA required of a circuit breaker is usually made on the assumption that it must clear a three phase fault because, as that is almost the worst case, it is reasonable to assume that the circuit breaker can clear other fault. Simulations are performed considering 3LG (three-phase-to-ground) fault near the generator at line 2 as shown in the system model. It is also considered that the fault occurs at 0.1 s, circuit breakers on the faulted line are opened at 0.21 s, and closed again at 1.2 s (Mohd *et al*. 2007). Simulation step is considered as 1μs to capture the high frequency TVR phenamena. Fig. 4 show the load angle responses for both 3LG fault. It is clear from this response that BR effectively enhance the transient stability. Fig. 5 depicts the firing-angle response of the thyristor switch for phase 'a'. The firing-angle varies from 0 Deg to 180 Deg according to the value of controller output.
When the firing angle of thyristor is zero degre the complete resistor is in circuit and conversly, when firing angle is 180° the complete resistor is not in the circuit. Considering the firing angle of thyristor two important points are obtained:

1. Before opening CB1 at 0.2 sec, breaking resistor is in the circuit because of the fault in the transmission line.
2. During investigation TVR (which starts from opening the CB and lasts at most two cycles), firing angle of thyristors are zero and in other words, BR is fully in the circuit.

The TRV has various parameters such as a Rate of Rise of Recovery Voltage (RRRV). The RRRV is an important parameter in the power system operation, specified in volts per microsecond (V/μs) in IEEE C37.41 Standard (Lin Ye *et al*. 2007).

Fig. 6 shows the CB1's TRV with and without the BR. As can bee achieve from this figure, the value of RRRV is about 5.03 kV/μs for the case without the BR. BR presence has caused to eliminate TRV and decreasing the value of RRRV to 0.3 kV/μs. The simulation results are shown only for phase 'a'. The results are similar for the other two phases. It is shown that BR presence improves TRV and RRRV. Impact of BR is investigated for different faults in differents parts of the transmission lines. The aformentioned two important points are satisfied for all the cases.

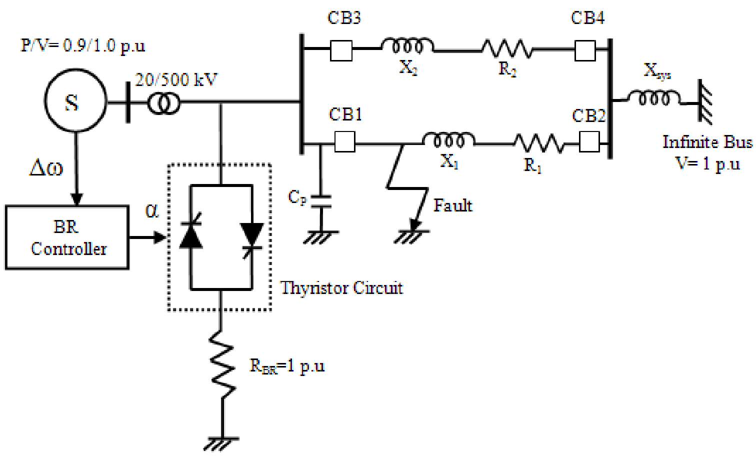

Fig. 1: Sample system with BR.

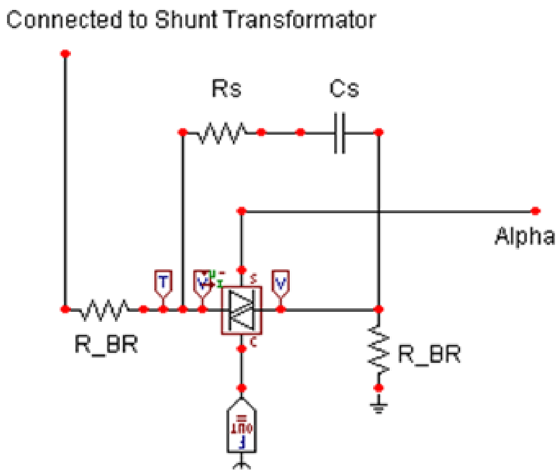

Fig. 2: The phase A related to BR which is modeled in EMTP/ATP.

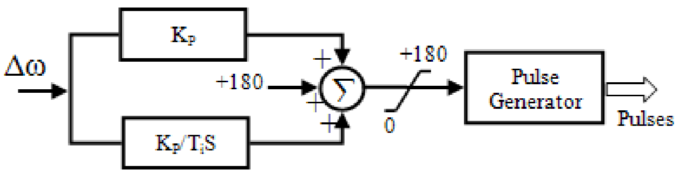

Fig. 3: Block diagram of PI controller.

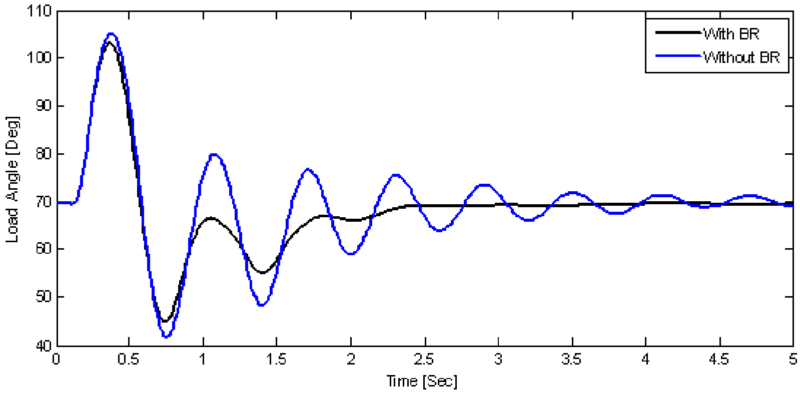

Fig. 4: Load angle responses for 3LG fault.

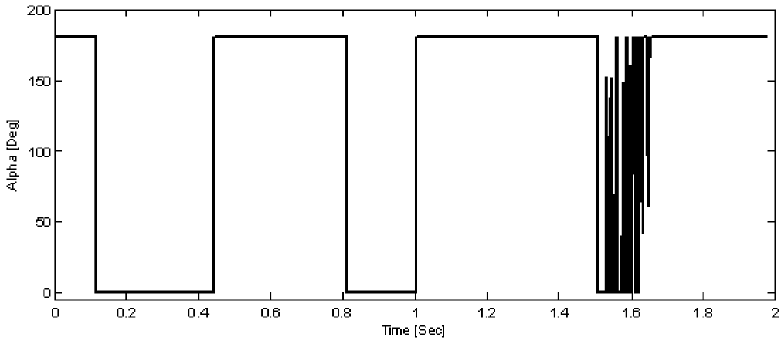

Fig. 5: Firing angle for phase 'a'.

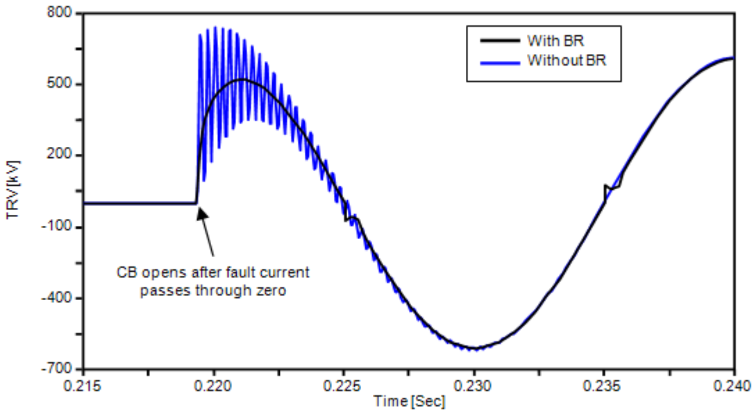

Fig. 6: Circuit breaker's TRV with and without the BR.

Conclusion:

The investigations in EMTP/ATP environment shows that using breaking resistor besides synchronous generator not only improves the transient stability of the generator but also eliminates TVR in CB and decreases the RRRV value significantly. TVR phenamena is analysed for different types of faults in different parts of the transmission lines. In all the cases BR eliminates the TVR across a Circuit Breaker. When a fault occurs in transmission line, the output power of the generator decreases. BR opretes to compensate for this decrease. When CB tries to clear the fault, BR is fully in the circuit and eliminates TVR. So, eliminating circuit breaker TVR is another advantages of using BR.

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