

- CHAPTER 6 -

RELAY TESTING WITH A REAL TIME DIGITAL SIMULATOR

*“When I am told, I forget. When I see,
I remember. When I do, I understand”*

Confucius

6.1 INTRODUCTION

A Real Time Digital Simulator (RTDS) is a modular, digital power system simulator that can be used for performing analytical power system simulations and testing of protection relays [35]. The simulator uses software namely RSCAD (similar to PSCAD) which enables the user to create a power system model on a PC. With compilation of the model, an executable file is created on the PC, which can be downloaded onto the RTDS.

The simulated currents and voltages on different power system busses in the PC model can be reproduced by means of physical voltage and current outputs on the simulator. The simulator voltage and current outputs are amplified by an Omicron current and voltage injection set. A protection relay can be connected to the voltage and current outputs of the Omicron to test the relay response for different fault scenarios.

An ABB REM543 multifunctional relay was programmed with the new pole-slip protection function and was tested by connecting the outputs of the Omicron injection set to the current and voltage inputs of the relay. The relay binary trip output was connected to the RTDS, which was used to check that the relay issues a trip before the RTDS simulated a pole-slip. Figure 6.1 provides a general overview of the operation/setup of an RTDS. Figure 6.2 shows the RTDS that was used to test the ABB REM543 protection relay.

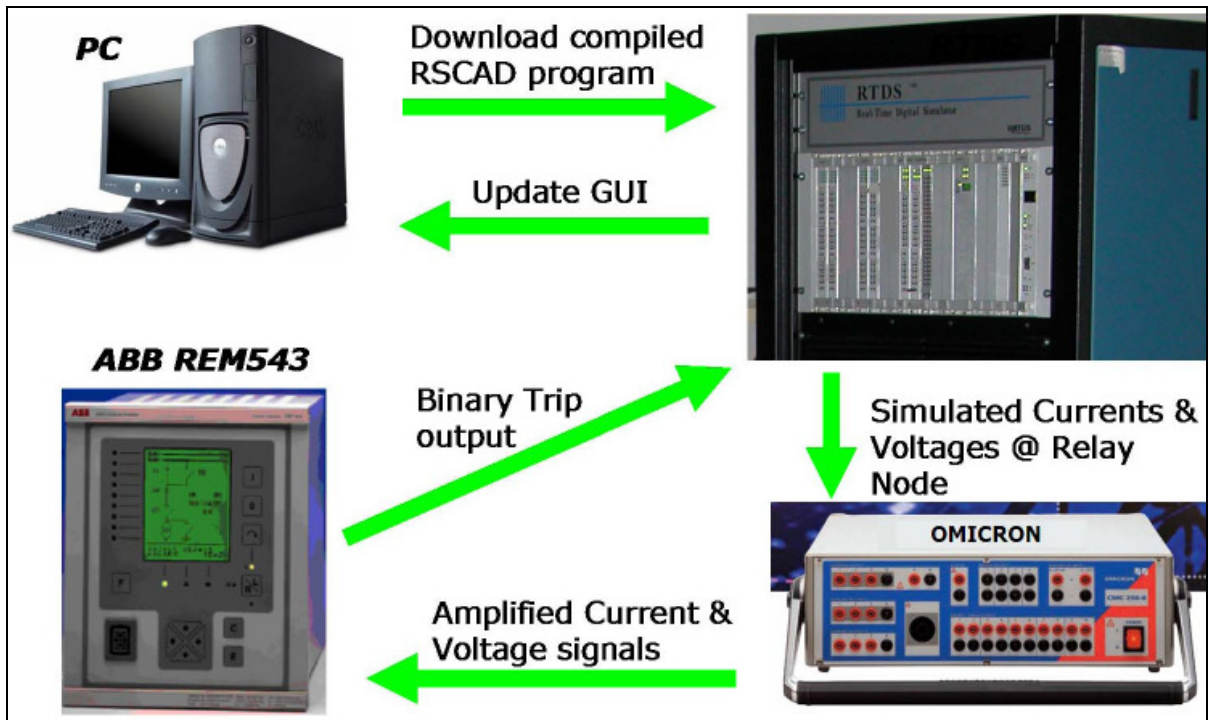


Figure 6.1: RTDS setup with ABB REM543 relay



Figure 6.2: ABB REM543 relay testing with RTDS

6.2 RSCAD POWER SYSTEM SIMULATION

Figure 6.3 shows the RSCAD power system layout that was used to do different pole-slip simulations on the relay. The voltage and current signals at the terminals of Generator 1 was fed to the ABB REM543 protection relay via the Omicron. Although the top branch with transmission lines show that the fault was applied between the transmission lines, the transmission line closest to the generator was simulated to be very short. This was done to make the simulated power system similar to the power system that was used in PSCAD (refer to Figure 5.1).

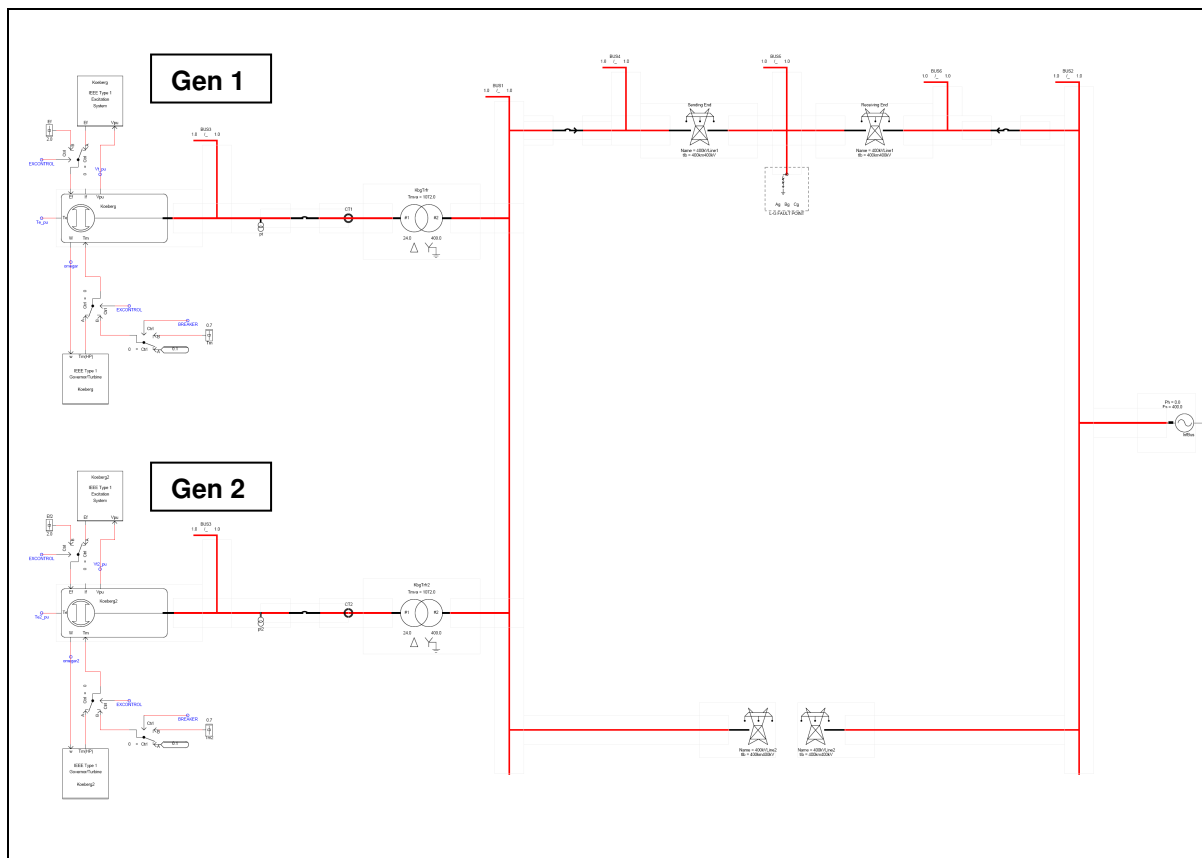


Figure 6.3: RSCAD Power System Simulation

6.3 MIMIC MEASUREMENT INDICATIONS

In order to verify the relay mimic indications, the RTDS was used to inject arbitrary currents and voltages into the ABB REM543 relay. The mimic indication on the relay corresponded to the injected three-phase voltages and currents. This indicated that the CT-ratios and VT-ratios were set up correctly in both the RTDS and the protection relay. CT polarity was verified by observing the power angle calculation as is explained in section 6.5.1.

6.4 POWER FACTOR CALCULATION

The ABB REM543 relay uses its own power factor calculation function block (MEPE7) to calculate the displacement power factor (fundamental frequency). The power factor on the relay mimic corresponded to the three-phase power factor as injected with the RTDS.

6.5 STEADY-STATE TESTS

6.5.1 POWER ANGLE CALCULATION

Different synchronous motors and generators were simulated with different quadrature-axis reactance (X_q) values. The X_q value of the machine is required for the power angle calculation as is explained in Table 2.1. A synchronous generator was simulated in the under- and overexcited states. The relay calculated power angle was compared with the corresponding RTDS power angle at all steady-state operating conditions.

A 55 MW-machine was simulated on the RTDS to check if the RTDS power angle and REM543 relay calculated power angle correspond with each other. Table 6.1 gives the values of the RTDS power angle as well as the relay calculated power angle for different excitation conditions in generating mode. It can be seen from Table 6.1 that the relay power angle corresponds well with the RTDS power angle (less than 0.5 degrees error) for the over- and underexcited state.

Table 6.1: 55 MW Generator simulated on RTDS – Power angle compared with Relay calculation

Excitation mode	Power Factor (pu)	RTDS Power Angle (deg)	Relay Power Angle (deg)
Underexcited: $P > 0, Q < 0$	1	16.7	16.6
	0.75	22.4	22.2
	0.59	27.4	27.1
	0.38	47.0	46.8
	0.36	55.0	54.8
Overexcited $P > 0, Q > 0$	0.96	15.2	15.0
	0.8	13.4	13.3
	0.68	12.3	12.2
	0.6	11.6	11.4
	0.38	9.3	9.2
	0.36	8.9	8.8

6.5.2 PRE-FAULT NETWORK SCENARIOS

Table 6.2 presents different network scenarios similar to the scenarios discussed in section 5.5. The only difference is that no shunt loads were simulated with the RTDS. The algorithm with shunt loads was

properly tested with PSCAD as discussed in section 5.5. The 590 MVA generator no C in Table 5.1 was used in the RSCAD simulations to follow.

Table 6.2 presents the power angle calculation for the generator, transformer and transmission line. It can be seen that the relay algorithm calculated the power angles with an error of less than 0.5 degrees. This is considered an adequate accuracy for stability studies.

Table 6.2: Comparison of Power Angles calculated by Relay and RTDS (RSCAD)

Pre-fault conditions	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
P_{GEN1} (pu)	1	1	1	0.5	0.25	0.6
P_{GEN2} (pu)	1	0.5	0.25	1	1	0.5
P_{GEN3} (pu)	0.5	0.5	0.5	0.5	0.5	0.5
P_{GEN4} (pu)	0.5	0.5	0.5	0.5	0.5	0.5
$Z_{network}$ (pu)	0.0206 +j0.2024	0.0206 +j0.2024	0.0206 +j0.2024	0.0206 +j0.2024	0.0206 +j0.2024	0.0206 +j0.2024
Z_{inf} (pu)	j0.01	j0.01	j0.01	j0.01	j0.01	j0.01
RTDS						
δ_{gen} (deg)	56.9	55.6	55.0	39.3	20.6	42.8
Relay						
δ_{gen} (deg)	56.7	55.2	54.8	39.1	20.3	42.3
RTDS						
δ_{tx} (deg)	5.5	5.3	5.7	2.8	1.2	3.3
Relay						
δ_{tx} (deg)	5.5	5.2	5.8	2.9	1.3	3.3
RTDS						
δ_{line} (deg)	14.2	10.1	4.9	10.6	6.5	6.1
Relay						
δ_{line} (deg)	14.1	9.8	4.8	10.4	6.6	6.0
RTDS						
$\delta_{transfer}$ (deg)	76.6	71.0	65.6	52.7	28.3	52.2
Relay						
$\delta_{transfer}$ (deg)	76.3	70.2	62.4	52.4	28.2	51.6

6.6 TRANSIENT TESTS

6.6.1 ROTOR SPEED INCREASE CALCULATION

It was initially decided to measure voltage frequency to determine generator speed increase during a fault. While testing the REM543 relay on the RTDS, it was found that the voltage frequency could not be properly measured during fault scenarios close to the generator terminals. The reason for the inaccurate measurement was due to distortion in the voltage signal when a fault occurred close to the generator terminals. The relay logics were therefore changed (refer to Appendix A) to calculate the speed increase by measuring the active power reduction during the fault. The active power reduction is used with the

generator inertia (or H-factor) to determine the speed increase. This method was discussed in section 4.8.3.

It was found that the relay calculated the rotor speed increase during the fault with an error of approximately 10%. An error of 10% is not considered good enough to be used in the equal area criteria for stability purposes. The reason for the poor accuracy is due to a slow active power function block inherent to the protection relay as will be explained in more detail in sections 6.6.2 and 6.6.3.

6.6.2 FAULT-OCCURRED AND FAULT-CLEARED DETECTION

Fault detection is fairly easy, since only the generator current needs to be monitored. When a generator current of more than 1.2 pu is detected, the algorithm activates. If the 1.2 pu current is only an overload situation without a real fault, the algorithm (equal area) will sense that the rotor speed did not increase and therefore no pole-slipping can occur.

Appendix A shows the REM543 relay logics for the fault-detected and fault-cleared algorithm. The fault-cleared algorithm observed the generator active power. If the active power increased to the value before the fault occurred, a “fault-cleared” signal is generated. This caused complications since the power measurement function block had a time delay of 20 ms to 40 ms. Although the relay logics fault-cleared algorithm worked, the accuracy in which the fault-cleared event was detected was not considered accurate enough (15% error). Another method was later used in PSCAD simulations as was discussed in section 4.8.2. This method used the calculation of *Area 1* (which is a combination of the generator active power and the generator power angle). When *Area 1* was not decreasing from the one simulation step to the next, it means that the fault is cleared. This method proved to be more accurate than the use of the generator active power alone due to the reasons as discussed above.

6.6.3 EQUAL AREA CRITERIA

The ideal way to test the equal area criteria tripping accuracy is to plot *Area 1* and *Area 2* as the fault occurs (as was done with the PSCAD simulations in section 5.8). It was however not possible to export data from the relay logics to draw curves of *Area 1* and *Area 2* for the different fault scenarios.

For every unstable fault, the relay was monitored to issue a trip before the fault is cleared. The ABB REM543 relay performed at a lower accuracy than the PSCAD simulated results (refer to section 5.8) due to hardware limitations. The PSCAD logics detected an unstable fault with an error margin of less than 10 ms fault duration. That means that there is a less than 10 ms fault duration margin in which a fault can occur that will cause the PSCAD logics not to trip, where the machine could become unstable. The pole-slip algorithm is designed conservatively to ensure no spurious tripping occurs. For inaccuracies, the logics

will rather refrain from tripping than to issue a trip where a generator could have remained stable after the fault was cleared.

The ABB REM543 relay logics presented an error margin of between 10 ms to 30 ms for different fault scenarios. A 30 ms error margin is not regarded as acceptable for stability purposes. The reason for the high error margin is mainly due to the slow response of the active power measurement function block (MEPE7) of the ABB REM543 relay. It was found that the MEPE7 function block only updates the active power measurement every 20 ms to 40 ms. It was not possible to measure active power in any other way than using this function block in the relay. Since the equal area criteria relies on a fast response (10 ms to 20 ms) for active power measurement, a larger error margin was tested on the relay than that obtained with the PSCAD logics.

6.7 SUMMARY

The chapter discussed the testing of an ABB REM543 protection relay with a RTDS. The steady-state testing and transient testing were discussed. Steady-state testing included steady-state power factor and power angle calculations. Transient testing included rotor speed increase during a fault, fault-occurred and fault-clearance detection and the equal area criteria calculations.

The pole-slip algorithm concept was verified to be working correctly, although there were some practical limitations. For example, the voltage frequency could not always be used to determine generator speed during a fault due to voltage distortions when the fault occurs close to the generator terminals. Instead of using the voltage, the inertia of the machine and the active power reduction was used to determine the rotor acceleration during the fault. Some other challenges included a slow reaction time of the active power measurement function block of the relay. Since the active power measurement is a key variable in the equal area criteria, the slow response caused the pole-slip algorithm to be less accurate as was simulated in the PSCAD logics. The PSCAD logics simulated to have a fault duration error margin of less than 10 ms, while an error margin of 10 ms to 30 ms was tested with the protection relay.

The ABB REM543 logics interface is flexible and user friendly, which allows the user to program almost any protection algorithm. However, the slow active power measurement function block makes the ABB REM543 relay not the ideal solution for the pole-slip function. Nevertheless, the powerful ABB REM543 relay logics assisted in proving that the new pole-slip concept can be feasible if the correct relay hardware is used.