Protection Power System Course and Smart Grid Laboratory Integration
Burns & McDonnell – K-State Smart Grid Laboratory

KANSAS STATE UNIVERSITY

Burns & McDonnell SINCE 1898

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1. Introduction

In the spring of 2013, the Protection Power System course (ECE686) was integrated into the Burns & McDonnell - K-State Smart Grid Laboratory at Kansas State University. Based on the multidisciplinary nature[1] (i.e., power systems, protection, communication, metering) of smart grid education, the Burns & McDonnell - K-State Smart Grid Laboratory integrated educational activities into the ECE686 course.

2. Course Integration

2.1 Achievements

The achievements of the Burns & McDonnell - K-State Smart Grid Laboratory integration with ECE686 course are:

- Introduction to the smart grid laboratory.
- Application of course (ECE686) knowledge into experiments and demonstrations applying relays.
- Articulation of smart grid laboratory equipment and software in order to better understand protection, communication, control and measurement functions of relays.

2.2 Integrated Activities

These achievements were obtained by presentation of lectures (L), experiments (E), and demonstrations (D) in the Burns & McDonnell - K-State Smart Grid Laboratory. Topics of these activities included smart grid laboratory introduction[(L)], inverse time over-current (ITOC) protection with selective coordination[(L) (E)] and pilot distance protection with permissive overreaching transfer tripping (POTT) scheme[(L)(D)].

3. Smart Grid Laboratory Introduction

3.1 Smart Grid Laboratory Objectives

The objectives of the Burns & McDonnell - K-State Smart Grid Laboratory are:

- Provide state-of-art education to the industry's future workforce.
- Enhance smart grid research opportunities.
- Support smart grid and networking courses.
- Integrate knowledge, hardware, and software in order to understand protection, communication, control and measurement functions that could be used in smart grid applications.
- Integrate activities with undergraduate courses.
- Promote engineering education applications for prospective students.

3.2 Smart Grid Laboratory Equipment

Figure 1 shows the network (A), protection (B, E and F), control (C), and simulator (D) panels in the Burns & McDonnell - K-State Smart Grid Laboratory.

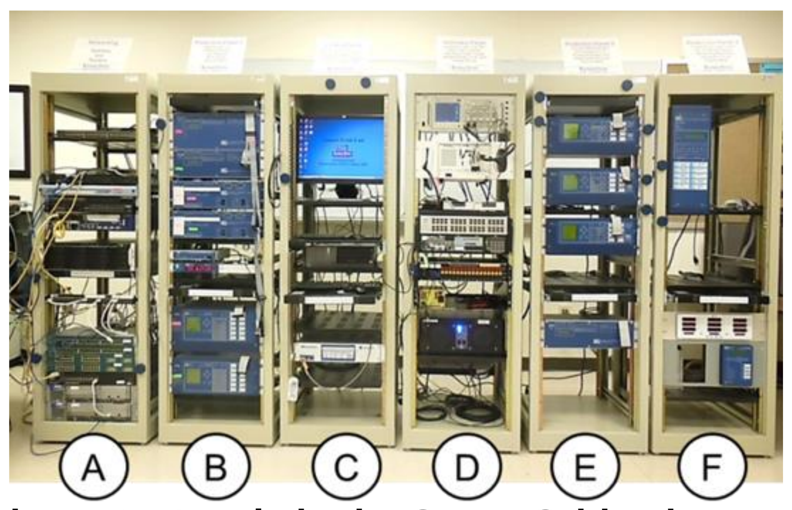

Figure 1: Panels in the Smart Grid Laboratory

Equipment on panels are (A) switches and routers, (B, E, and F) meter, control recording device, Relay Test System and Adaptive Multichannel Source[2] (RTS-AMS), and protective relays for feeder, line current differential, distance and multi-function applications, (C) remote terminal units and satellite-synchronized clock, and (D) real time simulators.

4. Experiment and Demonstration

4.1 Objectives

- The objective of the experiment was to verify the principles of the inverse time over-current protection with selective coordination for a power line in a radial power system, by collecting measured relay and clearing times.
- The objective of the demonstration was to verify the principles of the pilot distance protection with POTT scheme for a power line in a non-radial power system, by collecting front-panel led sequences for both relays.

4.2 Methodology

The methodology of the experiment and demonstration is based on RTS-AMS with relay/s in the loop. The pre-fault, fault, and post-fault states and breaker status are simulated by the RTS-AMS. Equipment and software were integrated into the experiment and demonstration. Figure 2 represents the experiment and demonstration sequence. The PowerWorld Simulator[3] software estimates the maximum load and fault currents, AcSELerator Quickset[4] software sets the relays, and SEL-5401[5] software creates RTS-AMS files and collects the measured relay and clearing time.

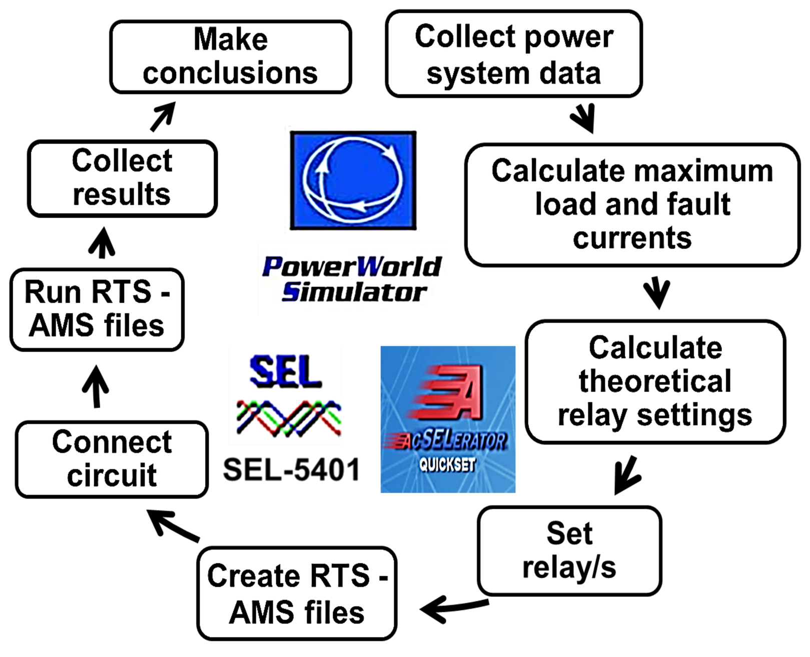

Figure 2: Cycle Chart - Sequence

4.3 Experiment : Scope, Results and Technical Accomplishments

A radial power system is represented in Figure 3. The principle of ITOC protection with selective coordination is based on the primary relay trips faster than the backup relay for a fault located in the common protection area, as shown in Figures 3 and 4.

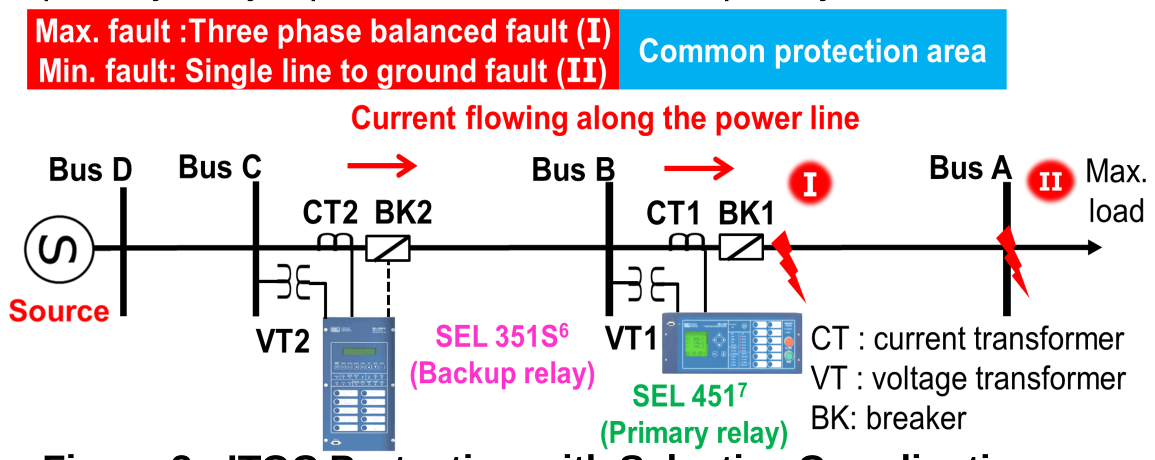

Figure 3: ITOC Protection with Selective Coordination

$$RT = TDS \times \left(0.18 + \frac{5.95}{Mp^2 - 1}\right) \quad (1)$$

$$M_P = \frac{I_{primary}}{CTR\ Ip} \quad (2)$$

RT = Relay time in seconds

TDS = Time dial setting

Mp = Multiple of pickup

CTR = Current transformer ratio

Ip = Overcurrent pickup in amps

$I_{primary}$ = Primary current in amps

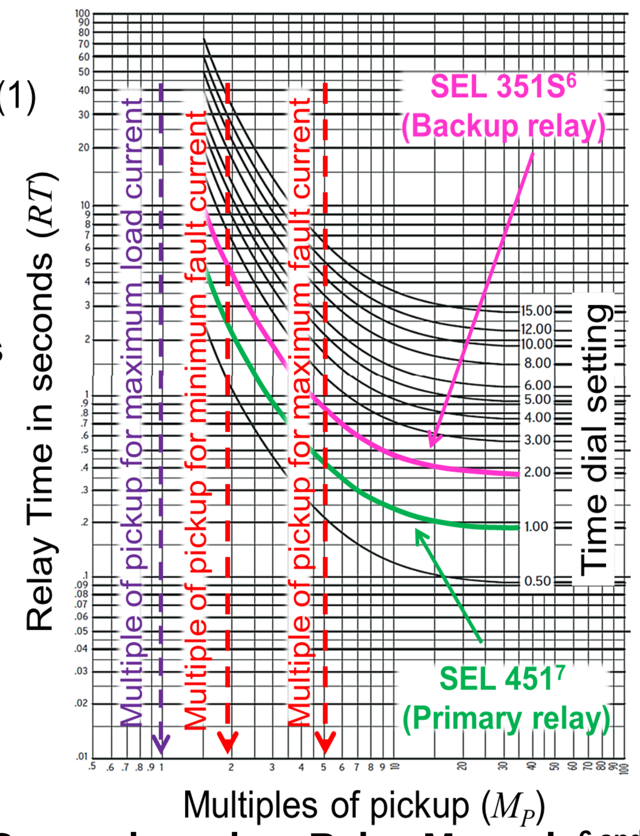

Figure 4: US Inverse U2 Curves based on Relay Manuals[6 and 7]

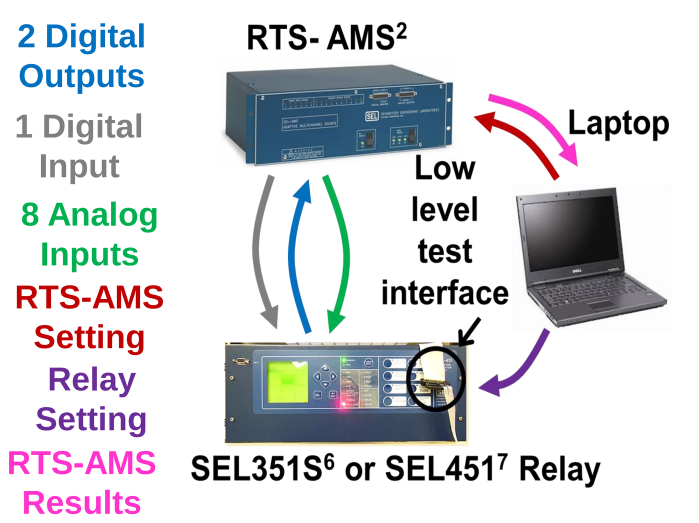

Figure 5: ITOC Protection Circuit

The circuit in Figure 5 represents the RTS-AMS with the relays in the loop.

In Figure 4, primary and backup relays are set by the green and pink curves. These curves are the time dial settings of the US Inverse U2 curves that are represented by Equation (1). In this experiment a delay time (breaker-arc-flash plus communication delay time) of four cycles (67 milliseconds) was considered. The results were based on collecting the measured relay and clearing times for the primary and backup relay. The technical accomplishments reached the objectives. The primary and backup relays did not trip for the maximum load current (violet dash line), and the primary relay tripped faster than the backup relay for the minimum and maximum fault currents (red dash lines), as shown in Figure 4.

4.4 Demonstration : Scope , Results & Technical Accomplishments

A non-radial power system is represented in Figure 6. The principle of the pilot distance protection with POTT scheme is based on the assumption that both relays trip for faults inside (case II and III) of the common protection area. However, for a fault outside (case I) of the common protection area, the relays do not trip.

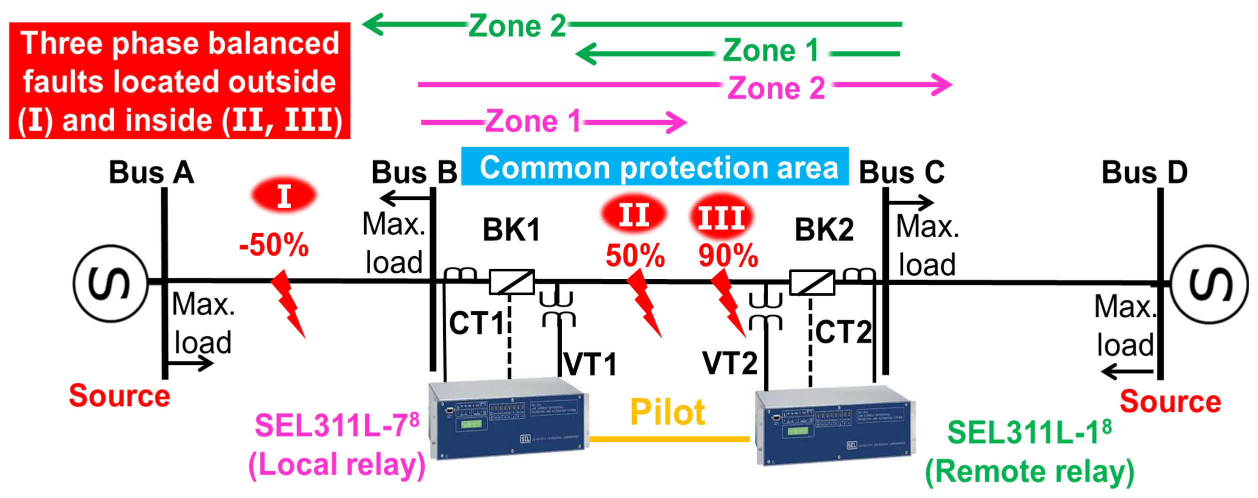

Figure 6: Pilot Distance Protection with POTT Scheme

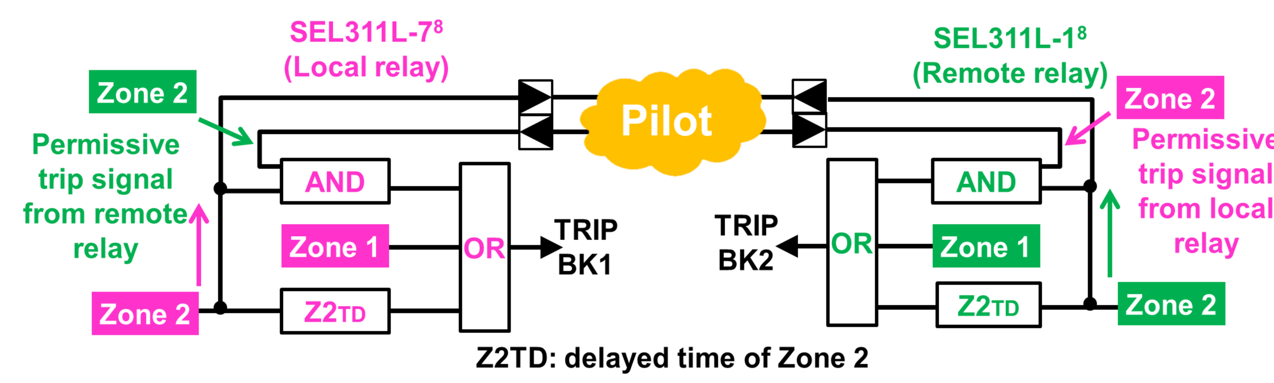

Figure 7: Simplified POTT Scheme

The distance setting of these relays is represented by an under- and overreaching zone denominated zone 1 and 2, respectively.

Zone 1 is a Mho distance protection set at 80% of the power line impedance forward-looking with non-delayed time. Zone 2 is a Mho distance protection set at 120% of the power line impedance forward-looking with assisted communication and time-delayed tripping.

The POTT scheme is set on both relays. Figure 7 represents a simplified POTT scheme. From the "OR" gate, the relay trips when any of the "AND", "Zone1" or "Z2TD" gates are available. The circuit in Figure 8 represents the RTS-AMS with the relays in the loop.

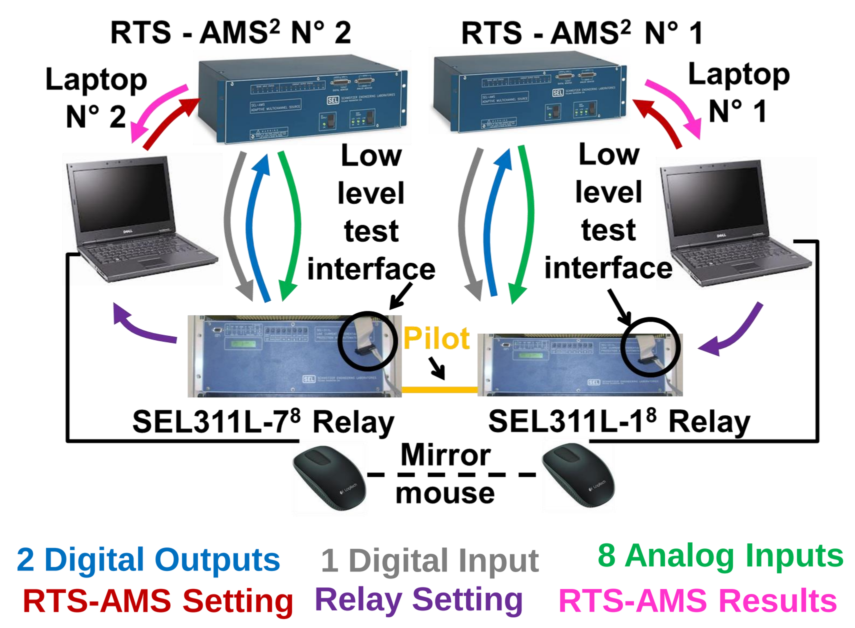

Figure 8: Pilot Distance Protection Circuit

The results were based on collecting the front-panel led sequences for both relays. The technical accomplishments reached the objectives. The relays trip for a fault inside of the power line, and relays did not trip for a fault outside of the power line. In addition, the relay communication based on POTT scheme for zone 2 was verified during the demonstration.

5. Conclusions

- The integration of the Burns & McDonnell - K-State Smart Grid Laboratory with the ECE686 course resulted in a valuable experience because a majority of the students had not previously utilized protective relays.
- In the Burns & McDonnell - K-State Smart Grid Laboratory, students combined ECE686 course knowledge with relay test system experiment and demonstration.
- The experiment and demonstration performed with relays, RTS-AMSs, and software presented a relevant exposure for students who performed relay operations typically implemented by power engineers in electrical substations to verify relay settings.
- Instructor and student satisfaction was measured by verbal communication. Preliminary results with regards to learning value of the experience warrant further development of a future controlled study.

Figure 9: Lecture in the Smart Grid Laboratory

Figure 9 shows the pilot distance protection with POTT lecture and demonstration offered to on- and off-campus ECE686 students in the Burns and McDonnell – K-State Smart Grid Laboratory.

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Abstract

In the spring of 2013, the Protection Power System (ECE686) course was integrated into the Burns & McDonnell - K-State Smart Grid Laboratory. Based on the multidisciplinary nature[1] (i.e.: power systems, protection, communication) of smart grid education, the smart grid laboratory integrated educational activities into the ECE686 course. The achievements of the lab-course integration were: introduction of students to the smart grid lab, application of course knowledge into relay experiments and demonstrations, and articulation of smart grid lab equipment and software to understand relay functions. This was achieved by presentation of lectures, experiments and demonstrations in the smart grid lab. Topics of these activities included smart grid lab introduction, inverse time over-current (ITOC) protection with selective coordination, and pilot distance protection with permissive overreaching transfer tripping (POTT) scheme. The ITOC protection with selective coordination protected a power line in a radial power system. The objective was to verify the selective coordination of relays, by collecting relay and clearing times. The pilot distance protection with POTT scheme protected a power line in a non-radial power system. The objective was to verify the selectivity and communication of the relays, by collecting the front-panel led sequences. Technical accomplishments for experiment and demonstration reached selected objectives for the ITOC protection with selective coordination and pilot distance protection with POTT scheme. Integration of ECE686 course and smart grid laboratory was a valuable experience for students because they integrated course knowledge into an experiment and demonstration by articulation of equipment and software to understand relay functions.

Experiment and Demonstration

In a radial power system experiment, ITOC protection with selective coordination was utilized to protect a power line between two buses, using a primary[2] and backup[3] relay. Both relays were set by US Inverse – U2 curves collected from relay manuals[2 and 3]. The objective was to verify the selective coordination of the relays, by collecting the relay and clearing times. In a non-radial distribution power system demonstration, a pilot distance protection with POTT was implemented to protect a power line by two relays[4]. Both relays were set for a Mho distance protection at 80% of the power line impedance forward-looking with non-delayed time, and Mho distance protection at 120% of the power line impedance forward-looking with assisted communication and time-delayed tripping. The objective was to verify the selective coordination and communication of the relays, by collecting the front-panel led sequences for both relays. The methodology of the experiment and demonstration was based on relay test system[5] with relay/s in the loop. The pre-fault, fault, and post-fault states and breaker status are simulated by the relay test system[5]. The relay opens a breaker during a fault situation but also needs to close the breaker to restore energy. Based on this application, a relay needs two digital outputs to open and close a breaker, one digital input to sense if the breaker is open or closed, and eight analog inputs to measure the three phase and neutral-ground voltages and currents. Technical accomplishments based on objectives of experiment and demonstration were reached satisfactorily. In the experiment the primary relay tripped faster than the backup relay. In the demonstration for a fault inside and outside of the power line, relays did and did not trip, respectively. In addition, the relay communication based on POTT scheme was verified. Integration of ECE686 course and smart grid laboratory was a valuable experience for students because they integrated course knowledge into a relay experiment and demonstration by articulation of relays[2, 3 and 4], relay test systems[5] and software[6, 7 and 8] to understand protection, communication, measurement and control functions of relays.

Conclusions

Opening the Burns & McDonnell - K-State Smart Grid Laboratory to ECE686 students was a valuable experience because a majority of students had not previously utilized relays. Students communicated with relays to set and verify protection functions. The experiment and demonstration were performed with relays[2, 3 and 4], relay test systems[5], and software[6, 7 and 8.] The experiment and demonstration represented a relevant exposure for students who performed relay operations usually implemented by power engineers in electrical substations to verify relay settings. Instructor and student satisfaction was measured by verbal communication. Preliminary results with regards to the learning value of the experience warrant further development of a controlled study in the future.

Bibliography

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Bibliographical Information

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