Circuit Breaker Module for Protection Laboratory Experiments at Cal Poly State University, San Luis Obispo

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Executive Summary

At Cal Poly State University, we are currently developing microgrid lab and power system protection lab to complement existing power system and protection courses. For the purpose of conducting the protection component of these labs, circuit breaker modules are needed to simulate different types of power system faults. This project focuses on the design and construction of the breaker modules to aid students conduct lab experiments that better visualize how faults affect power systems in the real world while utilizing industry standard protection equipment. The breaker module was constructed based on a previous design with two main improvements: the use of a typical wall outlet to power the module for enhanced adoptability while reducing cost, and more intuitive faceplate layout for ease of wiring and troubleshooting. Hardware tests demonstrate that the circuit breaker module design functions successfully to simulate different types of power system faults. Several protection laboratory experiments utilizing the breaker module were developed whose results have been published by the ASEE. Summary of the breaker module design and test results are presented in this report.

Introduction and Background

Due to the increased complexity of modern power systems with their associated technologies and protection, it becomes critical to train future power engineers to understand the circuit theory and device functionality necessary to maintain and operate a power system with adequate protection. To receive this training, many universities teach power system analysis and design courses. However, in terms of power system protection, a university could most effectively teach students using hands-on models that simulate power systems in a laboratory setting. This would allow students to be more prepared to enter a career in the power systems industry with a full understanding of basic power system protection, how it operates, and how to improve it. To better simulate a real-world system, one option is to make a microgrid system within a laboratory room. This would require equipment such as solar cells, other power generated from the grid, transmission lines, relays, and circuit breakers. With these tools, students should have the ability to recognize all types of faults, simulate them, and know the effects of each fault configuration on the power system. Since microgrids are small replicas of the full power grid, they are important tools for students to visualize and practice with the operation of power systems that exist in the real world but in an environment where making minor mistakes will not disrupt or endanger real customers and critical equipment. A microgrid laboratory course would provide students with practical experience in power system protection design and in implementing various protection devices such as digital relays.

At Cal Poly, we are currently enhancing the hands-on laboratory experience in our power program by developing a microgrid lab and a power system protection lab to complement the existing power systems lab course EE444. The lab courses must have circuit breakers as one of critical components for learning to use modern microprocessor-based relays for power system protection. To achieve these goals, circuit breaker lab modules will be required to enable students to test and visualize various fault connections conveniently in lab setting. One such breaker module design was completed by a previous student but had several drawbacks with the two main ones being power supply and wiring requirement issues. The main focus of this project is therefore to improve from the present design to address these issues and others, as well as to reproduce the modules for future lab uses.

Design Requirements

Figure 1 shows the block diagram for the circuit breaker. It shows the inputs and outputs as well as the basic internal connections and parts within the circuit breaker. As shown, there are three inputs: power, three phase current input, and fault input. Only one output exists which is to the protection relay. Within the breaker, there will be a mechanical switch, a three phase motor contactor, indicator LED's, manual close and trip buttons and relay contacts. The targeted dimensions of the proposed circuit breaker are shown in Figure 2. These dimensions do not include any extruding parts such as the power cable or the top connection points.

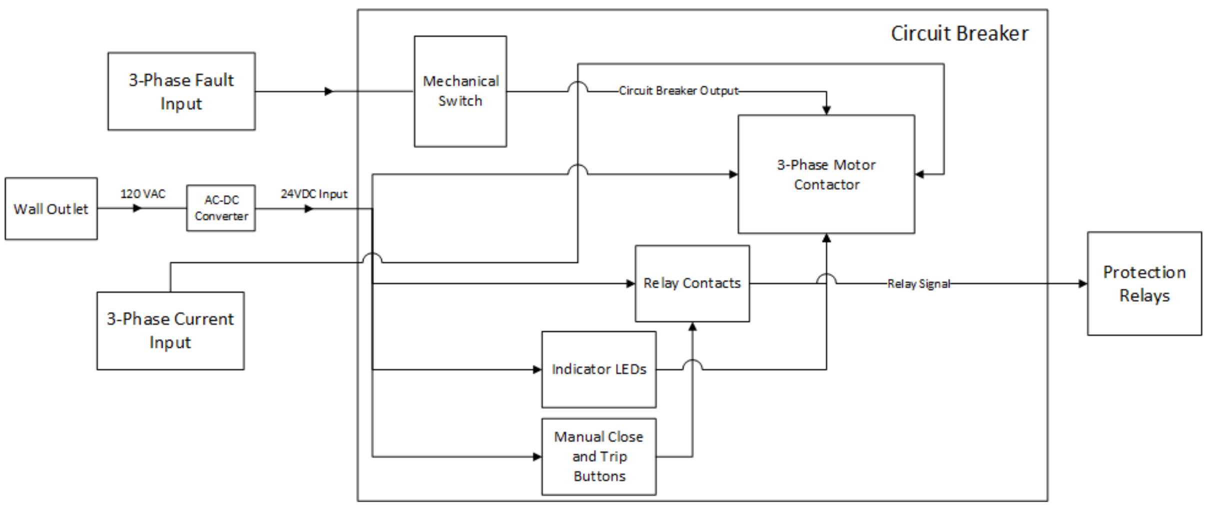

Figure 1. Block Diagram of Circuit Breaker Module

There are 6 design objectives in order to improve from the previous breaker module design:

1. Lab bench DC input voltage removal for minimizing the number of manual physical connections
2. Banana jack removal for simpler connection
3. Faceplate rearrangement for clearer and cleaner cable connections
4. Construction of 12 to 15 breaker modules
5. Lower the total cost of each breaker

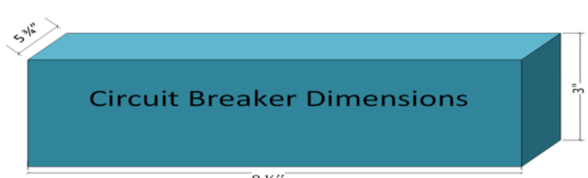

Figure 2. Circuit Breaker Dimensions

Hardware Design

The first improvement was rearranging and removing parts on the faceplate. Hole sizes for banana jack terminals, LEDs, and buttons were determined by referring to the AutoCAD files provided with the existing circuit breaker. Some component placements were shifted on the faceplate, such as the input and output banana jack terminals. The terminals for each of the three phases were changed to lay out vertically and connect linearly from the left side to the right side of the faceplate for more intuitive use. Other banana jack terminals were removed from the faceplate altogether and connected internally to further improve ease of use. This was done by internally connecting the Circuit Breaker Output connections to the Input Fault connections, then to the switch and the Output Fault connections terminals. The new redesigned faceplate schematic is shown in Figure 3.

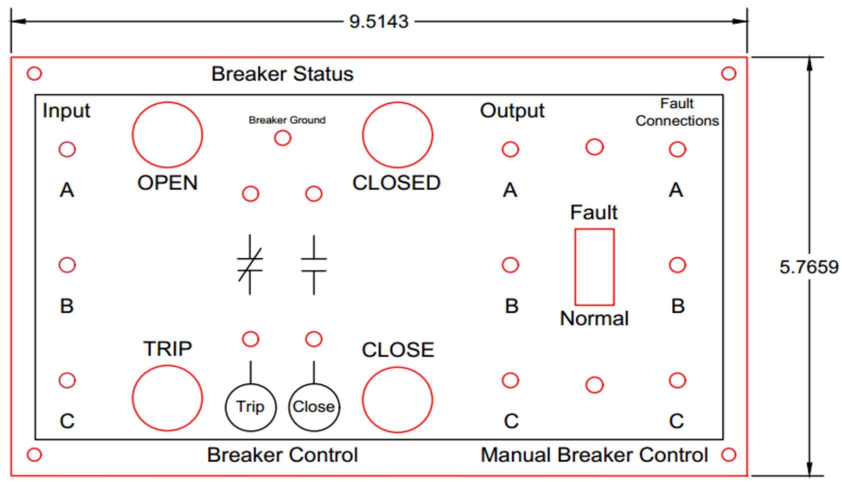

Figure 3. Dimensions of Redesigned Acrylic Faceplate. Red coloring indicates cut-through lines; black indicates surface etchings for text and symbols.

The next step in the design process was implementing an AC to DC converter to allow the circuit breaker to receive power from a common wall outlet. A laptop charger was chosen to achieve 24 VDC from a 120VAC wall outlet. The charger is plugged into a jack on the side of the breaker which will serve as the main power connection to the inside of the breaker. Running off of 24 VDC rather than 125 VDC allowed the costs and rating sizes of several components to reduce significantly. As another improvement, the new circuit breaker design addresses issues with layout, versatility, and cost. The new layout makes the circuit breaker connections more intuitive and logical for students, and its cost was decreased due to removing components and lowering several component ratings. Figure 4 depicts the interconnection diagram of internal hardware of the new circuit breaker module. The use of the motor contactor is necessary to manage the number of switches needed for proper operation. The motor contactor itself contains a series of switches. The default position of the switches, normally open or normally closed, is stated on motor contactor datasheets. Figure 5 shows the top view of a finished breaker module.

Hardware Test and Results

The newly designed circuit breaker module was tested for its functionality to demonstrate faults: single line to ground, double line to ground, line to line, and three-phase faults. Figure 6 illustrates the breaker module's wiring connection for a line to line fault. The final test is to put the circuit breaker into a simple circuit in the power lab. An example of the schematic of the test circuit is shown in Figure 7. This test will be checking to make sure that the fault switch and fault configurations work as designed. This testing of the circuit breaker involves the use of a SEL710 relay, and an induction motor, and a Variac autotransformer. Figure 8 shows the oscillogram that demonstrates the successful operation of the circuit breaker module in simulating a line-line fault. Other test circuits were constructed to further test the breaker module to simulate different faults utilizing various SEL digital relays. These procedures were completed and they successfully verified the functionality of the breaker module. Following the successful completion of these tests, more circuit breaker modules were constructed to accommodate for students use in multiple lab benches.

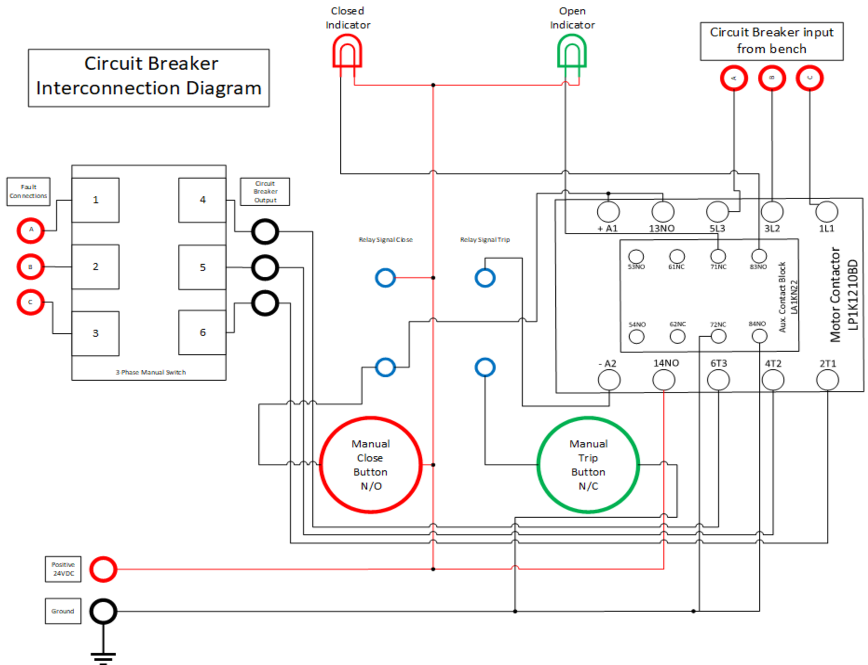

Figure 4. Interconnection diagram of internal hardware

Figure 5. Top View of Final Circuit Breaker

Figure 6. Top view of the Line-Line Fault Configuration

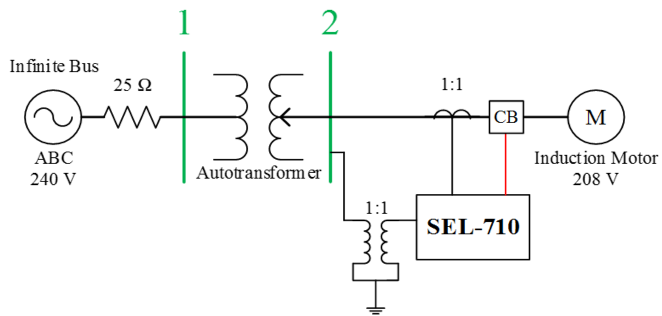

Figure 7. Top view of the Line-Line Fault Configuration

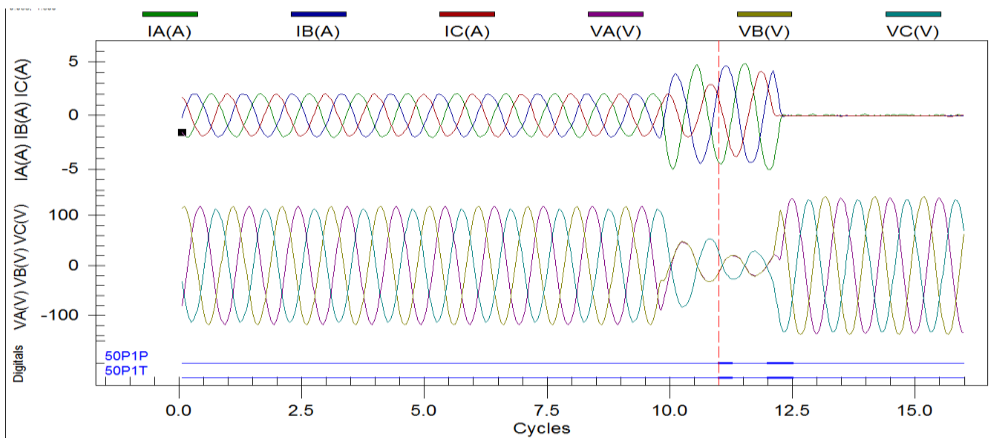

Figure 8. Line-to-Line Fault Oscillogram Plot.

Publication

Part of the results from this project was presented at the 2017 ASEE PSW conference

- K. Pretzer, A. Shaban, Taufik, "Development of Laboratory Experiments for Protection and Communication in Radial and Bidirectional Power Systems", Proc. of 2017 ASEE PSW Conference, April 2017.

Conclusion

In this project, a circuit breaker module that can simulate different type of power system faults was designed, constructed, and then tested. The design has significantly improved the module from its previous design as demonstrated through hardware functionality tests. Further improvements in the design may be achieved for example by using a larger chassis which allows for more space to wire the circuit breaker. More space could be introduced between the switch and the output terminals for safer operation of the module. Lastly, eventhough the design could be replicated at other universities, unfortunately a number of the parts used in the design are somewhat hard to find. It would be preferable to find an alternative manufacturer for each of these parts; thus, making the logistic better especially if all the parts can be obtained from one vendor.

Acknowledgement

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