A Solid-State Device for Fault Protection in Low Voltage Wind Turbine System

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Abstract

This paper presents how to design and build electrical protection equipment to apply for a wind turbine generator system which is modeled on low voltage 3 phase 380 volts system. This electrical equipment acts as a switch to open-close an electrical circuit to prevent an electrical system as well as equipments or devices in the system. It will open the circuit quickly and decrease the contact arcing of a circuit breaker. The implementation of power electronic properties is used instead of mechanical parts which is called "Solid-State Beaker". This article presents a method of solid-state breaker simulation on the mathematical analysis via MATLAB/ Simulink program in the cases of fault occurring in an electrical system. The simulation is used as a comparison when it is brought into the system. The fault voltage is detected by RMS Method which is implemented in LAB View program. The detection signal will be sent to the solid-state breaker and order it to cut off all three lines simultaneously to confirm the efficient running of solid- state breaker. But this paper has not yet considered the effect of Harmonic.

Key words: Solid State Circuit Breaker, IGBT

1. Introduction

From low voltage faults protection system study, when there is fault in the electrical system, protection equipment is required to decrease damage to the electric system and loads. The concept is applied to power generation systems from wind to protect a wind turbine generator. That act of cutting fault from electrical system must be fastest. Therefore, the protection equipment must be designed to be high-performance. The present circuit breaker tries to apply new technologies to get the property performance and the best protection in the electrical system. The study of the problem of the conventional circuit breaker caused to the concept of using power electronic device in a power system. Moreover, the study of power electronic devices is currently to have developed the capabilities of each device type to withstand higher voltage and current. We can use the properties of the semiconductor device which could conduct the current and stop the flow of the current in order to implement according to the conditions of a protection equipment in a system to create a reliable power protection and reduce the impact on electricity in case of voltage sag, voltage swell, surge, voltage interruption or noises that result in rapid voltage changes and voltage waveform distortion as well as effecting on consumers. Most of the electric loads in the present are sensitive to the occurrence of abnormal voltage caused damage to the equipment.

2. Short circuit current analysis of each fault

The occurrence of short circuit current is the condition which protection devices have to quickly interrupt a faulted system. [2]

1. Three Phase Fault is the three phase short circuit which is very difficult to happen in the distribution system. But if it happens, the short circuit current will be more serious than other faults as shown in Figure 1.

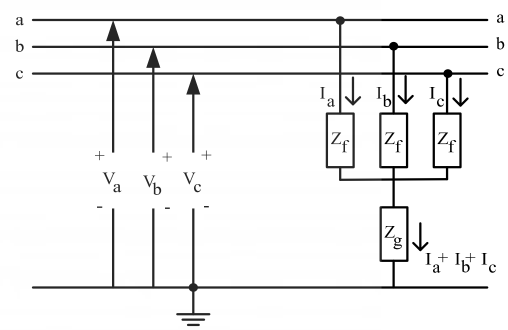


Figure 1: Three Phase Fault

Three phase fault can be found in the following equation:

$$I_a = \frac{V_f}{Z_1 + Z_f} \qquad (1)$$

2. Line to Ground Fault is the simplest short circuit that could occur easily and may be caused due to lightning flash across the units of insulator or a conductor touching the structure on the ground as shown in Figure 2

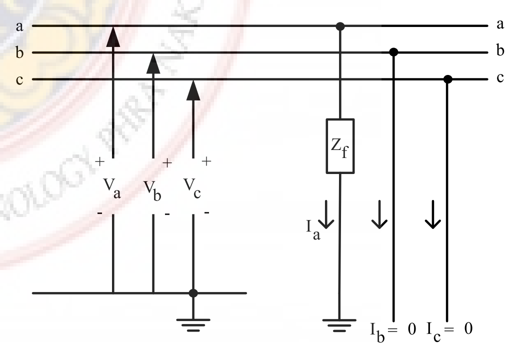


Figure 2: Line to Ground Fault

Line to Ground Fault can be found in the following equation:

$$I_a^0 = I_a^1 = I_a^2 = \frac{V_f}{Z_0 + Z_1 + Z_2 + 3z_f} \qquad (2)$$

3. Line to Line Fault is the short circuit between phase and phase. Figure.3 show an example of Line to Line Fault between phase b and c through the impedance between phase b and phase c shown in Figure 3

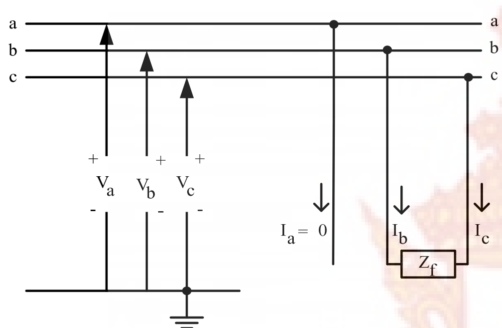


Figure 3: Line to Line Fault

Line to Line Fault can be found in the following equation:

$$I_a^1 = \frac{V_f}{Z_1 + Z_2 + Z_f} \qquad (3)$$

4. Double Line to Ground Fault is the short circuit between phase b and phase c through the impedance to the ground as shown in figure 4

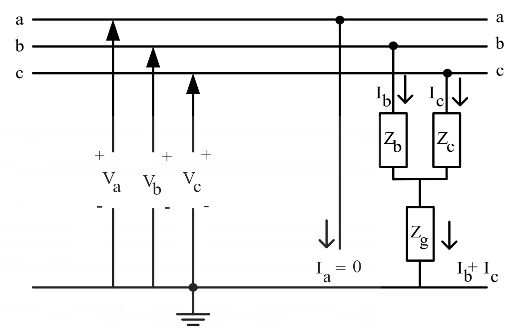


Figure 4: Double Line to Ground Fault

Double Line to Ground Fault can be found in the following equation:

$$I_{abc} = AI_a^{012} \qquad (4)$$

The purpose of analyzing each fault and their violence is the basis to calculate fault current and fault analysis in order to determine the suitability of the associated equipment such as circuit breaker.

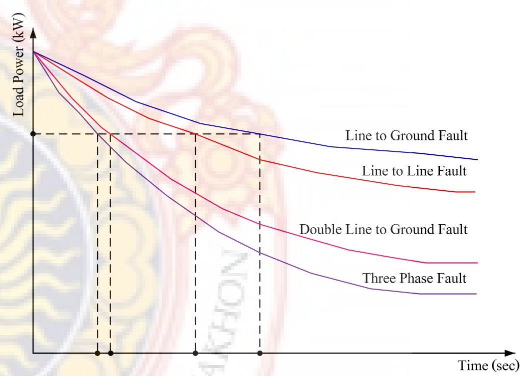


Figure 5: The stability of the system of each fault

Each individual fault will make the different change of system loading equal. Figure.5 show that the three phase fault will decrease the stability of electrical system more than single phase to ground fault. Thus, during the operation of protective equipment need to trip at higher speed. [3]

3. Comparison of a solid-state circuit breaker and the conventional circuit breaker

From study of circuit breakers to be foundation for designing power systems, it is important to know the main function of the circuit beaker which is to protect the over current situation arising from overload or short circuit conditions. The circuit breakers used in Thailand is referred to IEC 60898 standard. The circuit breaker according to this standard is used for the residential homes and buildings. According to that when the short circuit the current flowing through the circuit breakers in large amounts. If the amount of electricity that flows through is overcorrected instantaneous tripping of circuit breakers will cutting cycle is now within 0.1 seconds.

Table 2.3 IEEI Std 242-2001: Estimated clearing times of protective devices.

Working conditions of circuit breakers	Current range size 225–600 A (AT)
Instantaneous, cycles	2–3
Short time, cycles	10-30
Long time, cycles	Over 100
Ground fault, cycles	10–30

4. Preliminary analysis

Basic properties of single phase equivalent circuit when fault happens is analyzed in an ideal case as shown in figure 6. During the fault time, the voltage drop across circuit breakers will be up and waveform of current decreases to be zero amp. [4]

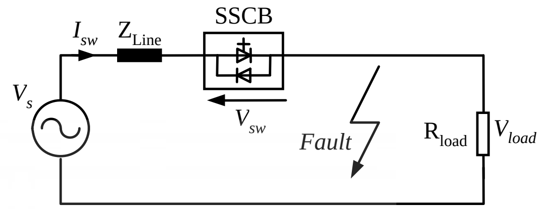


Figure 6: Equivalent circuit of solid-state circuit breakers

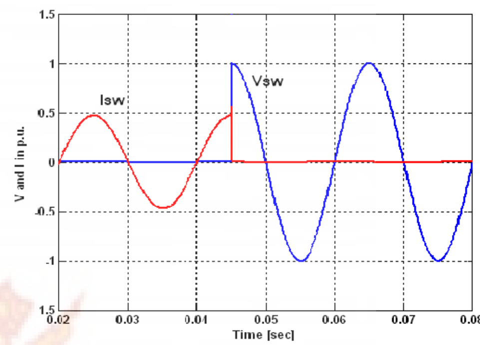


Figure 7: Ideal interruption simulation of solid-state circuit breaker

From the simulation of low voltage distribution system in Thailand nowadays, the equivalent circuit is shown in figure 8. The fault in the electrical system simulation starts at time of 0.2 seconds and its period is 0.05 seconds.

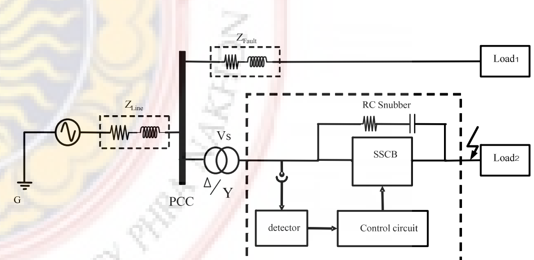


Figure 8: Simulation of a fault at downstream

Testing via MATLAB / Simulink program, voltage testing with low-voltage distribution system in per- unit starts at the beginning time to 0.05 seconds. It is found that when the three phase fault occur in the system at 0.05 seconds to 0.25 seconds shows how to detect the RMS voltage after RMS voltage less than 0.9 p.u.

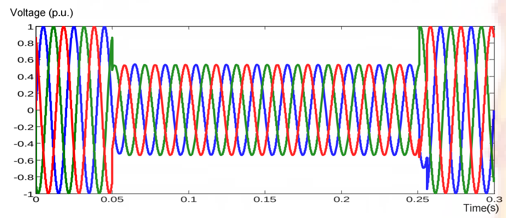


Figure 9: Three phase voltage when three phase fault is occurred

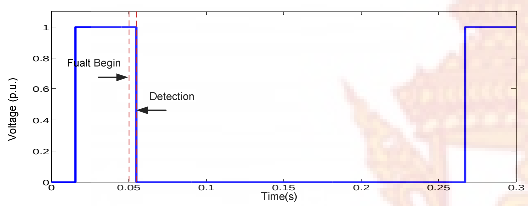


Figure 10: Simulation results for detecting voltage on the RMS value of voltage less than 0.9 p.u.

Testing via MATLAB / Simulink program, current experiment with low-voltage distribution system in per unit starts at the beginning time to 0.05 seconds. It is found that when the three phase fault occur in the system at 0.05 seconds to 0.25 seconds shows how to detect the RMS current after RMS current higher than 0.2 p.u.

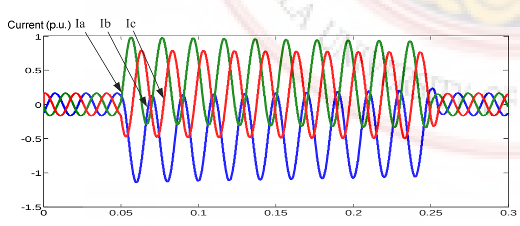


Figure 11: Three phase current when three phase fault is occurred

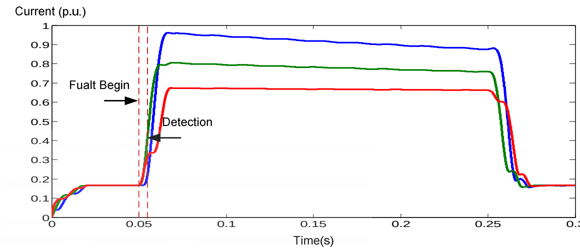


Figure 12: RMS current with the fault of phase a, b, c

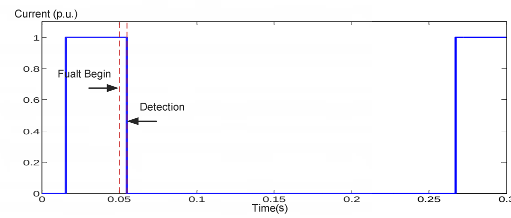


Figure 13: Signal from RMS current sensor when three phase fault is occurred

Operation condition of the circuit interruption will detect the short circuit current or over current of all three phase and use of fault detection by Root Mean Square (RMS) Method. It is found that the time of RMS measurement lower than 0.9 p.u. equals as 0.0543 seconds when fault at 0.05 seconds. [5]

$$V_{rms} = \sqrt{\frac{1}{T}\int_{t=o}^{t+T} v^2(t)dt} = \sqrt{\frac{1}{N}\sum_{n=1}^{N} v_n^2} \qquad (5)$$

$$I_{rms} = \frac{I_p}{\sqrt{2}} \qquad (6)$$

4. Building technology

The basis of semiconductor with high-speed switching is brought and nowadays current rating of semiconductor is high. Figure14 shows an overview circuit design of solid-state circuit breakers including:

- 2 IGBTs
- RC snubber

- 2 Diodes
- Varistor

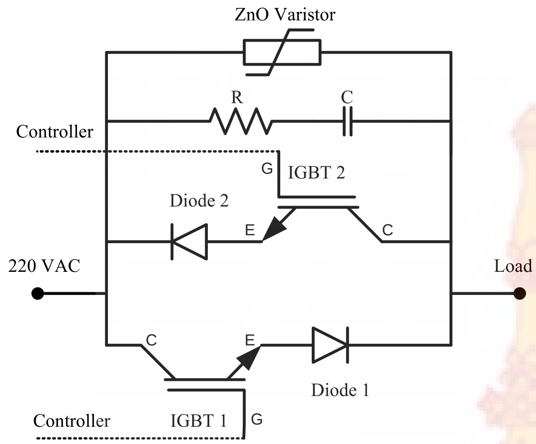


Figure 14: IGBT solid-state circuit breakers circuit

Fault detection by RMS Method, when voltage is lower than 0.9 p.u., short circuit current is higher than 0.3 p.u. sends signals to drive the gate of IGBT simultaneously to interrupt the circuit from the system. From the above principle, it can lead to design the voltage and current detection using Lab View program when there is fault in the system. Figture14 shows a program which is written on the Lab View program, called “Visual Instrument (VI)”. The appearance on a computer screen looks like a common measurement tool. Another section shows the block diagram for programming using the G-Programming (G Language) to write a program scheduled to run Lab View program and external devices to bring external data into computer using:

1. Analysis by measuring voltage and current through the CT, PT and processing

2. Use of automatic control systems by computer to create the conditions on and off of the signal SSCB and send to the gate of the IGBT.

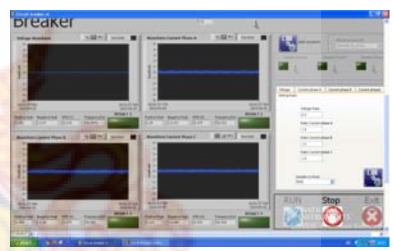
-Create virtual instrumentation for monitor the operating state of the system

-Create Data Logger to collect data

The above operating conditions is used together to create SSCB and a virtual wave in the virtual instrumentation laboratory

Programming by connecting to the wind turbine system and the detection signal is checked by comparing to the scope.

Case 1: SSCB on the condition ON



Case 2: SSCB on the condition OFF

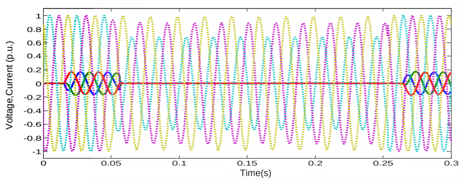
Figure 17: Show Instrumentation Lab View program of SSCB

Figure 15: ON OFF test of the SSCB when connected to a Lab View program

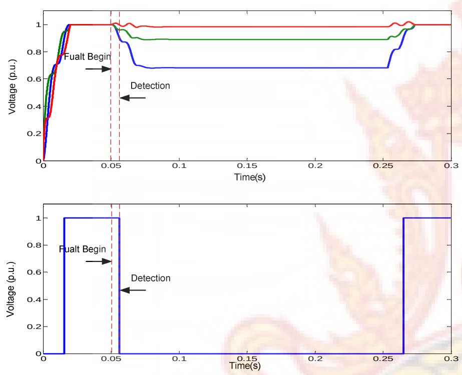
5. Results

The result of using MATLAB / Simulink program, when fault for a phase to ground on Phase A shows that 2 phase's voltage changes, the phase A and phase B but phase C has not changed

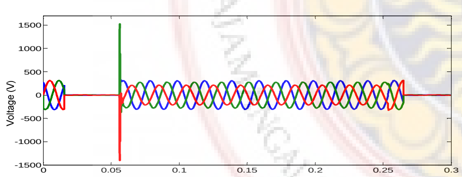
1. Fault case of one phase into the ground



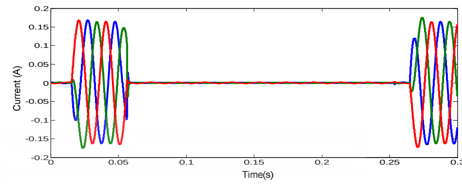
(a) Simulation results of voltage and current on the load when the solid state breaker opening-closing the circuit



(b) Simulation results of RMS voltage detection when the voltage is less than 0.9 p.u.



(c) Simulation results of the voltage when the solid state breaker opening-closing the circuit



(d) Simulation result of the current when the solid state breaker opening-closing the circuit

Figure 16: Simulation results of opening-closing the circuit of Solid-State circuit breakers in case of the phase to ground fault

Test results from the actual system when connected to wind turbine is compared between the Lab View program and the scope

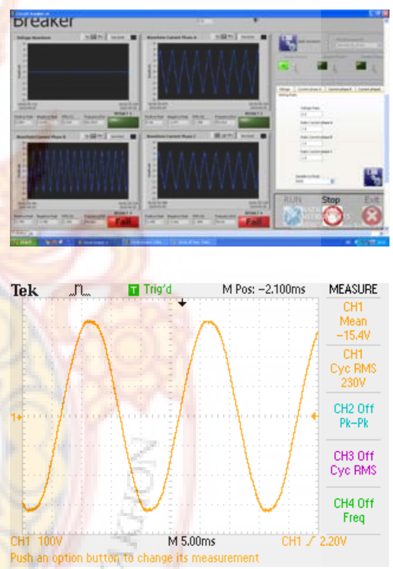


Figure 17: Test when normal system

Load voltage measurement shows that the voltage is 220 volts per phase, while the SSCB is not working

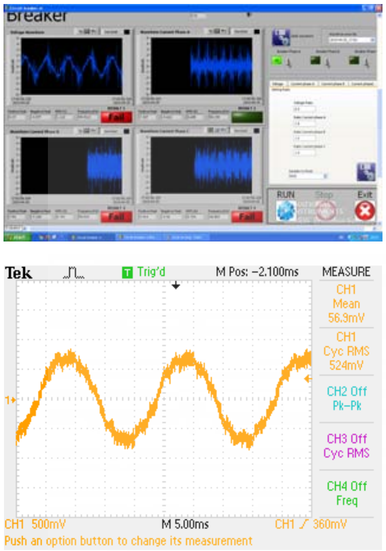


Figure 18: Test when SSCB cut the load off from the system

Load voltage measurement shows that the load voltage is approximately 0.5 volt.

5. Conclusions

The SSCB is implemented in this paper in order to test its performance and response time without the contact arc phenomenon. Operation states of the SSCB have the timing of switching on and off which are controlled by the signal from fault detector. Lab View program is applied to detect a fault condition in the system and send the ignition signal to the IGBT gate so as to stop the conduction of current. According to the analysis of the protection device, SSCB will interrupt the circuit immediately when there is some instant change of voltage. Both of symmetrical and asymmetrical faults could be detected by the RMS detection method. The fault signal will be used for controlling the SSCB to cut three phases off at the same time.

6. References

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